High-tech **PHOTONICS** solutions to protect the environment and preserve resources

LIGHT

as the key to
global environment
SUSTAINABILITY

A study by

Messe München

SPECTARIS
Verband der Hightech-Industrie

in cooperation with

Fraunhofer ILT

Fraunhofer LIGHT & SURFACES

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Exploration of photonics markets

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Photonics as a driver of global sustainability

FOREWORD BY MESSE MÜNCHEN

Dr.

REINHARD PFEIFFER

Deputy Chairman of the
Board of Directors
Messe München GmbH

When the American physicist Theodore Maiman operated the first ever laser on 16 May 1960, he could never have imagined how much this technology would have evolved by 2019.

Reactions at the time were split – one local newspaper even reported that a 'science fiction death ray' had been invented. It was unclear what uses a laser could have. Today it's difficult to imagine a world without lasers, and they have become indispensable in many industries including medicine and manufacture.

The concept of sustainability saw a similar development: In the 18th century, the Saxon army captain Hans Carl von Carlowitz criticised the popular thinking of his time, which focused on short-term gain over careful management of resources. He called for more considerate treatment of resources, particularly wood, which ultimately brought about the term 'sustainable'. Though the word and its meaning had the reputation of being awkward and difficult to communicate for a long time afterwards, today the term has grown into a global concept.

This study examines the profitable use of photonics for the sustainable treatment of resources from all angles. From reduced material consumption through to saving energy – the examples and data uncovered throughout this study make one thing clear – photonics is a driver of global sustainability and as such strikes a chord with the current mentality.

The LASER World of PHOTONICS, the global trade show for optical technologies, shows just how much the applications of lasers and photonics have evolved since 1960. Every two years, the industry meets right here on the trade show premises in Munich for the world's greatest photonics trade show and the simultaneous World of Photonics Congress. Here, sustainability is presented in the context of electromobility, for example. This would not be possible without laser technology, which is used in areas ranging from battery manufacture and lightweight construction through to cockpit component manufacture.

Visitors can find out more about this in our large exhibition area 'Laser Systems for Manufacturing'. Solutions from the areas of imaging and sensor technology also contribute to environmental protection, such as through small field sensors which can be used in water and soil protection and for smart farming.

Many of our exhibitors belong to companies which carry out pioneering work in connecting the areas of photonics and sustainability. Whether in industry or in science, as a trade show company it is especially important to us to provide a platform for their innovations.

Dr. Reinhard Pfeiffer

Light and innovation in the race against climate change

FOREWORD BY SPECTARIS

Dr.
BERNHARD OHNESORGE
Managing Director
Carl Zeiss Jena GmbH
Chairman of the Photonics
Trade Association
SPECTARIS e.V.

JÖRG MAYER
Managing Director of
SPECTARIS e.V.

Climate protection is one of the most important challenges of our time. The first signs of the dramatic consequences of global warming caused by humans give an indication of the price that all of us will pay if we respond too little too late. The price will consist of the loss of wealth, increased migrations, more extreme weather conditions and further species going extinct, to mention just a few of the effects. The technologies to limit the rise in temperature are already partially available, however. At this point it should be said: photonics, i.e. the technical application of light, plays a key role in this.

The Paris Agreement set the target for a temperature rise of significantly below 2 degrees Celsius, preferably 1.5 degrees compared to pre-industrial levels. This aim requires changes in everyone's behaviour as well as in governments' policies. But this alone is insufficient.

We also need technical innovations which enable us to combine the environmental, social and economic elements of climate protection and gain acceptance from all sides.

3 BILLION TONS LESS CO_2:

This is the predicted indirect potential impact of photonics on climate protection in 2030, resulting from just a handful of example applications. From photovoltaics through to low-energy lighting and early detection of forest fires, none of these climate protection measures could properly fulfill their potential without photonics.

The significant potential to save CO_2 highlights the enormous potential of innovative technologies to generate, amplify, shape, transfer and utilise light.

As a key technology, photonics offers high-tech solutions for numerous applications that can significantly contribute to sustainability thanks to their properties, possible uses and effects – for example through reduced energy consumption, CO_2 emissions or fertiliser use, through the economical use of resources, or through enabling new recycling processes and technologies to protect the environment.

In this publication, we want to highlight the potential, diversity, and capacity for innovation of photonics as an 'enabler' of sustainability. It should also be seen as a plea to support the high significance of photonics through dedicated research, funding and through parameters which promote innovation.

We hope you enjoy reading this report and that our joint efforts to protect the climate and environment will be successful.

Dr. Bernhard Ohnesorge
Jörg Mayer

Table of Contents

Page

Light as the key to global environmental sustainability

"Photonics makes it possible to constructively combine economy and environmental protection. This is achieved by both increasing the efficiency of manufacturing processes and producing optimised components for Germany's transition to renewable energy, particularly through precision work using ultra-short-pulse lasers or by using additive manufacturing processes. Components optimised according to economic and environmental criteria can be found in solar, battery and wind power technologies, for example."

Prof. Dr.

REINHART POPRAWE

Director of the Fraunhofer Institute for Laser Technology ILT/RWTH Aachen University – Lecturer in Laser Technology LLT

Dr.

STEFAN TRAEGER

Chairman of the Management Board of JENOPTIK AG

"Light manifests itself increasingly in different areas of our lives and is intrinsically linked to sustainability. Photonic technologies enable sustainable, resource-efficient production processes. Modern lighting methods contribute to protecting the environment. Endless examples demonstrate the advantages of photonic technologies over other processes in relation to sustainability. This is one side of the coin. We must also consider, however, the potential significance of the applications we have yet to discover and whose importance we can only guess at, and thus the enormous untapped potential of light. We must make sure to tap into this potential, and sustainability is one important driver."

“Photonics has made it possible to identify the hazards of climate change. It gives us the tools to protect our world. What matters now is that we make sure to use these opportunities wisely.”

Dr.
BERNHARD OHNESORGE
Managing Director
Carl Zeiss Jena GmbH

Prof. Dr.
ANDREAS TÜNNERMANN
Director of the Fraunhofer Institute for Applied Optics and Precision Mechanics IOF

Photo: Anne Günther/FSU

“Inline-capable photonic sensors for industrial production increase process safety and efficiency, and thus results in sustainably lower energy and resource consumption.”

“Measuring using light reveals emissions and shows us where infrastructure is weak. Pressures can be minimised and resources can be saved.”

Prof. Dr.
KARSTEN BUSE
Director of the Fraunhofer Institute for Physical Measurement Technology IPM

Dr.
ANDREAS NITZE
Managing Director of Berliner Glas KGaA Herbert Kubatz GmbH & Co.

“Technologies using light are indispensable today and make a substantial contribution towards a sustainable future. They support climate research, enable resource-saving manufacturing processes and significantly drive the development of medical technology.”

Dr.
WILHELM KAENDERS
Managing Director
TOPTICA Photonics AG

“The new opportunities provided by quantum technology in the areas of sensor technology and precision metrology offer us a vast toolbox for capturing environmental change (climate change, land elevation, tides, currents, volcanoes, earthquakes, etc.). They allow us to perceive, record and quantitatively measure global changes from space and from the earth’s surface for the first time, at an unprecedented level of precision.”

“Laser technology can be crucial in driving sustainable agriculture. Photonics makes it possible to work very precisely. The use of lasers can revolutionise weed control with robust processes.”

Dr.
DIETMAR KRACHT
Managing Director of
Laser Zentrum Hannover e. V.

Executive Summary

The challenge of climate protection

Photonics – meaning the technical deployment of light – makes it possible to make much more efficient and environmentally friendly use of resources, materials and processes.

Thanks to photonics research, sunlight is converted into electrical energy highly efficiently. The reversal of the process, the generation of light from electrical energy, is also much more efficient today than even a few years ago thanks to the advances made in photonics. In global communication, photonics provides fibre optic networks and thus the basis for minimum loss transmission of vast data volumes across long distances, traversing countries and continents. Photonics is also responsible for data production using imaging systems and optical sensors. All of these optical technologies work highly energy-efficiently and at zero emissions, and thus contribute significantly to achieving climate protection and sustainability targets. Photonics solutions have already received the German Environment Award, the environmental award with the highest prize money in Europe, three times.

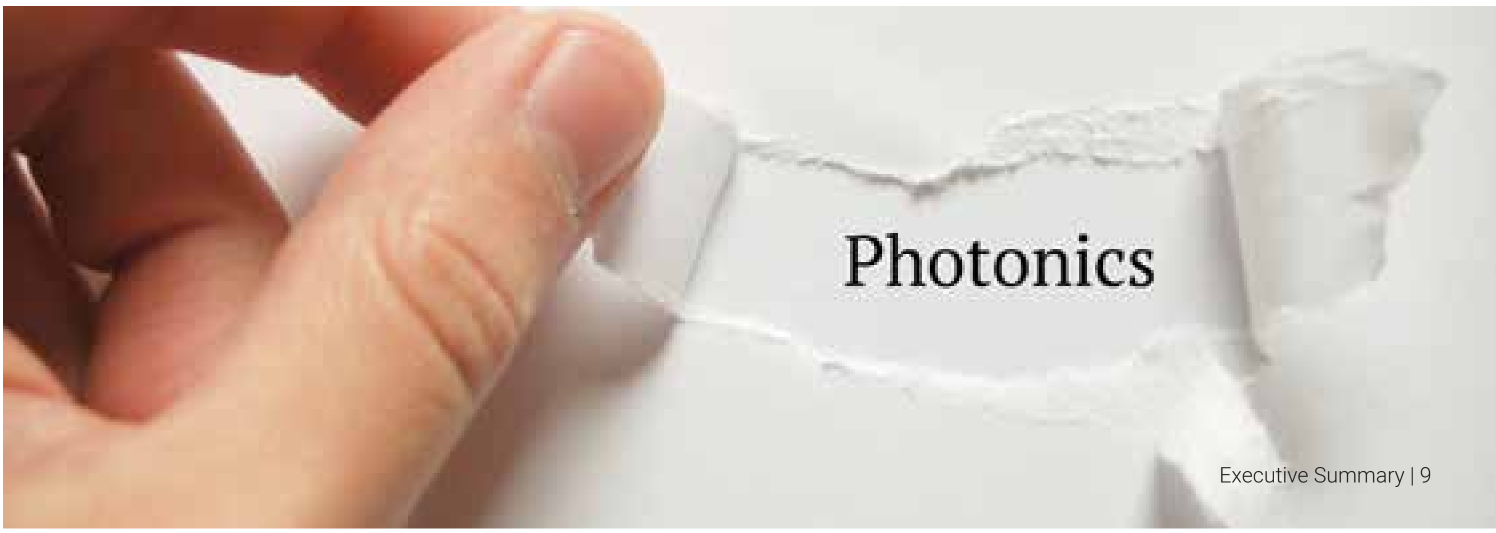
INNOVATION ACROSS MANY AREAS

The potential of photonics technologies is highly promising in many application areas. In the area of climate protection, satellite-based lasers are currently being developed which measure the distribution, creation and adsorption of greenhouse gases globally online. This also opens up opportunities to record local climate change events in real time. Land-based optical systems for the early detection of forest fires are used increasingly, while pseudo-satellite-based systems are about to be deployed.

The proportion of secondary production (recycling) of metals and other materials, such as from cars and mobile phones, can increase significantly thanks to contact-free, extremely fast and precise photonics based processes. For example, processes are currently being developed to disassemble and separate different materials found in mobile phones using 'LIBS' (laser-induced breakdown spectroscopy), while homogeneous metal recycling systems are already in use.

In farming, photons are used to analyse the local and temporal factors that influence the growth status of plants to precisely does fertilisers and herbicides locally. The removal of undesirable weeds using lasers is being researched. Photonic technologies also significantly contribute to efficient manufacture in energy generation, in increasing the efficiency of solar panels, in energy storage and conversion, in reliable and safe battery cells, as well as in compact electrical drives for electromobility. Optical processes for wear and tear protection using environmentally friendly materials are already being deployed. The manufacture of compact high-performance electronics becomes highly reproducible using laser joining techniques which could adapt to different materials.

In thin layer technology, lasers are better suited to the economical and environmentally friendly manufacture and modification of extremely thin functional layers than any other tool – such as for photovoltaics and electronics. When generating renewable energy such as wind power, Photonics based manufacturing processes allow for greater efficiencies and longer lifespans of wind turbines, for example.



Combustion processes for both traditional fossil fuels and for the development of turbines for renewable energy can be optimised, particularly using additive laser processes of extreme temperature-resistant materials and precision drilling for optimised cooling. This allows CO_2 emissions to be reduced systematically.

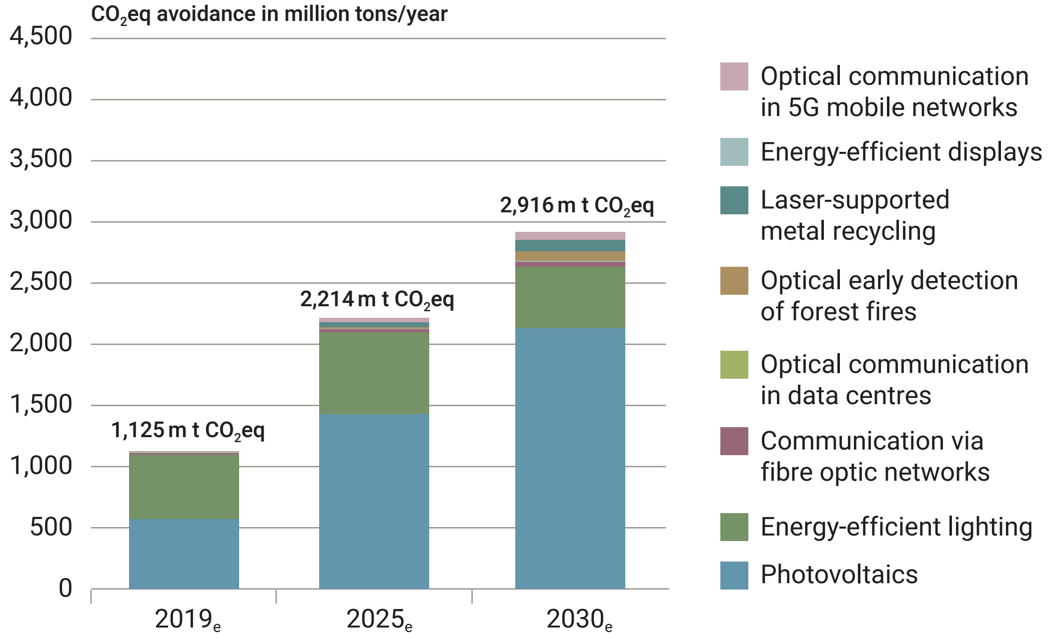
'3D printing' offers new design freedom throughout production technology. Lightweight construction, collision safety and crash behaviour, stability, recyclability, and integration of sensor technology are no longer conflicting objectives. Highly precise process controls utilise measurement results in real time in order to adapt ongoing production and minimise the proportion of rejected parts.

Application examples of photonics solutions for environmental sustainability

Photonics solution	**Application area**	**Sustainability effect**
Energy-efficient lighting	Lighting	Energy saving
Energy generation using photovoltaics	Energy storage and generation	Reduction of greenhouse gas emissions
Laser technology in photovoltaics: Sustainable electricity generation through efficient solar panels	Energy storage and generation	Reduced production costs for modules and increased efficiency for solar panels
Laser process for sustainable energy storage	Energy storage and generation	Reduced production costs for modules and increased efficiency for solar panels
Optical communication technology in data centres	Information, communication, entertainment	Energy saving
Optical communication technology in 5G mobile networks	Information, communication, entertainment	Energy saving
Energy-efficient displays	Information, communication, entertainment	Energy saving
Communication via fibre optic networks	Information, communication, entertainment	Energy saving
Lasers to destroy weeds	Agriculture and forestry	Reduction of herbicides
Optical early detection of forest fires and wildfires	Agriculture and forestry	Reduction of greenhouse gas emissions, protecting people and nature
Efficient turboengines for aircraft technology using laser-based processes	Mobility	Efficiency increase, reduced weight, fuel use and emissions
Laser technology in lightweight construction	Mobility	Decrease in the energy required for mobility, particularly in electromobility
Extreme lightweight construction for optical and mechanical components through additive manufacture	Mobility	Reduction of weight in transportation, including in space travel, and therefore reduced energy usage and fuel consumption
Laser processes for high-performance batteries in car manufacture	Mobility	Increased efficiency of manufacturing processes through high performance batteries, and therefore significantly reduced costs and increased customer acceptance of electromobility
Maintenance of traffic infrastructures through laser scanning to monitor large structures	Mobility	Resource-saving treatment of raw materials and energy when creating and maintaining traffic infrastructure
Laser spectroscopy for emissions measurement technology	Mobility	Improved engine development through new and ultra-precise measurement processes, and therefore reduction of harmful emissions (such as nitrous oxide)
Manufacture using extremely high-speed laser deposition welding	Production	Environmentally friendly and economic coating, repair or manufacture of components
Manufacture using additive manufacturing	Production	Weight optimisation for lightweight construction and resource-saving manufacture of complex or small-lot components, resource efficiency
Laser functionalisation of surfaces	Production	Energy-efficient functionalisation and optimisation of components, avoidance of environmentally damaging additives
Digital holography in production control	Production	Optimisation of manufacturing processes, reducing rejected parts
Metal recycling of the future: Measuring and sorting metals and alloys using lasers	Environmental protection and recycling	Recovery of valuable materials, energy saving
Laser cleaning	Environmental protection and recycling	Reducing the use of cleaning agents and unnecessary waste, saving energy
Recycling of mobile telephones and computer electronics: urban mining using laser technology	Environmental protection and recycling	Recovery of valuable materials, energy saving
Tailored laser technology for climate research in space	Environmental protection and recycling	Environmental and climate research
Earth observation satellite with optical high-performance grid in space	Environmental protection and recycling	Environmental and climate research

Source: Study "Licht als Schlüssel zur globalen ökologischen Nachhaltigkeit [Light as the key to global environmental sustainability]", Messe München, SPECTARIS, Fraunhofer ILT

Indirect climate protection potential of photonics, based on selected examples



Source: SPECTARIS/TEMATYS

ON A GROWTH TRAJECTORY

Example calculations for various application areas demonstrate the enormous potential of photonics. Some areas are still at the beginning of their growth trajectory, such as optical early detection of forest fires, laser-supported metal recycling or optical communication in 5G mobile networks. Others have already significantly contributed to climate protection in the past and still have enormous potential. One example is the substitution of filament light bulbs with energy-saving bulbs, which was only a first step towards today's 'LED lighting revolution'. Other examples are photovoltaics and communication via fibre optic networks. Both technologies are already widely available, but the proportion of photovoltaics in the energy mix is increasing further, as is the expansion of broadband networks. Even in areas of technology where photonics has already proven to improve sustainability and where the market sees mature products and market saturation, new, even more efficient solutions are already ready to be deployed.

One example is LED televisions, which have replaced the 'energy-guzzling' cathode ray tube TVs and for which lower-energy ELED or quantum dot displays are about to see a large-scale market launch.

The eight example calculations presented in this study already result in an indirect contribution to climate protection of 1.13 billion tons CO_2eq. The potential is expected to more than double by 2030, with the value of prevented CO_2 eq. emissions increasing to around 3 billion tons per year.

As such, photonics contributes significantly to achieving the global targets of the Paris Agreement. The greenhouse emissions prevented through photonics correspond to at least 11 percent of the agreed target of limiting the temperature increase to 1.5 °C compared to the start of the industrial age.

This is only a small proportion of the contribution that photonics can make to environmental sustainability, as demonstrated by the many further example applications in this study. Its true potential is much greater.

THE FUTURE OF PHOTONICS

The future of photonics has only just begun. This publication is aimed at highlighting its potential – the diversity and innovative capacity of photonics as a key technology for sustainability. First, an introduction describes the development of photonics, its application areas and its contribution to solving environmental sustainability. This is followed by worked examples for selected technology areas which will demonstrate the reductions already achieved, as well as the capacity for future CO_2 reductions. A further chapter then presents high-tech German solutions from industry and research, which highlight the diverse applications of photonics and illustrate why it is an important link between economic efficiency and environmental protection.

This study is also a plea to continue the support of photonics development through committed research, research funding, and through parameters which promote innovation.

Photonics as an ‘enabler’ of climate and environmental protection

Light has fascinated people since the beginning of time.

Prof. Dr.
REINHART POPRAWE
Director of the Fraunhofer Institute for Laser Technology ILT/RWTH Aachen University – Lecturer in Laser Technology LLT

This may well be due to the fact that vision is the earliest developed of our senses and therefore also perceived to be the most important to our existence.

There are colours, objects, beauty and warmth, all of these wonderful and life-shaping elements which we perceive through light. So it is no surprise that light also plays such a special, significant role in our lives.

In addition to these highly individual aspects, the scientific research of light has also influenced our practical lives, particularly in the last few decades. If, tomorrow, all lights, lasers and light based sensors were switched off, it would not only be dark, but many of the things that we are so used to in our everyday lives would also stop working.

But what are the real, fundamental reasons for the significance and ongoing success of photonic technologies in our societally relevant processes? Light, and therefore photons, are the only zero-mass energy. This special characteristic not only allows them to be distributed at the speed of light. If photons are stimulated when they are created, meaning bundled into a laser beam, this generate the highest quality of energy in the entire universe, basically the highest order.

If photons are stimulated when they are created, meaning bundled into a laser beam, this generates the highest quality of energy in the entire universe, basically the highest order. The measure of disorder reduces to zero: all of the energy is concentrated in only one state. This thermodynamic exception, combined with the characteristics of zero mass, allows for the most dynamic physically imaginable flexibility and the conversion into other, lower-quality forms of energy, such as electrical energy, mechanical energy or heat energy.

Therefore, photons – especially in the shape of a laser beam – are not only fascinating in the ramifications of their occurrence but also in their related importance for our natural existence. They also enable us to trigger and drive practically all imaginable physical processes, with the highest imaginable degree of effectiveness.

THE DIVERSITY OF PROCESSING METHODS: "ENABLING TECHNOLOGIES"

It follows from the physical properties of the types of energy 'light' and 'LASERS', that all imaginable processes which play a role in our lives can be driven with maximum precision by photons. Furthermore, the characteristic of zero mass allows for the ultimate dynamics in positioning, and combined with the right scaling, results a new level of manufacturing speed. A further benefit of zero mass is that the 'tool of light' does not wear out, meaning that it can be used for any number of operating hours in automation.

For these reasons, many of today's processes have already been developed to maturity over the last few decades and have made an impact on our society.

The development of suitable sources of radiation is a key condition for the successful use of photons. The expression 'tailored light' describes choosing the right light for an application, meaning that the properties of the source regarding spatial, temporal and spectral quality must be matched to the relevant application. This brings to mind the analogy of electrical energy, where the right combination of voltage and current must be provided for each application by the relevant power supply. However, light energy has an even greater degree of freedom, which explains the diversity of sources and the even greater adaptability of this form of energy to the desired effect, resulting in an even wider spectrum of potential applications.

Cutting metal using lasers was already developed and implemented industrially in the same decade in which the laser was invented. This cutting process is not only characterised by its high quality, but also its flexibility and controllability, resulting in the capability for automated individual cutting. The contours of any design can be transmitted to real products at the touch of a button, at speeds which cannot be matched with other processes.

The joining processes of laser welding and brazing were soon integrated into metal and plastics processing. The semiconductor industry uses lasers to pattern crystalline silicon by turning some of it into amorphous silicon, thus customising it for specific applications. The precision the use of lasers allows is also used to control the time-temperature flow during solidification in the condensation of matter. These qualities also make lasers a useful tool in lightweight material processes, such as CFK and GFK, as well as in joining these materials with metals and ceramics, and generally in joining different types of materials.

Many processes in surface technology benefit from the high maneuvrability of light in time and space, such as the tempering of carbon steels and the compressing of metal surfaces to achieve top corrosion and wear and tear resistance ('shot peening'). Heat treatment of thin outer layers and surface smoothing to combat interfacial tension were also developed and led to laser polishing, which creates atomic-level precision for dielectrics like glass.

The fusion of thicker layers for protection against wear and tear was further developed for additive manufacturing through deposition welding. In addition to repair and maintenance applications, interest in the industry focused on rapid prototyping. Alongside deposition welding, this mainly uses the laser-powder-bed-fusion method.

The systematic increase in productivity meant that not only could '3D printing' be used to create design and functional templates and prototypes, but much value could also be created in rapid manufacturing – meaning the additive manufacturing of individualised or complex components in only a short time, and at a similarly affordable cost as serial production.

Stereolithography, a pioneering processes in plastics, thus gained an entirely new relevance in production technology. Components made from materials including metal and ceramics could be manufactured using sintering and other 3D printing methods.

Current developments are working on scaling system technology to make it suitable for serial production of more than 50,000 items, which is expected to revolutionise production technology. One variant of deposition welding is the "EHLA process" (Extremely High Speed Laser Deposition Welding). This makes environmentally damaging chemical processes such as chrome plating obsolete by using macroscopically relevant surface area coating.

Laser removal makes it possible to drill precisely at extremely high aspect ratios in all imaginable materials. Building on this, the stripping process of 'photonic milling' was developed, meaning the ability to manufacture individual free-form shapes with sub-micrometer precision, straight from the design on a computer. This technology can be implemented in all materials and thus allows for serial production of individual products with a batch size of 1.

This falls under the umbrella of 'Digital Photonic Production', meaning the additive, subtractive or structuring manufacture of individual components directly based on a computer design, without the use of any tools and without intermediate steps before production. In addition to their use as continuous laser beams, lasers with an ultrashort pulse (USP lasers) are particularly useful for removal and cutting, drilling, structuring or polishing. They allow for many areas of application, such as the processing of temperature-sensitive materials or in high-precision material processing.

Contactless measuring technology should not go unmentioned. Through the expansion to include analytics, It has not only found its way into everyday life and in geometric applications, but also particularly into areas such as material separation and medical diagnostics. Biotechnology offers great application potential for lasers, ranging from the ability to position individual cells (optical tweezers, Nobel Prize 2018) to 'bioprinting', the vision of printing entire organs. The development of short-wave coherent sources in the 'EUV' (extreme ultraviolet) range for cell diagnostics or even x-ray lasers to treat individual cells in an organic compound is underway.

APPLICATION AREAS IN THE MEGATRENDS OF OUR SOCIETY

Our society now faces the challenges of megatrends such as mobility, energy, communication, climate protection, security and health. Fast and effective solutions are needed to address these. Photonics offers solutions for the challenges resulting from these megatrends The environment benefits in many situations, including from solutions which were not originally developed for climate protection.

Photonics offers solutions for the challenges resulting from these megatrends. The environment benefits in many situations, including from solutions which were not originally developed for climate protection. Or vice versa: sustainability is playing an ever greater role, perhaps even the main role, in these megatrends, because climate protection affects all other megatrends and therefore is of significant importance. Solutions which are damaging to the environment are no longer deemed acceptable.

Photonics makes it possible to constructively combine economy and environmental protection. These challenges can be managed thanks to the opportunities provided by the extremely efficient and effective applications and processes of photonic technologies. Innovative solutions have already been developed and implemented in numerous areas.

It is clear that the development of the light diode as a substitute for thermal light sources has increased the efficiency of lighting by several magnitudes in only a few years, while reducing energy consumption and therefore the impact on the environment. This achievement is one of the inspirations and motivations behind this study. Its aim is to demonstrate how the potential of photonic technologies can still be leveraged further – in addition to this example and other generally evident application areas such as photovoltaics (solar panels) – or simply where photonics has not yet been exploited at all.

Today, satellite-based lasers are being developed for climate protection which measure the distribution, creation and adsorption of greenhouse gases globally online in a similar way to a GPS system. This also opens up perspectives of how to record local climate change events in real

time, such as forest fires and volcanic eruptions. The regulation and design of a sustainable, environmentally friendly atmosphere looks palpable. The circular economy is currently suffering from utterly insufficient recycling, which can be resolved through logistical measures in simple areas such as plastic packaging.

The situation looks quite different for goods produced using complex production technologies. The high level of functional integration in products in particular requires a highly compact use of a variety of materials. This soon becomes apparent if we look at the examples of cars or mobile phones. Other than steel, extensive recycling for the materials from these products is unavailable in spite of their wide distribution and growing markets. However, technical solutions are available, especially using extremely fast and precise contactless photonic processes. For instance, processes are currently being developed to dismantle and separate the different materials in mobile phones using 'LIBS' (laser-induced breakdown spectroscopy).

In the agricultural industry, the analysis of growth statuses by local and temporal factors using photons is deployed to precisely dose fertilisers and herbicides locally. In medicine and medical technology, photonic technologies have long played a key role. The diversity of methods and processes will systematically drive 'smart medicine' and 'individualised medical technology' in the future.

Photonic technologies also significantly contribute to efficient processes in energy generation, for example in increasing the efficiency of solar panels, in energy storage and conversion, in reliable and safe battery cells, as well as in compact electrical motors for electromobility. Wear and tear protection using environmentally friendly materials has already been demonstrated. The manufacture of compact high-performance electronics is highly reproducible using material-adapted joining techniques. In thin layer technology, lasers are better suited to the economic and environmentally friendly manufacture and modification of extremely thin functional layers than any other tool – such as for photovoltaics or electronics. When generating renewable energy such as wind power, photonic processes allow for greater efficiency and longer lifespans.

Combustion processes, both for traditional fossil fuels, and for the development of turbines for renewable energy – including hydrogen and chemofuels – can be optimised, particularly using additive laser processes of extreme temperature-resistant materials and precision drilling for optimised cooling. This allows CO_2 emissions to be reduced systematically.

3D printing offers new design freedom throughout production technology. Lightweight construction, collision safety and crash behaviour, stability, recyclability, and integration of sensor technology are no longer conflicting objectives. Highly precise process controls can also be used to create measurement results in real time in order to adapt ongoing production and minimise the proportion of rejected parts. 'Industry 4.0', the systematic merger of production processes with 'Big Data', and the development of the corresponding algorithms to 'artificial intelligence' make an excellent combination with 'DPP' (Digital Photonic Production) because of their systematic independence from the level of individualisation and from lot sizes.

New designs and new product and component functionalities will contribute to solving the challenges of today's megatrends with photonic processes. Productivity, quality and design freedom promise industry actors market leadership in their industries at full utilisation.

OUTLOOK

Analysis of the significance of photonics, as we know, further develop and apply it today, quickly shows us that its future has only just begun. An end to the benefit of further research is not in sight. On the contrary, the range of applications – particularly in conjunction with the increasingly important aspect of sustainability – is getting ever broader.

But to conclude, the outlook should also include a visionary aspect of photonics which cannot yet be fully substantiated today: quantum technology. Thinking in our Western cultures is still largely characterised by a mechanical world view. This was further expanded by computer technology and related information technology. The digitisation of our societies continues and also influences manufacturing technology and production. Photonic technologies are playing a key role and enable many relevant innovations.

What's next? The economic and social sciences have long shown us that our existence is not predetermined in the traditional sense, not subject to a causality which can be traced back to basic laws as in mechanics. The complexity and non-linear effects of events make it impossible to draw up extensive models to describe the future of such systems.

Such phenomena have also been discovered and described in the 'exact' science, in physics, which after all forms the basis of all of our technologies. The quantum nature of the atomic world contains statuses which can be occupied and unoccupied at the same time, which can only be described using probabilities. This does not fit our mechanical worldview. But intuitively, this is easy to understand because our life is subject to many probabilities, and changes caused by these. Quantum computers no longer 'calculate' sequentially but superimpose quantum statuses and thus determine the target status. Their powers are such that fewer than a hundred quantum systems (such as atoms) are sufficient to describe the number of all atoms in the entire universe.

The perspective of quantum communication is also promising, as it allows for potentially bug-proof communication channels to be developed. Quantum imaging uses interlocked photons to give access to and analyse material areas which would otherwise not be accessible, which one day might lead to entirely new possibilities in medicine. Will quantum technology provide us with fundamentally new findings? To return to our original point: could it make a material contribution to social development? We can already identify this potential in the area of technical research: for example, one vision might be predicting atmospheric changes, the development of greenhouse gases and the weather over previously unachievable time scales. This would provide an entirely new, reliable basis for sustainability. Various scenarios of the measures taken could be simulated, and thus undesirable effects could be predicted reliably. This would mean genuinely sustainable actions.

In addition to the technical perspectives, it might one day also be possible to give a much better estimate of the consequences of sociological, economic and perhaps even political actions using such simulations.

One thing is for sure: The story of photonic technologies is nowhere near its end.

"If, tomorrow, all lights, lasers and light based sensors were switched off, it would not only be dark, but many of the things that we are so used to in our everyday lives would also stop working."

Prof. Dr. Reinhart Poprawe

3 billion tons less CO_2:

The global minimum contribution of photonics to climate protection based on selected examples

INNOVATION TO PROTECT THE CLIMATE

Photonics offers high-tech solutions for a wide array of application areas which can materially contribute to sustainability thanks to their features, potential uses and modes of operation. Below, several examples are presented to illustrate the vast potential and diversity of these key technologies. Some areas are still at the beginning of their growth journies, such as optical early detection of forest fires, laser-supported metal recycling or optical communication in 5G mobile networks. Others have already contributed significantly to climate protection in the past yet still harbour enormous potential, such as photovoltaics, LEDs or broadband communication via the fibre optic network.

Even in technology areas where photonics have already proven their sustainability, and where the market environment sees mature products and a market saturation, more efficient new solutions are already ready to be deployed. One example is LED televisions and their potential successors, OLED and quantum dot displays.

The eight examples in this chapter alone already contribute indirectly to climate protection of 1.13 billion tons CO_2eq. The potential is expected to more than double by 2030. With a global CO_2eq saving totalling 2.9 billion tons, including an additional 1.8 billion tons since 2018, photonics will contribute 11 percent to the 15 degree climate protection target by 2030 and 22 percent to the 2 degree route of the Paris Climate Agreement.

This study only examines technologies which have not yet been exploited or have not been exploited in full (in terms of distribution/market penetration). The use of the technology in the respective year is compared with a scenario in which this technology does not exist (hypothetical or real).

However, this is only one part of the contribution that photonics can make to environmental sustainability, as demonstrated by the many further application examples in this study. The actual potential is vast and even greater but cannot be predicted exactly.

CLIMATE PROTECTION POTENTIAL IN 2030

CO_2

–2.92 billion tons
CO_2eq in 2030

corresponds to a contribution of

11 % to the target value of the
Paris Agreement

to reduce greenhouse gas emissions compared to 2019

Calculation of potential based on selected examples

Source: SPECTARIS/TEMATYS/era energy research

Tematys
Exploration of photonics markets

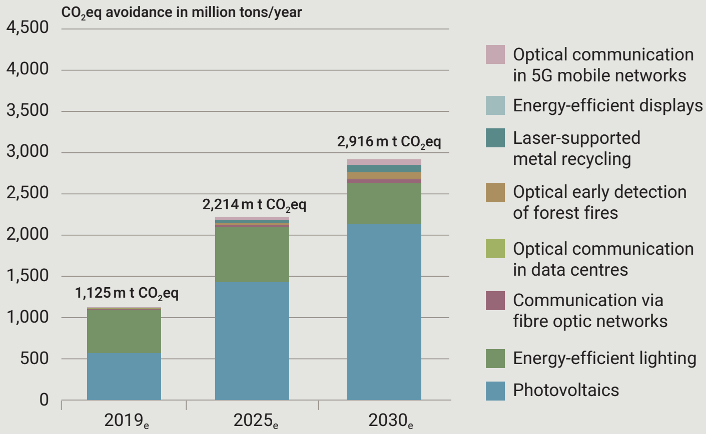
TEMATYS

The French market research and consultancy firm TEMATYS, with its head offices in Paris, specialises in studies and strategies in the areas of optics, photonics, sensor technology, imaging, material technology and their applied markets. The examples presented here were calculated by TEMATYS taking into account numerous studies, other sources and discussions with industry experts.

For more details of the calculations, visit:

www.spectaris.de/fileadmin/download/greenphotonics

Indirect climate protection potential of photonics,
illustrated based on selected examples



Source: TEMATYS

CALCULATION EXAMPLES

CO_2 avoidance through:

Photovoltaics ➔ **Page 20**
Energy-efficient lighting ➔ **Page 21**
Optical communication in data centres ➔ **Page 22**
Fibre optic communication networks ➔ **Page 23**
Energy-efficient displays ➔ **Page 24**
Optical early forest fire detection ➔ **Page 25**
Laser-supported metal recycling ➔ **Page 26**
Optical communication in 5G mobile networks ➔ **Page 27**

For the sources for the calculations, see pages 28–30

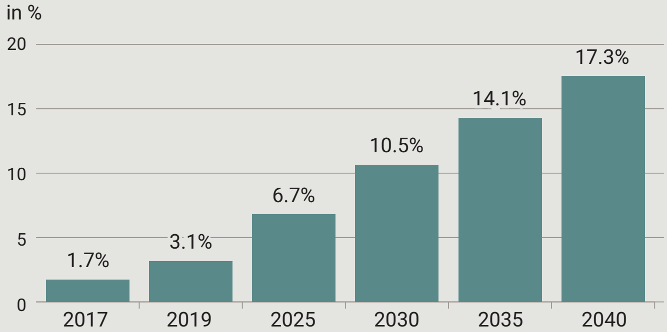
CO_2 AVOIDANCE THROUGH PHOTOVOLTAICS

The realisation that climate protection targets cannot be reached without scaling up the proportion of renewable energies has now registered with people. The simplest solar technology is solar thermal technology in which solar energy is converted and heat is collected. However, the most promising technology is photovoltaics which generates electricity from sunlight.

The widespread use of this technology over the last decade has led to a gradual reduction in investment and operating costs. The International Agency for Renewable Energies therefore expects that photovoltaics will be able to compete with fossil energy sources everywhere from 2020 [1]. Not only for this reason, it is expected that its share in the global energy mix will continue to grow very strongly in future years. Countries around the world are relying on the massive expansion of photovoltaics. According to calculations by the International Energy Agency (IEA), in 2040 more than 17 percent of electricity generated globally will come from photovoltaics [2].

The effects on climate protection are significant: Even today, according to calculations by TEMATYS, the energy generated by photovoltaics corresponds to an equivalent annual saving of around 569 million tons of CO_2. Given the continuing increase in the distribution of this technology, this effect – assuming sustainable policies (Sustainable Policies Scenario) – will nearly quadruple by 2030, which will correspond to an annual avoidance of 2,130 million, or 2.13 billion tons CO_2eq.

Proportion of photovoltaics in global electricity generation



Source: OECD/IEA, World Energy Outlook 2018 (Sustainable Policies-Szenario)

The degree of efficiency of photovoltaics in relation to energy generation and storage is increasing continuously, which promotes this development. A further major benefit of photovoltaics is that its production is virtually carbon neutral. Several comprehensive studies of the life cycle of photovoltaics plants have shown that their emissions factor is between 0.020 and 0.050 t CO_2eq/MWh [3].

Global energy production through photovoltaics

TWh	2019	2025	2030
	711	1,940	3,268

Source: TEMATYS, OECD/IEA [2, 4]

Global CO_2 avoidance through photovoltaics

in million t CO_2eq/ year	2019	2025	2030
	569	1,426	2,130

Source: TEMATYS [2, 4]

Thanks to solar cells, solar energy can be converted into electrical energy highly efficiently. The degree of effectiveness of solar cells reached 45 percent in the laboratory.

CO_2 AVOIDANCE THROUGH ENERGY-EFFICIENT LIGHTING (LEDS)

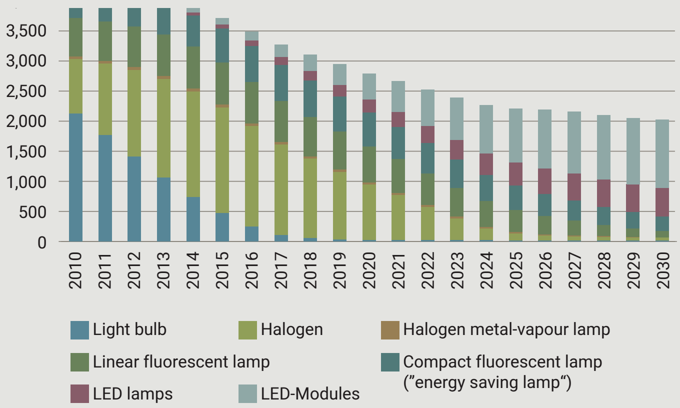
Lighting accounts for around 15 percent [1] of global energy consumption. The climate protection effect that is already achieved and expected through the use of energy-efficient lamps is high.

In the 1990s, the light sources installed mainly consisted of light bulbs and fluorescent tubes. In 2008, the European Union (EU) decided to phase out traditional light bulbs, with similar laws passed in many other countries. Even though the light capacity that was installed continued to increase, the use of energy savings lamps had already started to have an effect. After a peak in 2010, the energy consumption for lighting in the EU fell by more than 5 percent by 2013.

We are now living through an "LED revolution" with a vastly increased efficiency of LEDs compared to regular light bulbs, resulting in significant energy savings and, through that, a significant reduction in greenhouse gas emissions.

Based on the global energy consumption for the lighting of 4,050 TWh in 2012, it is assumed that savings of 25 percent will already be achieved in 2019 (3,000 TWh) and savings of 50 percent will be achieved by 2030 (2,000 TWh). Following this, energy consumption will initially stabilise, since by then a large proportion of the installed lamps and modules will be LEDs. However, research is already underway into technologies which are even more efficient than LEDs.

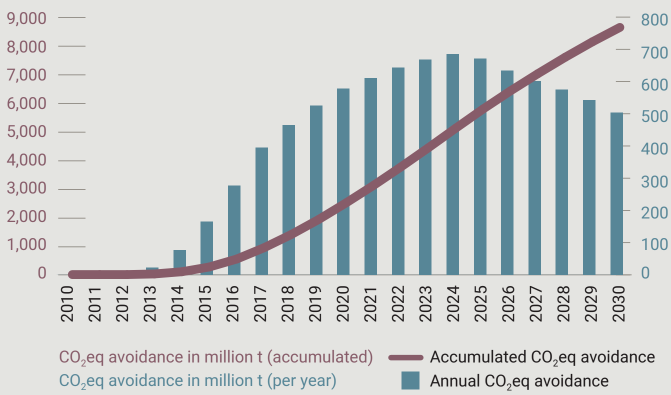
Global energy consumption through lighting by types [in TWh]



Source: TEMATYS

Even though the volume of light will actually increase slightly, it is expected that the growing distribution of LED technology in 2030 will result in the avoidance of 503 million tons of CO_2eq per year. This development is also favoured by the continued increase in the efficiency of LEDs and the fact that smart lighting systems can optimise their use.

CO_2eq avoidance through energy-efficient lighting



Source TEMATYS

Sustainability effect through energy-efficient lighting (LEDs)

	2019	2025	2030
CO_2eq avoidance in million t/year	526	671	503

Source: TEMATYS

Photonics has developed white LEDs which require less than a tenth of the power of a filament light bulb.

CO_2 AVOIDANCE THROUGH OPTICAL COMMUNICATION IN DATA CENTRES

In the age of communication and digitisation, the required processing power is continuousl rising. While the data processed by data centres in 2010 was still 1 exabyte (1 EB = 1 million terrabytes), an increase to 220 zettabytes is expected (1 ZB = 1 billion terrabytes) by 2030 [1].

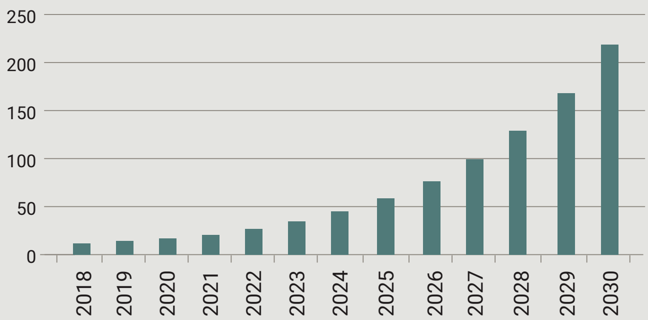
Assuming a global energy consumption of 180 TWh for 4 ZB in 2014, the energy consumption of data centres would therefore reach 9,900 TWh in 2030.

In 2014, the energy consumption of data centres was distributed as follows: More than 40 percent is accounted for by the general infrastructure, less than 10 percent to lighting and devices used to ensure uninterrupted power supply (UPS) and around 50 percent to the so-called IT infrastructure, which includes CPUs, memories and the IT network [4]. But these figures are changing.

Data centre providers use several approaches to counteract a possible drastic increase in greenhouse gas emissions.

Electricity is obtained from renewable energies such as photovoltaics. They aim to improve the Power Usage Effectiveness (PUE) value. This compares the total energy consumed by a data centre (e. g. for cooling) to the energy consumed by the IT infrastructure. Corresponding measures promise a large leverage effect, and it is assumed that energy consumption in 2030 will be below 700 TWh instead of the 9,900 TWh projected above.

Global IP traffic in data centres

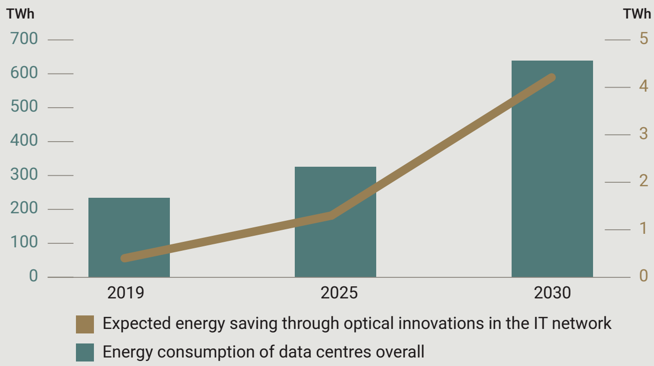


Zettabytes/year (1 ZB = 1 billion terrabytes)

Source: CISCO Global Cloud Index, 11/2018 [1]

In addition, a reduction in watt hours (Wh) per byte in the IT network, i.e. in the data centres' mobile and cable networks, is being aimed for. Optical data transmission plays an important role here [5]. Significant effects have already resulted from the substitution of copper with optical connections. This development is practically complete. Efforts to further improve the Wh-byte ratio, such as by using silicon photonics and other optical innovations, particularly in electronic circuits, can result in an annual energy saving of more than 4 KWh in 2030 [6, 7].

Global energy consumption in data centres



Source: TEMATYS

Sustainability effect of innovative photonics network components in data centres

	2019	2025	2030
TWh saving/year	0.4	1.37	4.21
CO_2eq avoidance in million t/year	0.2	0.55	1.1

Source: TEMATYS

Integrated photonic circuits in data centres avoid the high-loss conversion of optical to electrical signals and back.

CO_2 AVOIDANCE THROUGH FIBRE OPTIC COMMUNICATION NETWORKS

Whether streaming, cloud computing or FaceTime: Data traffic is on the increase, not least due to video content. This means higher bandwidth requirements and corresponding latency demands, which drives the expansion and distribution of fibre optic networks into the homes of communication users (FTTH – Fibre to the home) [1].

Governments have recognised the need for a high-performance digital infrastructure, and also promoting fibre optic and 5G networks for economic reasons (see also the 2025 targets of the European Union's Gigabits Society [2]).

Several internet service providers are increasingly shifting their core business towards FTTH. In remote areas, which are not appealing enough for private corporations, local authorities are supporting the expansion of the fibre optic network.

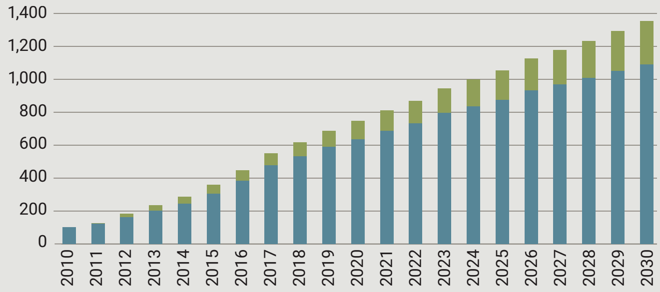
All in all, we can expect to see a rapid transition from copper-based infrastructure to FTTH networks.

The consultancy firm PwC estimates that in the first 15 years of implementing fibre optic networks, greenhouse gas emissions of approx. 330 kg CO_2 equivalent will be saved per year and user, primarily due to a reduction in the use of materials and electricity. For the following 15 years, the saving will increase to 780 kg CO_2 equivalent per year and user, because the network is already installed and only part of the infrastructure needs to be renewed [3].

For the situation in 2008, it was calculated that if all participants had shifted from DSL/cable networks to fibre optic networks, the corresponding GHG emissions could have been reduced by 88 percent. With the exception of a few countries, the potential for progress in FTTH or fibre to the building (FTTB) around the world is still vast due to the fact that only a small percentage of households are connected to fibre optic networks [1]. On this basis, the number of broadband users is expected to rise from 390 million in 2016 to 1.06 billion in 2030, i.e. three times as much.

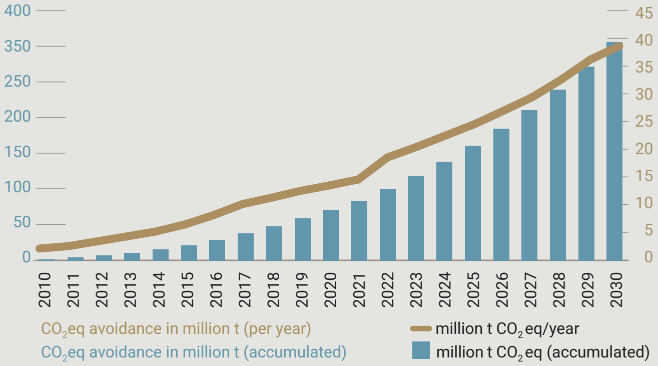
Taking into account the number of participants globally, fibre optic networks currently save around 13 million tons of CO_2eq compared to other technologies for home connections. This value will rise to 39 million tons in 2030.

Global number of broadband subscribers [in millions]

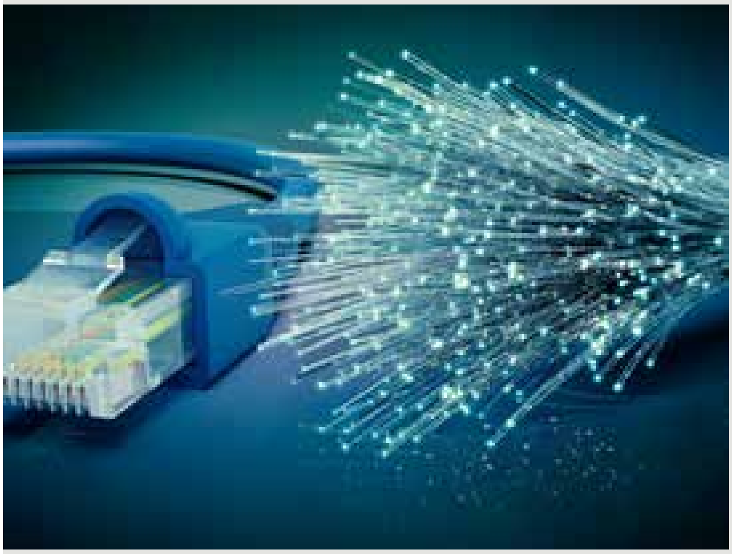


Source: TEMATYS, [4]

$C0_2$ avoidance through fibre optic communication networks



Source: TEMATYS



Signals in optical fibre optics can be transmitted 100 km without interim amplification, whereas electrical signals can only be transmitted 2km.

CO_2 AVOIDANCE THROUGH ENERGY-EFFICIENT DISPLAYS

More than 20 years ago, the success story of flat screen TVs began, replacing conventional “tube televisions” (CRTs) due to their more compact build, better colour reproduction and higher efficiency.

This resulted in a rapid global transformation of the market: In 2000, only CRT televisions were sold, in 2016 only flat-screen TVs. In contrast to CRT devices, LCDs have a significantly better CO_2 footprint, both in the production and usage [1, 2]. The increasing share of LCDs has largely compensated for the CO_2eq pollution resulting from the doubling of TV sets (+100 %) (+37 %) [3].

For the years 2016 to 2030, market researchers expect only a slight increase in the number of devices sold per year, from 255 to 301 million (ø +1.3 % p.a.). After a slight upturn for very large LCDs by 2023, for the subsequent growth for this period is forecast primarily for large OLED displays (55”+) [4].

Overall, however, an extensive market saturation of around two billion TVs installed globally is expected. The majority of these will still be LED-LCD televisions (both small and large), even though various new technologies will be launched after 2020 (QD-LED-LCD, OLED) [5].

Sustainability effect of new energy-efficient displays (OLED, QD-LED)

	2019	2025	2030
CO_2eq avoidance in million tons/year	–	1.7	6.3

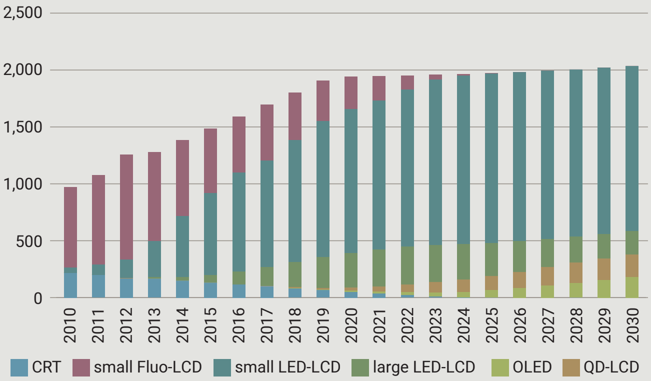
Source: TEMATYS

Currently, OLED (180-190 kWh/year) and QD-LED displays (130-150 kWh/year) are not yet as efficient as the now outdated LCDs (100-110 kWh/year).

Whereas LCDs with LED or fluorescent back lighting were already technologically mature in 2010, and no longer have any major efficiency reserves, the new technologies are expected to see a significant improvement in their CO_2 footprint by 2030.

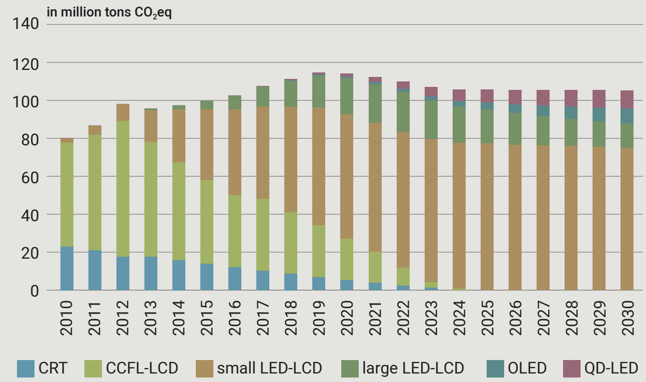
Both OLED technology and QD-LED technology have the potential to reduce energy consumption to as little as 80 kWh/year or 70-80 kWh, respectively, and thus below the consumption value of LCDs [6]. For instance, the phase energy used can be reduced. Also, no energy is lost in filters, with the entire energy input remaining available for back lighting. Since fewer components and process steps are required for OLED manufacture and fewer materials for QD-LEDs, it can also be expected that the production of these devices will also be more climate-friendly than that of LCDs once these technologies have matured.

Installed base of TV sets by technology [in billion items]



Quelle: TEMATYS

CO_2 footprint of TVs by technology [installed base]



Source: TEMATYS

CRT: Cathode ray tube | OLED: organic light emitting diode | QD: Quantum dot | LED: Light-emitting diode | CCFL: Back lighting cold cathode fluorescent lamp | LCD: Liquid crystal display

Photonics is revolutionising display technologies, while modern active OLED displays increasingly replace LEDs.

CO_2 AVOIDANCE THROUGH OPTICAL EARLY DETECTION OF FOREST FIRES

Forests play a major role in preserving the Earth's environmental balance, not least because of their capacity as a carbon sink. Even though forest fires can be caused by natural events such as lightning or volcanic eruptions, 90 percent of them are caused by humans, either intentionally or unintentionally, to expand the area of land used for agriculture. Taken together, these fires produce more than 23 percent of the CO_2 released to the atmosphere [1]. The result is catastrophic short and long-term consequences for humans and the environment, as the devastating fires in California, Canada, Australia, Spain and Portuga have shown in recent years [2].

The systems and methods used to detect forest fires are equally important, and today these are almost exclusively based on photonic technologies. They include binoculars that humans can use for monitoring as well as automatic optical systems for the early detection of forest fires or smoke, which are often used together with other sensors. Some detection systems not only detect fires as early as possible, they also help to evaluate the risk of forest fires depending on the weather, air temperature, soil humidity or other factors [3].

Satellite-based sight and IR cameras can help to efficiently monitor forest fires on the whole of the Earth's surface, evaluate damage and provide data for forecast models. For early detection however, these systems (e. g. MODIS or AVHRR), are of limited use as a satellite usually only flies over a region every 1-2 days. Automatic systems on watchtowers are more efficient in this regard. Since they can be in operation around the clock, they complement human observation well.

OPTICAL SYSTEMS FOR THE DETECTION OF FOREST FIRES

- Sight cameras detect smoke
- Thermal imaging cameras detect the heat of the fire
- Infrared (IR) spectrometers are used to identify the spectral properties of smoke
- LIDAR systems (Detection of Light and Range) measure the reflected laser beams of smoke particles

In the near future, additional pseudosatellites an altitude of 20 to 50 km with a field of vision of 500 km will also be able to contribute to monitoring large areas at affordable investment costs [4].

Forest fires emit the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The average total greenhouse gas emissions per year for the period 1997–2016, according to the Global Fire Emissions Database (GFED4s), were 7.3 billion tons of CO_2, 16 million tons of CH_4 and 900,000 tons of N_2O [1]. Taken together, this corresponds to an average CO_2 equivalent of 8.1 billion tons per year [5, 6].

Automatic forest fire detection systems (AWDS) are technologically mature but their distribution has only just begun. For a cautious estimation of the AWDS-potential, different assumptions are necessary [7]. Generally speaking, it can be assumed that more and more surfaces will be monitored in the future, initially on Earth, and then by means of pseudosatellites. Forecast models will also increasingly take effect. For 2019, initially a low avoidance potential of 0.1 percent of the annual CO_2 equivalence value caused by forest fires is assumed, which will rise to 1 percent until 2030, with a tendency to increase even further.

		CO_2eq/year
Average annual CO_2eq emissions caused by forest fires [1]		8.1 billion t
CO_2eq emissions potentially avoided through optical early forest fire detection systems		
2019	0.1 %	8.1 million t
2025	0.2 %	16.2 million t
2030	1 %	81 million t

Source: TEMATYS

It is only thanks to photonics that (smoke) signals can be detected quickly, sensitively and at a great distance without the need for contact

CO_2 AVOIDANCE THROUGH LASER-SUPPORTED METAL RECYCLING

Due to global economic growth, the demand for metals has been rising continuously for decades. Energy consumption to extract metals is significant and is associated with corresponding environmental effects.

Material	Primary production (kt CO_2eq/100kt)	Secondary production (kt CO_2eq/100kt)	CO_2 avoidance (kt CO_2eq/100kt)	CO_2 avoidance in % (CO_2eq)
Aluminium	383	29	354	92 %
Copper	125	44	81	65 %
Steel	167	70	97	58 %

Source: Bureau of International Recycling [3]

Fortunately, the most important metals can be easily recycled (secondary production). Today, more than 35 percent of the steel produced and more than 20 percent of the aluminium produced are from secondary production [1, 2]. Recycling requires significantly less energy than extraction from ore (primary production). Converted to CO_2 equivalent values, recycled steel can avoid 58 percent of the CO_2 equivalent emissions that would be produced in primary production, 65 percent of recycled copper 92 percent of recycled aluminium [3].

A comparison of the shares of global primary and secondary aluminium production (79 % to 21 %) shows that, for various reasons, these have hardly changed since the 1970s [1].

One reason for the comparatively low proportion of recycled metals is that scrap metal must be converted to standardised types of metal. In addition to the primary metal (iron, aluminium, for example), products will contain additives/other ingredients (carbon, chrome, for example), which are added in order to improve the quality of the metal.

If scrap metal is melted down to one grade, all the additives are also melted down, which makes it difficult to produce pure metals. This is where photonics offers a solution: Laser-induced breakdown spectroscopy (LIBS) is a quick chemical analysis method which generates a microplasma on the sample surface using a short laser pulse. This analytical method is very well suited to scrap metal and waste sorting, because it works contactlessly and at a range of a few centimetres to several metres. Another major advantage is the fact that the surface of the sample can be evaporated in order to remove paint or an oxidised layer.

This means that the core material to be identified can be reached easily. The recycling process and secondary production of standardised quality metals can be significantly improved [5].

Recycling management scenarios relating to the primary and secondary supply of iron and aluminium assume that the proportion of secondary production will also increase significantly in the future, for the period 2010 to 2100 – partly as a resul of pressure for more sustainable development [4].

LIBS technology for scrap metal sorting is currently still at the beginning of its development curve, but it has enormous potential. The percentage of CO_2eq emissions avoided due to LIBS in the context of secondary production is expected to increase from around 1 % today to 10 % in 2030. From the recycling of iron and aluminium alone, this could result in an annual reduction of emissions of around 90 million tonnes of CO_2eq.

CO_2eq avoidance through photonics due to the progressive implementation of LIBS technologies for analysis and the sorting of aluminium and iron

	2019		2025		2030	
	Iron	Aluminium	Iron	Aluminium	Iron	Aluminium
Primary production [million t]	1,492	57	1,824	68	2,090	78
Secondary production [million t]	512	29	676	35	779	41
CO_2eq emissions through primary production [million t CO_2eq]	2,491	217	3,046	261	3,491	300
CO_2eq emissions through secondary production [million t CO_2eq]	359	8	473	10	545	12
CO_2eq avoidance [million t CO_2eq]	497	103	656	122	755	144
Proportion of photonics to enable or optimise secondary production	1 %	1 %	5 %	5 %	10 %	10 %
CO_2eq avoidance enabled through photonics [million t CO_2eq]	5	1	33	6	76	14

Source: TEMATYS

Optical analysis enables extremely fast and selective, contactless identification of materials in the recycling process.

CO_2 AVOIDANCE THROUGH OPTICAL COMMUNICATION IN 5G MOBILE NETWORKS

In 5G mobile networks, 80 percent of power is supplied to base stations (BTS – Base Station Transceiver).

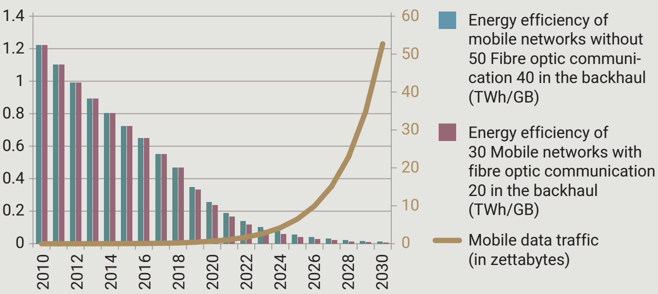
The more data traffic, the more power is required. In addition, the energy consumption of the stations depends on population density, the topology of the site and several other parameters [1].

A further 10 percent of the energy requirement relates to the backhaul network, i.e. the link between the base stations on the edge of the network, which are usually inferior to the inner network, the central network node (core) [2, 3]. Both cable-based and wireless connections are possible (fibre optics, microwave, free space optics).

Energy efficiency gains can result from the optimal interplay of suitable deployment environments, mobile architectures and technologies [4]. As part of the European research programme Green-Touch-Technology, it was shown that LSAS (Large Scale Antenna System) technology, in conjunction with the separate signalling system between small cells (Beyond Cellular Green Generation – BCG), exceeds all other technologies in a dense urban environments [5].

Market researchers expect the share of fibre optic connections in the backhaul network to increase further in the next few years, from 40 percent in 2015 to more than 50 percent in 2021. The second largest proportion will be made up of wireless microwave or free space optical connections, with copper connections playing only a minor role [6].

Mobile data traffic and increased efficiency through fibre optic connections in the backhaul network



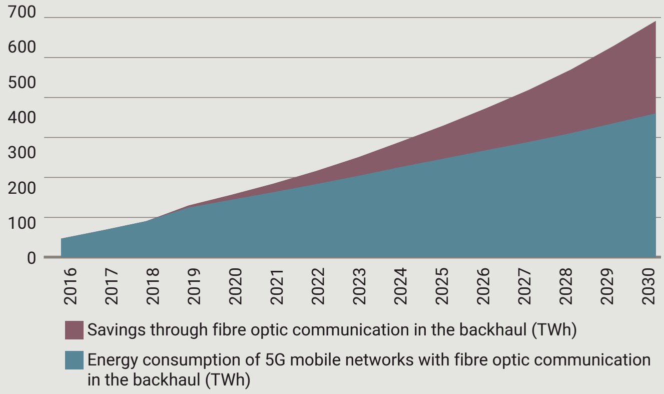
Source: TEMATYS

Sustainability effect of optical communication technology in 5G mobile networks

	2019	2025	2030
CO_2eq avoidance in million t/year	3	35	66

Source: TEMATYS

Global power consumption with and without fibre optic network in the 5G backhaul network

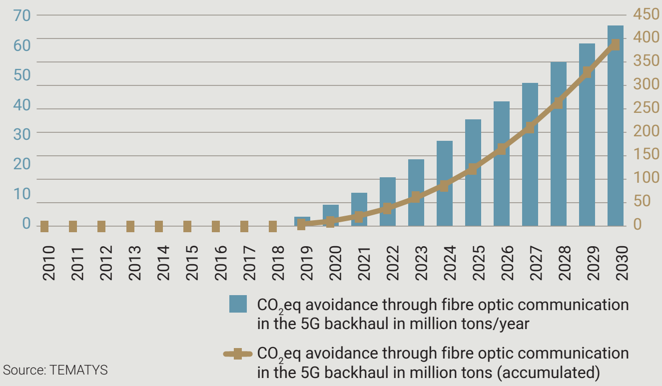


Source: TEMATYS, [4]

In light of the strong increase in mobile traffic to 50 zettabytes (1 ZB = 1 billion terrabytes) in 2030, and taking into account the ratios and parameters mentioned above, it can be assumed in the long term, a 10 percent reduction in consumption (kWh/GB) can be achieved through the use of optics in the backhaul compared to copper and microwave channels. According to the study, global energy consumption in 2030 would be 406 TWh instead of 668 TWh, which corresponds to a reduction of 40 percent.

Converted, this results in the potential to avoid 66 million tones of CO_2eq per year in 2030.

CO_2eq avoidance through the use of fibre optic connections in the 5G backhaul mobile network (compared to copper and microwave networks)



Source: TEMATYS

In optical fibres, a large amount of data can be transmitted at the same time – an important prerequisite for the interconnection of 5G network nodes.

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- The calculations are e. g. based on the McKinsey study “Lighting the way” (2013), the EU Joint Research Centre Scientific and Policy Reports “Energy Saving Potentials” (2012) and on further studies and publications.
- The forecast does not take into account an increase in the lumen (lm)/Watt (W) ratio. Instead, it is assumed that in the next 10 years, the current LED generation will continue to be used. LED technology has already reached a ratio of around 160-200 lm/W, the target value is 300 lm/W.
- The forecast does not take into account the effect of switching from oil lighting (high CO_2 emissions) to solid state lighting in developing countries.

CO_2-Vermeidung durch optische Kommunkationstechnik in Datenzentren [Seite 22]

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- Automatic forest fire early detection systems (AWDS) are already in use in many countries, such as Canada, the USA, Mexico, Chile, France, Portugal, Spain, Slovakia, Greece, Estonia, Germany, Cyprus, Italy, the Czech Republic, Finland, Sweden, Turkey, Australia, Thailand, South Korea, South Africa, Swaziland and Tunisia (3). It is assumed that there will be no significant deforestation in these countries to reclaim land and that the forest surface in these countries will not change dramatically in the next 15 years.
- The areas covered by an AWDS are still small compared to the total area of each country. Due to a lack of statistics, cover must be estimated.
- In the next few years, most systems will be implemented on watchtowers, but monitoring via pseudosatellites is also nearly ready to be deployed, and it is assumed that this will be fully functional within a decade or less.
- To simplify, a constant value is assumed for average annual CO_2eq emissions from forest fires.

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Note

The calculation of the potentials is based on the percentage of CO_2eq avoidance that can be attributed to the photonics solution. For most of the mentioned examples, this is 100 percent.

APPLICATION EXAMPLES

GERMAN HIGH-TECH SOLUTIONS FOR ENVIRONMENTAL SUSTAINABILITY

APPLICATION EXAMPLES

ENVIRONMENTAL PROTECTION AND RECYCLING

Environmental sustainability through photonics: the environment and recycling

The importance of the sustainable treatment of natural resources and energy to protect the environment has grown in light of the global increase in environmental issues, perceivable climate change and the increase in the world's population. At the same time, the economy and the environment must become increasingly interlinked. This is achieved, among other things, by the distribution and further development of progressive technologies, not only in modern industrialised societies. For instance, laser-based measurement processes are used in recycling or in climate research.

In Germany, the recycling of reusable materials is regulated by fixed quotas. The focus is not only on plastics: the systematic recycling of metals in a sustainable economy will significantly reduce greenhouse gas emissions. A study compiled by the EU as part of the project "Mineral Intelligence Capacity Analysis" recommends altering the entire material cycle, from mining and production, including product design, to recycling technology and infrastructure. As a result, the importance of an efficient recovery of rare and strategically important valuable materials, such as rare earths or technology metals, is growing.

Environmental technology and climate research can benefit from the advantages of flexibly adjustable laser systems, which are able to record physical, chemical and biological variables quickly and highly precisely, without the need for contact. Materials produced in recycling processes can be classified at an early stage, for example by means of direct laser analysis, and sorted specifically for recycling. This makes it possible to recycle valuable raw materials from used mobile phone or circuit board components.

In climate research, determining and analysing the sources of environmentally damaging gases, such as carbon dioxide, nitrogen oxides or methane, is an important step towards significantly reducing environmental impact. Compact sources of laser beams in satellite-based systems have proven especially useful in this area. For example, they enable precise, time-independent and efficient mapping of methane gases.

As such, photonics is making a key contribution to environmental protection and to designing future value chains, particularly in the area of recycling. The sustainable treatment of natural resources and the efficient recovery of important reusable materials is gaining in importance – in this, laser-based processes are indispensable for future applications.

APPLICATION EXAMPLES

Environmental protection and recycling: SPECTARIS in conversation

SPECTARIS in conversation with Edwin Büchter, Managing Shareholder of Clean-Lasersysteme GmbH, AiF Vice President and winner of the German Environment Award

SPECTARIS: Mr Büchter, in 2010 the then Federal President presented you and your fellow Managing Director, Dr. Winfried Barkhausen, with the German Environment Award. What was your experience of this, and what solution did you win the award for?

Edwin Büchter: Being awarded the renowned German Environment Award by the German Federal Environment Association (Deutsche Bundestiftung Umwelt – DBU) was a very special moment in our work as entrepreneurs, but it was also game-changing in the success of our technology. When the then Federal President presented us with the award, it was a big boost for our company cleanLASER and for the environmental friendliness of photonics. For the first time, it became clear to the general public that through the targeted use of laser light, surfaces can be cleaned in an environmentally friendly and sustainable manner without the use of chemicals and blasting agents, thereby achieving significant savings in resources.

SPECTARIS: What are the advantages of this process, and how well is it received by customers?

Edwin Büchter: Cleaning with light not only saves on cleaning agents, but also significant amounts of energy. In addition, the laser process is more economic than alternative processes in spite of a purportedly higher investment. This in turn minimises logistics costs and optimises the value chain. Cleaning processes using lasers can also be more easily secured, making it possible to increase the quality as required by the Industry 4.0 strategy. The precision of laser beam processing also allows for the partial cleaning of parts. Due to the precision of the laser beam processing, parts can also be partially cleaned. For example, it is possible to locally clean assemblies completely equipped with sensitive electronics at functional areas, for example before gluing or welding. These are possibilities which would be unthinkable with conventional methods.

EDWIN BÜCHTER

Managing Shareholder of Clean-Lasersysteme GmbH, AiF Vice President and winner of the German Environment Award

SPECTARIS: The technology of the process is based on a research project. Does this mean that knowledge transfer from research into science works well in Germany?

Edwin Büchter: We were able to achieve the technical breakthrough in laser cleaning in the early 2000s by developing a high-performance diode-pumped pulsed laser system. For the first time, this made laser cleaning efficient, affordable and readily available – thanks to the support of the German Federal Environment Association. But a broad focus and the transfer of research and knowledge from research into industry is also important when developing new application areas.

For example, as laser technicians, 20 years ago we had relatively little knowledge about bonding and joining processes, or about the problems of the aviation and automotive industries. What is needed, therefore, is market places for innovative exchange. One example of this is Joint Industry Research under the leadership of AiF e.V. This model of joint (pre-competitive) research using funds from the Ministry of Commerce is unique and successful in its form throughout the world. Through the initiatives of innovative medium-sized enterprises, new topics are researched on an interdisciplinary basis, which enables a transfer across different sectors, especially through the people involved in industry and through the participating Research Associations. If you look for optimal research transfer in Germany, you will find it in and through the AiF.

Nevertheless, this highly efficient transfer is currently funded with relatively modest means (EUR 169 million), so there is definitely room for expansion. If we want to improve transferability while maintaining the same high level of efficiency, at least EUR 200 million per annum would be needed, and would prove to be a good investment in joint industrial research.

SPECTARIS: In recent years, the German Environmental Prize has been awarded to two further solutions in the field of photonics. In 2012, the award was presented to the "visionaries of photovoltaics technology" Günther Cramer (SMA Technology AG), Dr. Andreas Bett (Fraunhofer ISE) and Hansjörg Lerchenmüller (Soitec Solar GmbH). Prof. Gunther Krieg (UNISENSOR Sensorsysteme GmbH) received the award in 2014 for his life's work and for the development of an optical measurement and analysis system which is used to recycle reusable PET bottles. Why is it that photonics in particular is so successful for environmental protection?

Edwin Büchter: Light as an industrial application does not create any dirt! The significant increases in power outlet efficiency have made the use of photonics more high-performing and efficient than ever before.

> Light as a tool doesn't just allow highly efficient and precise work with almost no waste of resources, but also sustainable energy generation. This gives photonics enormous potential for environmental protection.

SPECTARIS: As a medium-sized highly innovative company, you have never rested on your laurels. You are now offering an additional solution that can contribute significantly to environmental sustainability. What exactly is it about?

Edwin Büchter: For the last five years or so, cleanLASER has focused on further topics in the field of laser technology. By combining laser cleaning and laser emission spectroscopy (LIBS), we have been able to develop a unique product which cleans contaminated cut components while detecting them at the same time. The "optical fingerprint" created using our precise laser beam allows us to detect and then sort metal components and scrap metal in only a few milliseconds. For the first time, it is now possible to classify and sort aluminium components based on their alloy components in a highly efficient manner at a throughput rate of up to 10 t/hour.

Particularly in the field of lightweight and material-mixed automotive construction, new opportunities have opened up to economically and sustainably close the recycling chain and for example, melt down various aluminium alloys creating in pressing plants without aloss of quality.

This alone enables energy savings of a factor of 5 compared to the production of raw aluminium! These activities are so successful that we have not only opened up a new market but have also created new jobs by founding the company cleansort, with its headquarters based in Rösrath near Cologne.

SPECTARIS: In your opinion, does Germany have the potential to supply high-tech photonics solutions internationally – the properties, uses and effects of which could contribute to environmental sustainability in the future?

Edwin Büchter: German engineers continue to master complexity in an incomparable way. This competence is particularly important for the development of laser technology. Photonics requires interdisciplinary thinking and co-operation between electrical engineers, physicists, material scientists and mechanical engineers. We can meet these requirements and also ensure that sustainbility is achieved in the near future. However, current political financing priorities show that the proportionate investments in education, research and other future-proof fields are declining, while government spending on other, less sustainable areas is rising continuously. In my view, this is a very dangerous trend which, coupled with the sell-off of German industry and small and medium-sized enterprises and the "giving away" of our university knowledge, will certainly not help to bring Germany, with its great potential, back to the forefront as a business location.

SPECTARIS: Thank you for speaking to us!

GERMAN ENVIRONMENT AWARD

Each year, the DBU rewards services which have made a key contribution to protecting and preserving our environment. The environment award has the highest reward money in Europe (€ 500,000).

Metal recycling of the future: Using lasers to measure and sort metals and alloys

To achieve efficient metal recycling, individual types of alloys must be separated. For the first time, it is now possible to identify alloy components by laser quickly and sort metal pieces by alloy classes.

1 Quick identification of light metal alloys for automatic sorting

2 Multiple direct laser analysis (Laser-Induced Breakdown Spectroscopy, LIBS) on scrap metal on a conveyor belt

3 Laser measurement of the location and geometry of metal pieces on a conveyor belt running at a speed of 3 m/s

APPLICATION AREA

Metallic materials for specific applications typically contain valuable alloying elements that give them the desired processing and functional properties. The more precisely these alloys are distinguished from one another during recycling, the more effectively new alloys can be created and valuable alloying elements can be used. It is usually not easy to tell from the external appearance of metals which alloying components they contain.

Separation methods for the rough classification of metals for recycling have been known for a long time. They make use of the different physical features of the metals, such as their magnetic properties or their specific weight. A more detailed differentiation is made by X-ray methods, which can be used to distinguish between wrought and cast aluminium alloys, for example. However, a further differentiation up to individual wrought alloy classes is not possible in an automatically operating sorting plant.

For the time, a much more detailed insight into the chemical composition of metal alloys can be obtained using laser technology – at a speed far faster than with previous processes. In only a fraction of a second, a chemical fingerprint is created without the need to make contact, based on which alloying elements can be identified. This process is so fast that event metal parts moving on a conveyor belt at speeds of up to 5 m/s can be measured by the laser and allocated to alloying classes. When this is combined with the position and shape of the parts on the conveyor belt, both of which are also measured optically, the parts can finally be separated into individual sorting fractions.

The metals to be sorted are available as shredded aluminium scrap parts, production waste from tin processing lines, as used tools made from high-speed steel, titanium, or hard metals. They are transported on a conveyor belt as individual parts. A laser beam directed at the conveyor belt from above records the position and geometry of the passing parts. This data is used to aim an analysis laser beam onto the individual parts in real time in order to identify the alloying elements they contain. This is a pulsed laser beam which is shaped in such a way that it can penetrate the non-representative top layers of the objects to be measured and analyse the material underneath. More than 15 chemical elements can be recorded in this way at the same time to identify the relevant alloy. Depending on the application, up to 100 measurements
are performed per second.

In the case of aluminium, the identified shredded parts and production waste are separated into different alloy fractions at mass throughputs of up to 10 tons per hour.For used tools, a manipulator picks up the identified parts and moves them into up to six allocated sorting fractions.

SUSTAINABILITY

The inline measurement of the chemical composition of metal parts opens up new potential for saving resources. The better individual alloys are physically separated from each other, the more efficiently high-quality materials can be created. Pure metal alloys can be recycled as often as required without a loss of quality. If casting and wrought aluminium alloys are not separated, they can only be used to produce low-quality casting alloys. In 2017, secondary aluminium accounted for 58 per cent of total aluminium production in Germany. There is clear potential for expansion here. Secondary aluminium can reduce energy consumption by up to 95 percent compared to the energy required to produce primary aluminium from raw materials.

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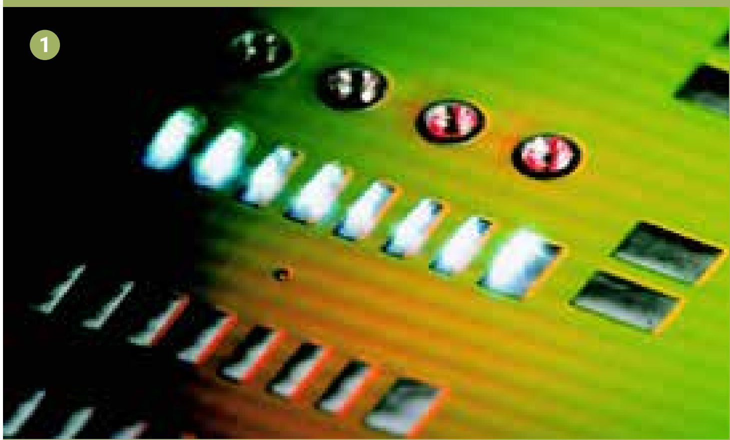
Environmentally friendly laser cleaning

Laser cleaning makes it possible to remove unwanted inpurities, lacquer and other coatings from technical surfaces in an environmentally friendly way that doesnt damage the base material.



1 Laser-based cleaning of components on a circuit board

2 Partial devarnishing of metal surfaces

3 Resonator of a fibre-coupled Nd:YAG laser with 2 kW output performance for mobile cleaning applications

APPLICATION AREA

Laser cleaning is contactless, efficient and environmentally friendly. As a result it is increasingly gaining importance compared to chemical, mechanical and thermal processes.

There are three main reasons for this: process-specific advantages (such as contactless processing, high precision and low heat transfer to the base material); the trend towards automation, and therefore also towards greater cost-effectiveness; and stricter legal requirements regarding hygiene and reduction of waste products and pollutants, for example contaminated cleaning agents.

As a result, laser cleaning has now become established across numerous different sectors of industry. One application area is regular maintenance involving large-scale cleaning of large, high-value components such as bridges and factory halls with steel grid constructions as well as planes and wind turbine masts. For example, old coatings, rust and oxides are removed to create a paintable surface for a new protective coating. In this context, it is especially challenging to remove layers selectively and preserve intact protective layers. In the automotive and automotive supply industries, laser cleaning is primarily integrated in line with existing process chains. It can be used as a local pretreatment before joining processes such as welding, soldering or glueing, for instance, or before further additive coating using functional materials to produce sensors, strip conductors or contacts. Laser-based cleaning is also useful for edge ablation of thin layer solar cells to electrically isolate and hermetically seal the modules.

Future developments of short-pulse laser sources with attractive pricing, as well as fast beam deflection systems, will result in a further market penetration of this cleaning technology.

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TECHNOLOGY

Laser cleaning is based on the locally confined contactless effects of pulsed or continuous laser radiation and achieves automated, almost maintenance-free cleaning. Depending on the composition and thickness of the top layer, and on the processing parameters, different removal mechanisms can be used. The most important mechanisms for laser cleaning are vapourisation or decomposition removal of the top layer (sublimation degradation) and removal using thermally induced voltages or laser-induced shockwaves.

For many technical top coat systems, several mechanisms can be used at the same time, with the different proportions being dependent on the properties of the materials and on the process parameters – especially the laser parameter wavelength, power density and interaction time.

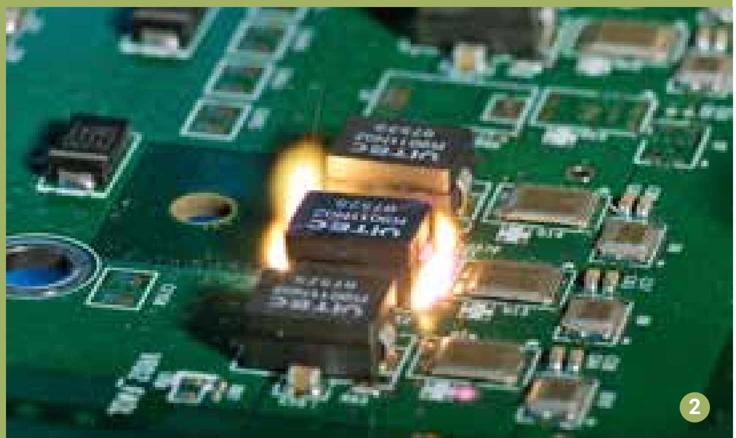
Additional parameters for laser cleaning include the optical properties, such as the absorption, transmission and reflection factors of the top layer to be removed, and of the base material. Ideally, the process can be designed so that it is self-limiting, which is usually the case for metal substrate materials. The option of automation and almost maintenance-free technology can result in even greater cost-effectiveness.

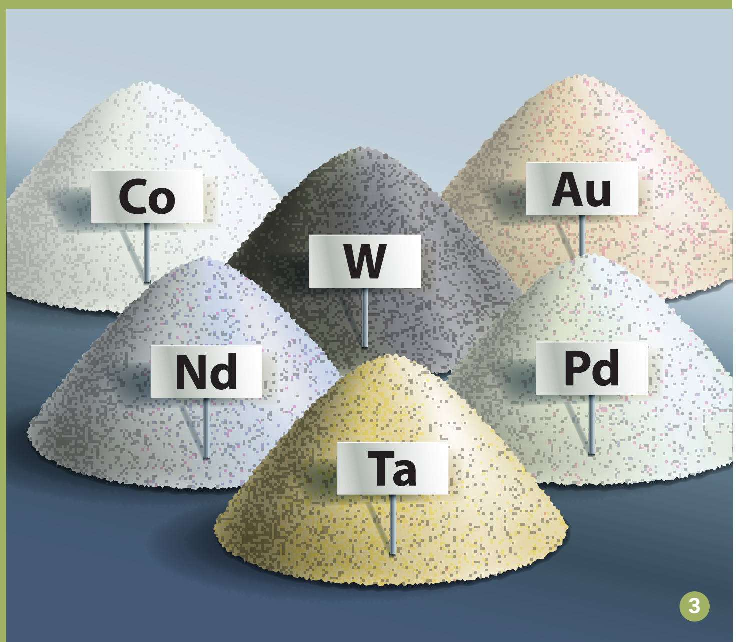
SUSTAINABILITY

Compared to conventional chemical or particle beam methods, no additional beam or cleaning agents are needed which would need to be recycled as waste after cleaning alongside the removed material. During laser cleaning, the maximum waste generated is the material that has been removed, and in many cases the total volume of waste can be further reduced by being incinerated. Waste products created during processing are directly disposed of and filtered at the processing plant using appropriate extraction equipment, which significantly reduces the risk of cross-contamination. This process is contactless and load-free, so that even sensitive substrate materials can be processed non-destructively.

Mobile phones and computer electronics – European project revolutionises urban mining

Optical technologies for the recovery of valuable materials: The European project ADIR focuses on innovative technologies to dismantle and separate components and recover valuable materials from used electronics to reach a new level of urban mining.





1 The ADIR project recovers strategically important materials from old mobile phones and computer circuit boards

2 Contactless desoldering of electronic construction elements on circuit boards using laser radiation in the process chain of the ADIR project

3 Economically important materials can be created at high recovery efficiency

APPLICATION AREA

In Europe alone, the widespread use of electronic devices with short life cycles, such as mobile phones and computer circuit boards, has resulted in hundreds of millions of these parts no longer being used each year. They contain valuable elements which will continue to play an important role in the industrial manufacture of high-tech electronics in future. In most cases, the valuable materials contained in them, such as technology metals, are lost in today's recycling processes, which rely on shredding and on the metallurgical recovery of a few metals.

The aim of the project 'ADIR – Next generation urban mining – Automated Disassembly, Separation and Recovery of valuable materials from electronic equipment' is to demonstrate the feasibility of a key next generation urban mining technology and to mine the treasures hidden in used electronics.

An innovative selective retrieval method enables the separation of highly-enriched material fractions which can be used to recover valuable materials in an efficient process. The concept is based on a process chain which contains various optical processes in several processing steps. For example, flexible laser technology is used for 3D measuring technology to determine the topography of electronic circuit boards, identify contents in real time, or contactlessly desolder electronic construction elements. Lasers are used, for example, to desolder tantalum capacitors from electronic circuit boards in fractions of a second and move them to their relevant sorting fractions by air flow. In this way, many high-quality materials can be recovered within a short processing time. Examples include materials with high economic importance and significant supply risk for the EU, such as tantalum, rare earths (neodymium), palladium, tungsten and cobalt.

TECHNOLOGY

From disassembling to measuring, analysing and retrieving used electronics and sorting reusable materials, the ADIR project partners are developing automated dismantling of electronic circuit boards and devices in order to separate out valuable components and recover reusable materials. The concept is based on image processing, robot handling, plasma-induced shockwaves, 3D laser measurement technology, real-time laser material identification (to identify reusable chemical elements), laser processing (to selectively desolder recoverable parts or to cut out parts of electronic circuit boards), as well as automatic separating into different sorting fractions. A machine concept which is able to selectively disassemble computer circuit boards and mobile phones in order to obtain sorting fractions of components with a high reusable material content has been developed.

The developed ADIR demonstrator consists of a link of four machines to automatically process mobile phones and computer circuit boards. In 2019, this demonstrator will be evaluated in field trials at a recycling company in Germany. The contained sorting fractions will be analysed in relation to raw material recovery.

The ADIR process is based on a patent held by the Fraunhofer Gesellschaft.

SUSTAINABILITY

Many high-tech products require special raw materials which must be imported into Europe. At the same time, used electronic devices and electronic circuit boards contain important technology metals. In one year, an industrial-scale inverse production line based on the ADIR concept could disassemble 1.4 million mobile phones, as well as approximately 470,000 computer circuit boards. Extrapolated to Europe, 270 facilities would be required in order to process used electronics in these categories. For tantalum alone, this could potentially reduce the EU's dependency on imports by 35 %.

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Customised laser technology for climate research in space

Laser technology in compact systems opens up the possibility of precise, sunlight-independent analyses of climate-related atmospheric gases in satellite-based climate research – e. g. for methane mapping as part of the MERLIN climate mission.

1 Artistic presentation of the MERLIN tool based on the Myriade satellite platform.

2 MERLIN – Climate research mission (Methane Remote Sensoring LIDAR Mission)

3 Optically parametric oscillator for construction technology suitable for use in space

APPLICATION AREA

In addition to carbon dioxide, the long-lived molecule methane contributes significantly to the greenhouse effect and global warming. The concentration of methane in the atmosphere has been increasing considerably for many years. In order to efficiently protect our climate, we now need to identify the sources of methane and reduce future emissions where possible.

In light of this, the French-German climate research mission MERLIN (Methane Remote Sensing LIDAR Mission) was founded in 2010. The small satellite MERLIN is expected to be launched in 2024 to map the methane in the Earth's atmosphere. The researchers involved want to understand in what regions methane enters the atmosphere and where it is broken down. A light radar system (LIDAR) sits at the heart of the satellite, sending light pulses into the atmosphere and determining the methane concentration based on the light scattered back from the earth.

Together with national and international partners such as ESA, DLR, Airbus Defence and Space, Safran-REOSC, TESAT Spacecom, von Hörner & Sulger and Space-Tec, Fraunhofer ILT has been developing laser technologies suitable for use in space for many years. One important task involves developing the laser system for the MERLIN mission. The requirements are extremely high: the system must be highly resistant to vibrations and temperatures and be able to work in space for many years without requiring maintenance. New optomechanical construction technologies are used to integrate components into the laser source precisely and stably.

Optical spectrometers for methane measurements require solar radiation. The MERLIN-LIDAR can be used to measure values independently of sunlight and hence also functions on the earth's dark side; moreover, measurements through small gaps in the clouds are also possible. These laser systems and construction technologies thus make an important contribution to climate research and environmental protection.

TECHNOLOGY

Laser technology for space missions: with the 'Future Laser System" (FULAS), Fraunhofer ILT, in partnership with Airbus Defence and Space for the European Space Agency ESA and with the support of DLR Space Travel Management, has developed a technology platform for the design and construction of individual laser systems.

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Manufacturing processes such as special soldering processes are used to make components suitable for use in space. A construction technology developed in this way enables a precise, secure and efficient installation.

The MERLIN mission will use a LIDAR system based on the FULAS platform. The requirements of the system are extremely high, as it must work reliably in space for many years without requiring maintenance. It must be able to withstand vibrations of up to 25 grms as well as thermal alternating loads of between −30°C and +50°C. Moreover, organic materials such as glues must be avoided because these can degas and contaminate ultraclean mirrored surfaces.

The LIDAR laser consists of a laser oscillator with an active longitudinal regulator, an INNOSLAB amplifier and a longitudinally regulated frequency converter. The wavelength of the radiation generated must be switchable and able to limit bandwidth, while efficiency must be as high as possible with minimal stress on the optical components.The system should be able to provide 9 mJ double pulses for two wavelengths around 1645 nm, of which one will always be set to a characteristic methane absorption line.

The MERLIN project is funded by the Federal Ministry of Economics and Energy (BMWi), and its project manager is the Space Travel Management of the German Centre for Aviation and Space Travel (DLR).

SUSTAINABILITY

Global warming has negative effects on the climate and vegetation, and there is an urgent need for action. The greenhouse effect is intensified by long-lived gases such as carbon dioxide and methane, which need to be continuously reduced. Satellite-based, robustly designed laser measurement systems meet the extremely high demands placed by many years of operation in space and enable the precise analysis of the sources of and decreases in climate-damaging gases. By mapping methane in the atmosphere, the MERLIN project makes an important contribution to our understanding of the causes of climate change.

Earth observation satellite with high-performance optical grid in space

The European Space Agency's (ESA) earth observation satellite Sentinel-5P, which forms part of the Copernicus Programme, measures the surface of our planet once a day. The data will be used primarily for environmental protection and air purification.

Sentinel-5P is one of a total of six satellites of the EU funded ESA Copernicus programme

APPLICATION AREA

The new earth observation satellite Sentinel-5P of the European Space Agency ESA was launched into space on 13 October 2017 at 10:27 AM CET. Sentinel-5P is one of a total of six satellites of the EU funded Copernicus programme. The data gathered by this sentinel satellite, which measures the entire surface of our planet once a day, will primarily be used to further environmental protection and air purification. Sentinel-5P researches the earth's atmosphere and, among other things, determines the contents of trace gases such as ozone or methane which influence the earth's air quality and climate.

The 820 kg satellite is equipped with the ultramodern measurement tool Tropomi. The tool was manufactured in the Netherlands by Airbus Defence and Space Netherlands and TNO, and contains several spectrometers , two of which are equipped with ZEISS optics. Since every gas demonstrates typical absorptions at specific wavelengths, Tropomi can be used to easily identify where different gases occur in the air and at what concentrations. These high-quality diffractive grids were developed and manufactured for Tropom by ZEISS.

The satellite Sentinel-5P, which already launched, is a precursor model: it is intended to bridge the transition between previous missions and the final Sentinel-5 mission, which will be launched from 2021. The 'P' stands for 'precursor'.

Further satellites will be launched as part of the Copernicus project until 2030. The first sentinel, Sentinel 1A, was launched on 3 April 2014.

TECHNOLOGY

The core elements of the spectrometers are their optical grids, which are notable for their high efficiency, low polarisation sensitivity and excellent imaging properties. The low level wavefront errors lenses and mirrors are known for must also be provided for by the grid in order to meet the high overall performance of the spectrometer.

ZEISS manufactures these grids using holographic interference lithography. The subsequent transfer of the grid profile using chemical etching creates monolithic grids which meet the requirements for use in space. This makes it possible to produce grids for use in low UV above the visible wavelength spectrum through to infrared.

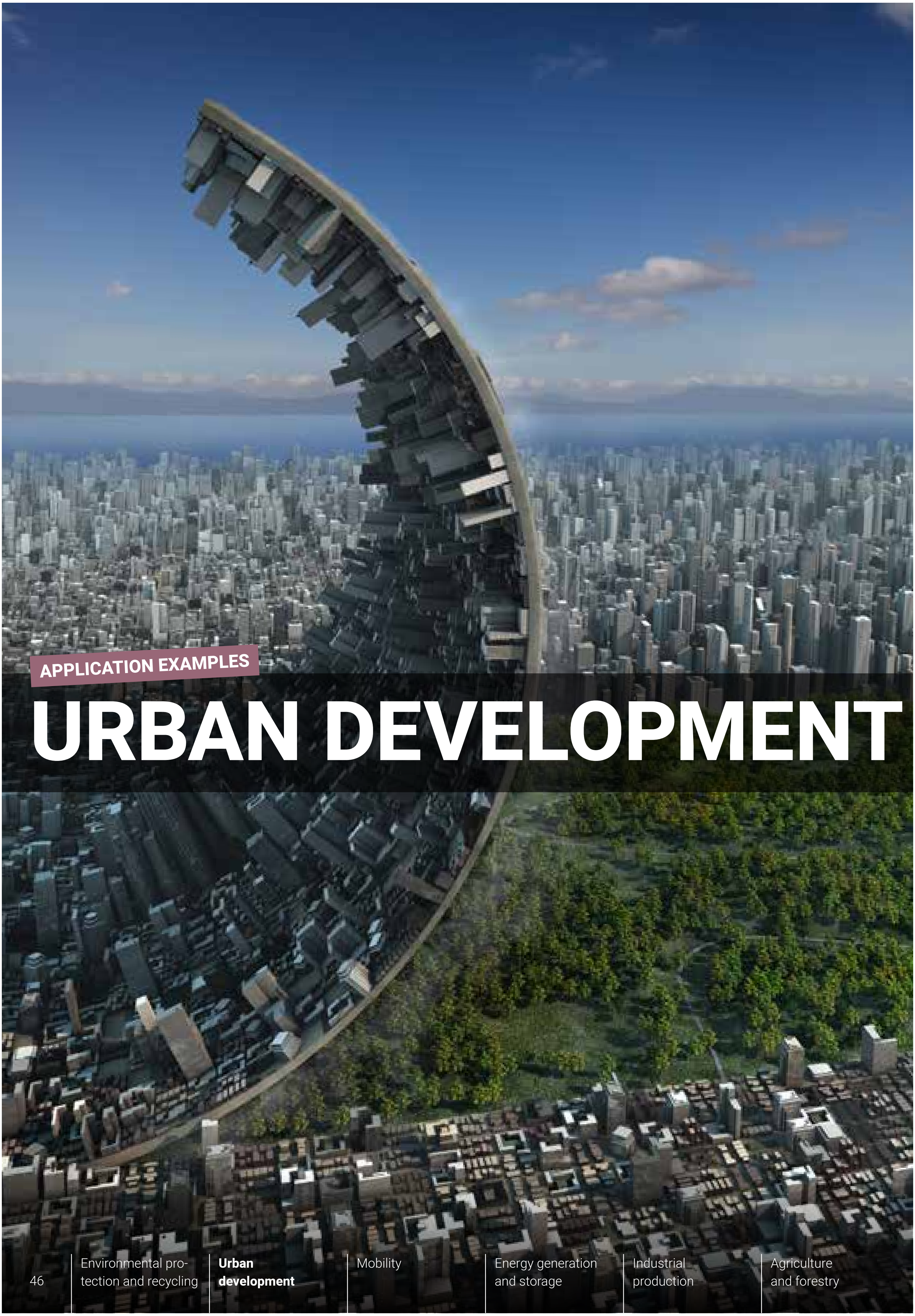
SUSTAINABILITY

According to the German Centre for Aviation and Space Travel (DLR), the highly precise data enables environment and climate researchers to improve their simulation models and make more precise predictions. Smartphone apps and internet services providing information on air quality or the effect of weather conditions on people will also benefit from the data in future. Detailed, highly up-to-date information, such as local ozone levels, can thus provide valuable pointers for day-to-day life. The World Health Organisation (WHO) now counts air pollution as one of the biggest global environmental risks.

Carl Zeiss AG
Gudrun Vogel | gudrun.vogel@zeiss.com

APPLICATION EXAMPLES

URBAN DEVELOPMENT



Photonics for environmental sustainability in urban development

The total urbanised area and the number of people living in cities is continuously growing. The OECD calls this the metropolitan century and reports that today, more than half of the world's population are living in cities. By 2100, this proportion is expected to rise to 85 percent. As a result, in just 150 years, the urban population will have increased from less than one billion in 1950 to nine billion in 2100.

The resulting challenges are enormous, but at the same time offer a variety of different starting points and opportunities for photonics solutions in many areas.

In order to prevent gridlocked traffic in urban centres and to reduce environmental impact to a minimum through urban mobility, we need not just coherent multi-modal traffic concepts but also innovative solutions for the mobility of tomorrow. The use of lasers and cameras to monitor traffic infrastructure enables measurements to be taken in flowing traffic and can help to reduce traffic jams in the future.[1]

Water utilities increasingly use UV light in order to deactivate any microorganisms that remain at the end of drinking water processing, and to quickly and safely prevent the spread of infections. This environmentally friendly disinfection process often replaces the chemical disinfectant chlorine dioxide. Research is being conducted on solutions for the removal of pharmaceutical residues using a UV light reactor or for the degradation of pharmaceutical residues, cyanides and pesticides using plasma processes.[2]

Another important issue is the lighting of public spaces. More and more cities are using energy-efficient LED technology, for example in street lighting or in public buildings. The resulting savings potential is impressive. But this is only the first step towards Smart Cities and Smart Lighting. Networked, digitally controlled LED systems enable lighting to meet requirements: When no one is moving around, the light is dimmed. On celebration or market days, when the police and rescue services are on duty, in certain traffic situations or under certain weather conditions, brighter illumination is provided.

This makes it possible to regulate individual lights or the lighting of entire streets. It is a fully responsible use of light, where the volume, direction and colour of the light can be optimally adapted to the intended purpose.

The solar potential in large cities also plays an important role in sustainable urban development. For instance, according to a current study on buildings in Berlin, six to ten gigawatts of photovoltaic power can be installed – more than enough to cover 25 percent of the electricity supply of Berlin with solar energy.[3]

APPLICATION EXAMPLES

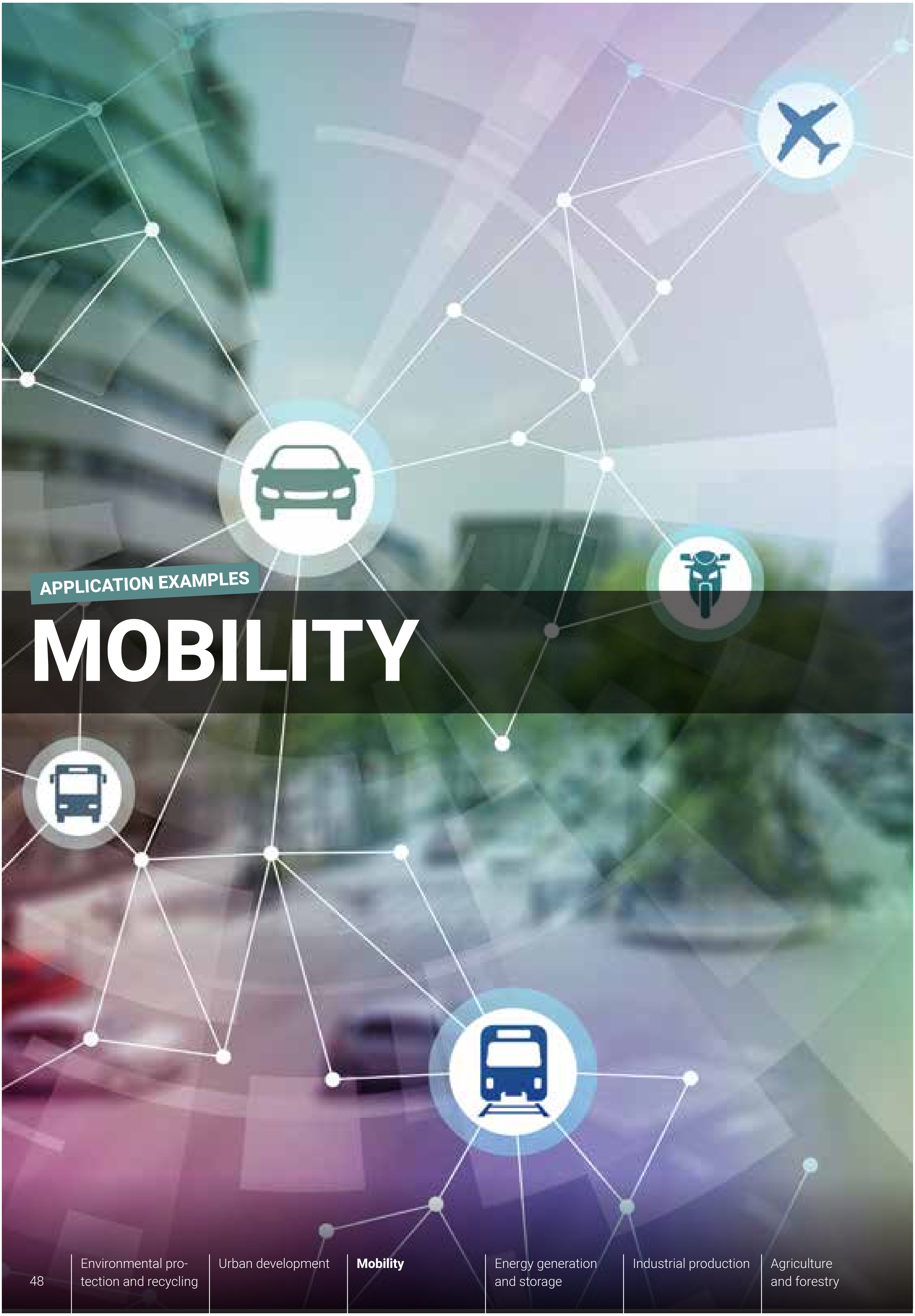
The potential of photonics solutions can be developed for urban areas in many different application areas, for example:

Environment ➔ **Page 32**

Mobility ➔ **Page 48**

Energy generation and storage ➔ **Page 62**

1. e.g. project 3D-AI from the Fraunhofer IPM in Freiburg: www.ipm. fraunhofer.de/de/gf/objekterfassung-laserscanning/anw/kognitive- dateninterpretation/verkehrsinfrastruktur.html (10/04/2019)
2. e.g. see the press release of the Münster Technical University from 05/06/2018, www.fh-muenster.de/hochschule/aktuelles/pressemitteilungen.php?pmid=7497
3. "Das Berliner Solarpotenzial [Solar potential in Berlin]", Technical and Economics University Berlin, 3/2019



APPLICATION EXAMPLES

MOBILITY

Photonics for environmental sustainability in mobility

Economic growth and technological developments are accelerating the trend towards becoming an increasingly mobile society. In its 2050 Climate Protection Plan, Germany has agreed a long-term strategy with the target of greenhouse gas neutrality. Electromobility combined with electricity produced by renewables is key to climate protection, relieving the environment of noise and carbon dioxide emissions. The focus of current developments in the industry is primarily on innovative battery technologies, high-performance electronics and lightweight construction.

Lasers are indispensable for achieving these ambitious goals. Optical technologies can be used to implement more efficient production methods for lightweight construction, and electronics and energy storage systems will be utilised in new markets. Laser-based joining and cutting processes and surface engineering technologies can be flexibly adapted to processing situations, operate almost wear free due to the fact that they are contactless and allow energy and materials to be used more efficiently. Thanks to the use of lasers, toxic chemicals can also be replaced in many places, for example in surface finishing.

Lightweight construction plays an important role in car body technology and chassis design. The aim here is to further reduce weight and consumption – particularly for hybrid vehicles. As such, manufacturing processes are being developed for lightweight construction, such as the welding of ultra-high strength steels and composites, the laser-assisted local softening of cold-pressed steels to optimise forming technology, the cutting of CFK components and the joining of different types of lightweight materials.

In the aviation industry, turbine construction offers many approaches for technical optimisation and cost savings. Laser deposition welding already makes it possible to efficiently repair used turbine parts. Innovative turbine design, lighter turbine blades, optimised cooling and cheaper repair processes are all aspects of laser-based manufacturing which benefit the environment.

New component designs and functionalities for the mobility of the future offer opportunities to create effective and efficient production processes in terms of productivity, quality and the freedom of design. The exploitation of the flexibility and effect of phonic manufacturing processes and their targeted use in industry will secure high market shares for stakeholders.

APPLICATION EXAMPLES

Efficient turbo engines for aviation technology through laser-based processes

Resource-efficient production and maintenance in turbine construction: Laser-based processes such as laser deposition welding or Laser Powder Bed Fusion (LPBF) make it possible for high-quality turbo engine components to be repaired, modified or additively manufactured in a way which saves resources

1 Powder-based laser deposition welding

2 Laser-Powder-Bed-Fusion-Process to manufacture gas turbine parts at MAN Diesel & Turbo SE

3 Repair of the front rotor of an aviation turbine

APPLICATION AREA

In an increasingly mobile society, the number of flight passengers is rising rapidly, while at the same time, there is a need to reduce the weight, fuel and environmentally harmful emissions of aviation technology. This has direct consequences for engine production, maintenance and repair, which can be performed more efficiently and more resource-efficiently using laser technology.

Aviation turbines are subject to high mechanical and thermal strains. Component repairs frequently require areas which have suffered wear and tear to be restored. To achieve this, tailored process chains are needed in which components can be prepared, digitised, cut, deposition welded, heat-treated and fully processed. Conventional welding and thermal spray processes have many disadvantages, such as too high energy inputs, component warpage or a lack of layer adhesion.

Since the energy inputs of lasers can be controlled extremely well, they are ideally suited to depositing material on highly sensitive components. During laser deposition welding, the additional materials are added as a wire or powder, melted down using the laser and combined with the base material using melt metallurgy. The laser powder bed fusion method is especially wellsuited to additive manufacture of turbo engine components. Different geometrical classes can therefore be produced and reproduced at a constant quality.

The "International Center for Turbomachinery Manufacturing – ICTM" in Aachen is dedicated to meeting the current challenges of turbo engine construction.
The Fraunhofer Institutes for Production Technology IPT and for Laser Technology ILT as well as the Machine Tool Laboratory WZL and the Chair for Digital Additive Production DAP at RWTH Aachen are combining their expertise to find sustainable solutions and working alongside renowned industry partners.

TECHNOLOGY

The production and maintenance of turbo engines requires processes which must be specifically tailored to the component geometries and materials. Laser deposition welding makes it possible to deposit material on high-quality components in a highly precise process which saves on materials. It uses modular powder and inert gas injector nozzles to ensure an efficient supply of powder as well as further components like a coaxial wire lead which enables direction-independent laser deposition welding.

When manufacturing turbine components, laser powder bed fusion achieves nearly unlimited geometrical freedom and makes it possible to produce monolithic components which would have previously needed to be manufactured as separate parts. Different geometries create different heat dissipation conditions, which can be challenging when a constant component quality is required. In the lead project, 'futureAM', six Fraunhofer Institutes are developing, among other things, system technologies and process management strategies, which enable the energy inputs in the LPBF process to be controlled in terms of time and location. This makes it possible to produce and reproduce different geometrical classes at constant quality.

One key success factor for an optimal parameter configuration and for ensuring that high-stress components can be used for their maximum service life is recording the operating conditions for a turbine.
The laser powder bed fusion can be used to integrate both embedded and applied sensor elements into components.

SUSTAINABILITY

As a flexible and precise tool, lasers are ideal for the repair and maintenance of high-quality turbo engine components, allowing them to significantly prolong their service life or to protect materials from wear and tear or corrosion. Additive processes such as laser deposition welding or laser powder bed fusion can be used to repair and manufacture turbine components economically and resource-efficiently. Laser processes contribute to increasing energy efficiency saving weight, fuel and emissions.

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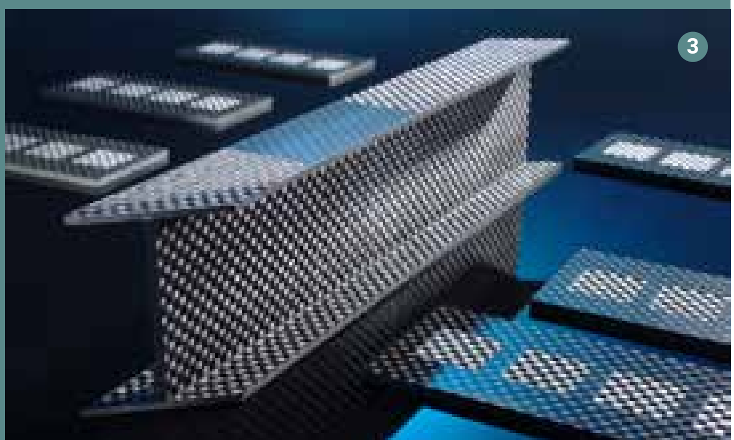
Laser technology in lightweight construction

In addition to high-strength metals, fibre-reinforced plastics are increasingly being used for lightweight automotive construction. Laser technology offers powerful methods to save on process time and aid the sustainable production of these innovative materials.

1 Automotive manufacturing process

2 The edge of a passenger car roof brace made from glass and carbon fibre-reinforced plastic

3 Paint removal from CFK components using lasers



APPLICATION AREA

Fibre reinforced materials are essential for lightweight automotive construction and an indispensable component of modern construction principles. Load-adjusted component designs with anisotropic structures, and combinations with high strength metals enable weight reductions of up to 30 percent, which are of particular importance in electromobility. This allows either larger batteries, or, with the same battery installation space, higher ranges. Duroplastic and thermoplastic fibre-reinforced plastics offer a high level of potential for extreme lightweight constructions. However, low manufacturing costs and short lifecycle are the primary objectives for applications suitable for large-scale production.

Lasers are an ideal tool due to their flexibility, zero wear and tear and high processing speeds. This requires processes which do not change the specific properties of the materials, and which retain their advantages to the full.

Due to its excellent temporal and spatial controllability, laser cutting reduces the processing time and enables the automated production of components made of fibre-reinforced plastics (FRP). This applies to a wide range of processes – from cutting prepregs, tapes and organic sheets to the trimming and cutting of FRP components.

High-speed processes or the use of short-pulsed laser radiation ensure that damage to the cut edge is reduced to a minimum, despite the different absorption, heat conduction, melting and decomposition temperatures of fibre and matrix.

Laser technology also offers suitable solutions for plastic-metal compounds with a high lightweight potential. High-speed laser micro structuring is used to create undercuts and sponge-like, porous surfaces. Subsequently, the matrix materials of the fibre composites can then be connected with these structures. Where the alignment, shape and number of structures can take a high-strain, there are a wide range of possible hybrid structures that can be achieved for many material combinations.

More efficient process chains for fibre-reinforced components: Laser technology offers a wide range of technical solutions to achieve more efficient process chains for fibre-reinforced components, with high energy saving potential as well as new procedures to reduce processing times and shorten process chains. Since stamping only offers limited processing options for fibre-reinforced plastics, high-speed finishing and installaion processes are needed. The use of high-performance fibre lasers and ultrashort pulse lasers makes it possible to process the composite without a loss of quality in spite of highly inhomogeneous thermal properties. Multipass structuring reduces the thermal load of the material in such a way that material vaporisation can be achieved without thermal influence. This opens up the possibility of heat impact zones of less than 100 μm.

When it comes to the joining technology of fibre-reinforced components and metals, the connection is achieved by a positive mechanical connection, in which the matrix material and fibre components are melted into structures that were previously introduced with the laser in the metal component. This allows a hybrid connection to be created without the use of adhesives – the stability of which resembles that of polymer matrix materials.

SUSTAINABILITY

One of the key tasks of engineers is to reduce the weight of automotive components in order to reduce the energy required for mobility. Lightweight construction plays a central role in electromobility in particular to compensate for the weight of the batteries used. The manufacture of fibre-reinforced components in automotive lightweight construction using tailored laser processes opens great potential for sustainable manufacturing, particularly in tooling technology. As processing does not involve wear and tear, the previously required milling tools are no longer required, particularly when processing carbon-fibre composites. In addition, energy-intensive duroplast manufacturing chains can now be replaced by high-performance thermoplasts. Laser-based taping can be used to generate components with similar properties to duroplastic FVKs – with significantly shorter process chains and a low energy requirement.

TECHNOLOGY

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Extreme lightweight construction for optical and mechanical components through additive manufacture

Additive manufacture provides enormous lightweight construction potential for opto-mechanical systems using highly complex structures. This saves materials, energy and fuel, which in turn reduces the CO_2 emissions of aviation and space travel.

1 The reduction of mass in space travel using additive processes offers enormous benefits for energy and fuel consumption.

2 Additively manufactured reflecting telescope after assembly

3 Metal optics reduced in mass by 70 percent using internal lightweight structures

APPLICATION AREA

Additive manufacture generates components directly from 3D-CAD data. From a fine metal powder, complicated components are directly generated by the use of lasers, without having to take into account the limitations of traditional machining. This makes it possible to produce highly complex bionic structures which are optimally adapted to the relevant application and to devise completely new designs for lightweight construction. In aviation and space travel in particular, this method achieves significant energy reductions thanks to significant weight savings and can thus improve the environmental balance. The process can currently be applied in the construction and manufacture of mechanical supporting structures, casings and high-performance optics for Earth observation instruments. Weight reductions of up to 70 percent in a single component have already been achieved here, with the ultimate objective being a further reduction in overall mass.

The raw material efficiency of this process is significantly increased compared to conventional manufacture.
In contrast to traditional subtractive processing, in which a semi-finished product (plates, rods, block) is machined by cutting up to more than 90 percent to generate a component and corresponding waste, additive manufacturing creates components from powder. This significantly reduces the material used, while any powder not required during the process is collected and can be reused. The process is nearly entirely waste-free. The technologically available metals for additive manufacture include the lightweight materials aluminium and titanium.

TECHNOLOGY

In additive manufacture, components are created directly based on a 3D CAD model. This is split into layers which are processed consecutively. The process is performed in a closed machine using selective melting of metal powder to match the cross-section of the respective layer, followed by subsequent rapid solidification of the liquid material. The energy required to melt the powder is introduced to the powder using a focused laser or electron beam, with the individual layers having a thickness of only a few micrometers.

This process allows the production of nearly any shape, including new, innovative structures. Even undercuts can be generated. This can be used to create complex lightweight structures to generate extremely light but rigid components, which would be impossible using conventional methods.

As in nature, geometries can be implemented in such a way that areas subject to high strain can be reinforced while material can be saved in areas not requiring stability. The finished component already has measurements resembling final contours and where necessary can be processed further by mechanical manufacture.

SUSTAINABILITY

The reduction of mass in transport and space travel offers direct benefits for energy and fuel consumption. To give an example, the transport of one kg of mass in a geostationary orbit incurs costs of approx. EUR 10,000. The total fuel mass of an Ariane 6 space launcher amounts to around 140 t of solid fuel, plus a maximum of 170 t of liquid fuel (hydrogen + oxygen). The maximum payload to be transported amounts to 11.5 t in a geostationary orbit or e. g. 8.4 t for a mission to the moon. This ratio makes it clear how valuable the available payload is. By reducing the mass, the number of transported instruments and components can be increased and the number of flights required can be reduced. Currently, the use of hydrogen as a fuel for space travel is one of the most efficient processes regarding specific energy (energy content per weight). Nevertheless, the productio of one ton of liquid hydrogen using the currently deployed steam reforming process generates around 10 t of CO_2. Advantages can be achieved by using metal powder as a source material to create components. This leaves hardly any waste because the powder can be reused several times. This in turn saves energy during recycling and for material logistics. Mass-reduced optical instruments used in Earth observation supply high-resolution data for climate and environmental monitoring as well as for precision agriculture.

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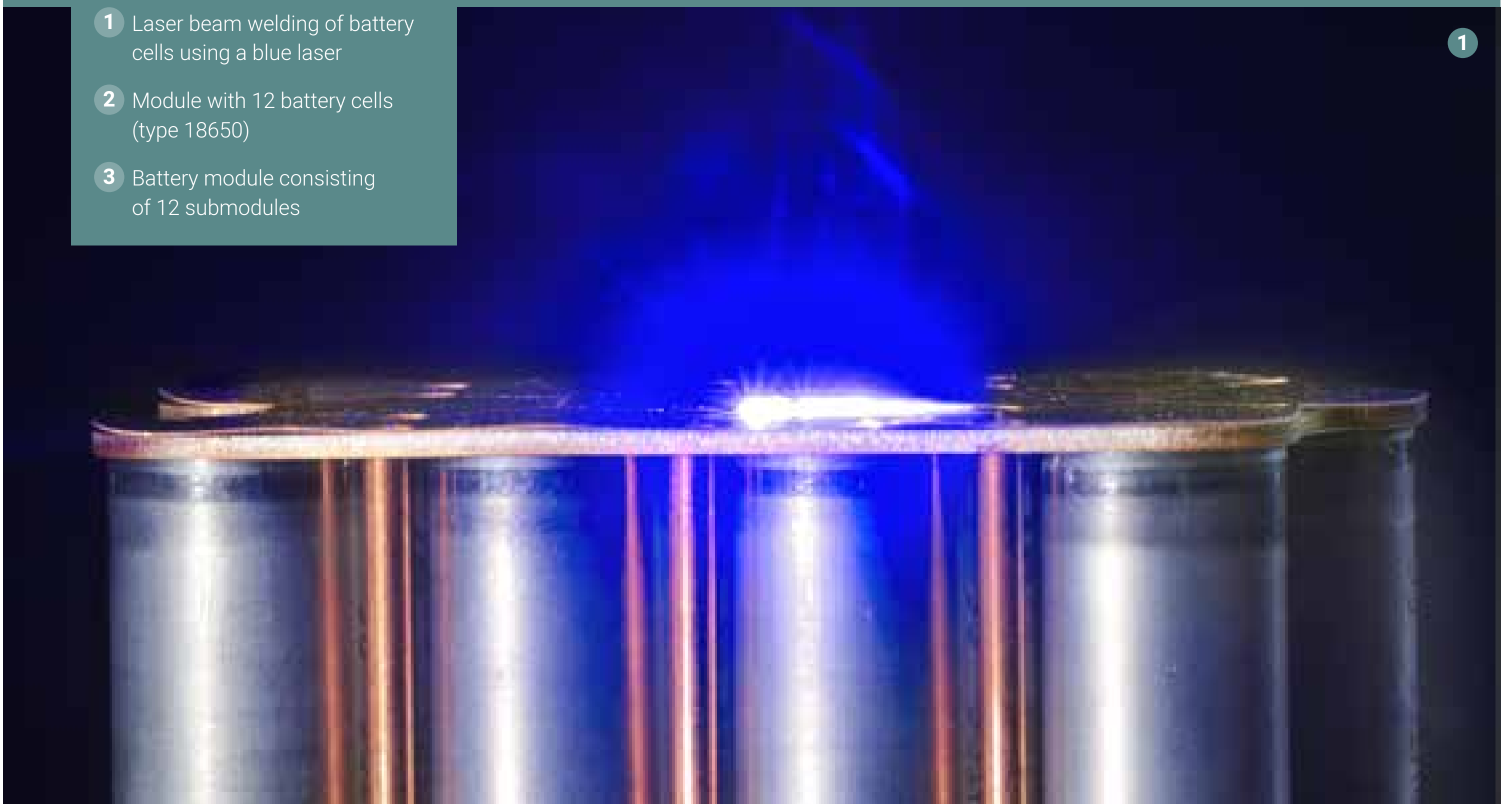
Laser processes for high-performance batteries in automotive construction

The increased electrification of cars has resulted in increased demand for high-performance energy storage systems. For the assembly of battery modules or packs, laser technology offers high-performance processes with maximum process reliability and productivity

1 Laser beam welding of battery cells using a blue laser

2 Module with 12 battery cells (type 18650)

3 Battery module consisting of 12 submodules



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APPLICATION AREA

The increased electrification of cars has resulted in increased demand for high-performance energy storage systems in the form of compact battery modules. In this area, laser technology offers highly productive, high-quality processes along the entire process chain to produce energy storage systems – from cell manufacture through to module and pack contacting.

Integrated circuit packaging is a particular challenge for battery modules in automotive technology. Higher current flows and performance require bigger contact areas and cross-sections to reduce contact resistance. At the same time, the connections must meet high mechanical and thermal requirements in order to achieve long-term stability. Until now, individual battery cells have been contacted to form so-called packs using wire bonds. To ensure high current flows, multiple wire bonds are normally required resulting in long production times. Copper as a highly conductive material can only be used to a limited extent when it comes to conventional wire bond technology on battery cells, due to high contact pressure. Larger conductor cross-sections in the square millimetre range which allow for current loads of 1,000 A and more cannot be implemented using conventional methods.

High brightness fibre lasers and tailored welding technology can now be used to create electrical connections in battery modules and power electronics, something which was previously unthinkable. Here, photonics provides a new tool which not only significantly expands the performance limits but also guarantees maximum process reliability.

In particular, the development of high-performance lasers with material-adapted wavelengths in the blue to green spectral range considerably expands the range of application areas

TECHNOLOGY

Automotive energy stores based on lithium ion batteries rely on the interconnection of individual round, pouch or prismatic cells. In this way, energy values of 20-100 kWh per battery pack can be achieved. The interconnection is made by using copper-based connectors which are increasingly contacted using laser welding. High brightness fibre lasers or frequency-converted disc lasers in the green spectral range, make it possible for even highly reflective materials, such as copper, to be welded together.

New developments such as laser bonding mean that this technology can now be combined with integrated ribbon connectors so that a compact contact technology for peak currents of more than 400 A is available. Furthermore, quick and localised modulation of laser radiation makes it possible to combine different types of materials such as copper and steel and, if suitable process controls are deployed, copper and aluminium. This eliminates the need for the previously used multi-metal composite materials, thereby also enabling more efficiency recycling and a more energy-efficient process chain.

SUSTAINABILITY

Energy storage technology based on lithium ion batteries is a central element of electromobility. To increase customer acceptance, significant cost reductions are required which can be achieved using high-performance manufacturing processes. Laser technology makes a key contribution to creating high-performance batteries with which environmentally friendly electric vehicles can be produced. Increasing battery cell and power electronics performance means higher requirements for electrical connection technology; this is where laser technology can offer productive solutions for lighter, more efficient batteries.

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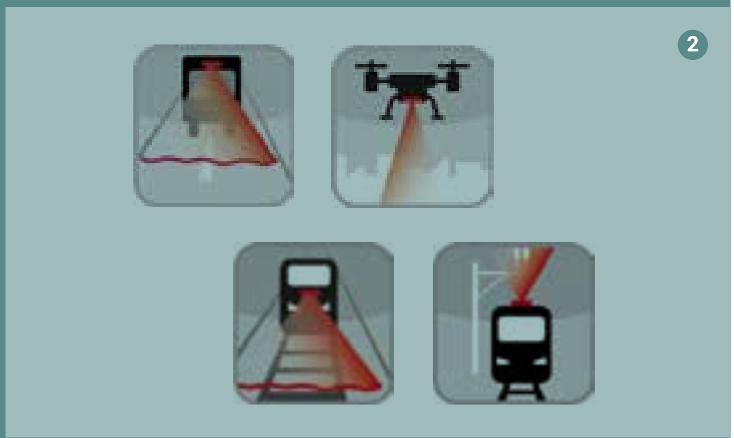
Preservation of traffic infrastructure through laser scanning to monitor large-scale structures

Optical measurement systems designed for mobile use on rail and road vehicles or drones can determine the condition of structures such as roads and tunnels very quickly and with high precision.

1 Road measurement vehicles to measure road condition

2 Laser scanners used to capture traffic infrastructures are installed on mobile platforms such as cars, drones or trains

3 Deutsche Bahn measurement train equipped with laser scanners



APPLICATION AREA

Infrastructure such as tunnels, bridges, roads and railway lines must be inspected regularly for safety reasons. But long-term observations of natural large-scale structures such as dams, hillsides and forests are also growing in importance. Regular records of their geometry can provide valuable findings about potential upcoming changes and as such can contribute to our understanding of the environment. Factors such as temperature and precipitation also play a key role.

The main objective is to capture and interpret changes (e. g. deformations) of large-scale structures (such as multi-storey buildings, bridges, tunnels, etc.). The focus is on sensor and data fusion, data interpretation (e. g. through deep learning) and mobile sensing (e. g. using robots, drones, etc.).

TECHNOLOGY

Laser scanners, lighting and camera systems measure the 3D geometry of objects and large structures three-dimensionally with high precision. Most systems apply the time-of-flight measurement principle. Combined with a scan unit, they record three-dimensional object geometries quickly and precisely, ranging from a few centimetres to the 100 metre range. The robust, eye-safe systems are located on mobile platforms. The systems have a highly robust design for use on measurement trains, road surface measurement vehicles or drones. The 3D measurement systems include data interpretation software. Adaptive algorithms are increasingly used to efficiently analyse 3D data to allow for an automated interpretation of the measurement data.

4 5 Infrastructure objects such as tunnels, bridges, roads and railway lines must be inspected regularly for safety reasons.

SUSTAINABILITY

Infrastructure consumes vast amounts of raw materials and energy when built and subsequently maintained. It can be challenging to build and operate infrastructure in such a way that resources are managed optimally and efficiently. Social and technical developments have resulted in ever larger, more networked infrastructure, the planning and reliable management of which involves ever greater complexities. A number of methods must be used systematically in order to achieve sustainable safety, reliability and resilience. The main challenge consists in combining, optimising and minimising their use, and in continuously capturing, visualising and communicating findings about the condition and changes to infrastructure.

In this context, it is as important to record extensive data as it is to analyse plentiful measurement data and targets using modern statistical analysis methods (predictive analytics). This enables reliable predictions and optimal decisions, also in order to sustainably use the available resources. For instance, measures to preserve tunnels, railway lines and bridges can thus be planned early on and implemented in a resource efficient manner.

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Laser spectroscopy for the measurement of exhaust gas emissions

Identifying emissions in order to lower them in a controlled way: Reliable exhaust gas measurement technology can also be used to detect nitrous oxide, which is particularly damanging to the climate. The system is based on the principle of infrared absorption spectroscopy using quantum cascade lasers as a light source.

1 This engine test bed of AVL Emission Test Systems GmbH uses the measurement system

2 The core of the measurement system with mirror optics and long optical path measurement

3 Complete QCL analyser for installation in a measurement system

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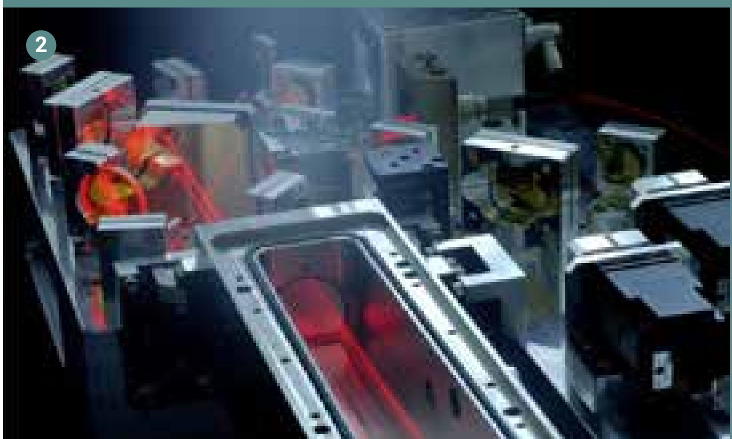

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APPLICATION AREA

As a result of stricter emissions laws, measurement systems have also had to become more precise: Requests for evidence in the range of 10 ppb are no longer rare (ppb =1 part per billion). Current greenhouse gas regulations require nitrous oxide (N_2O) to be measured in very low concentrations below 1 ppm (ppm = 1 part per million).

Nitrous oxide, commonly known as laughing gas, is created primarily when mineral nitrogen fertiliser in the ground is broken down, but also during fuel combustion in a petrol engine. Conventional technologies previously used to measure N_2O – such as non-dispersive infrared technology (NDIR) or electrochemical gas sensors – are either not sensitive enough for today's measurement requirements or have cross-sensitivities that are too high.

An optical spectrometer based on quantum cascade lasers (QCL), developed by Fraunhofer IPM together with an industry partner, has made it possible for the first time to measure emissions which meet the higher requirements. The gas analysis device is able to reliably detect nitrous oxide in very low concentrations – in the range of 10 ppb to 100 ppm (4 decades).

The QCL analyser used for this purpose is free from cross-sensitivities to other components in the gas matrix that typically occur in emissions from combustion engines.

Quantum cascade lasers are semiconductor lasers for wavelengths in the mid infrared range (MIR). In contrast to other lasers emitting in the MIR, the QCL has a comparatively high output performance and also works at room temperature – elaborate cooling, needed for example with liquid nitrogen, is no longer required.

TECHNOLOGY

When developing the N_2O emissions measurement system, Fraunhofer IPM was able to rely on many years of experience in the area of emissions gas technology. In 2002, Fraunhofer IPM developed the QCL-based emissions analyser DEGAS (Dynamic Exhaust Gas Analyser System) for a major automotive manufacturer as a measurement system for industry to use to quickly, sensitively and selectively evidence carbon monoxide, nitrogen monoxide and nitrogen dioxide. DEGAS can be used to simultaneously measure the concentrations of different emissions components in an interval of five milliseconds, at up to four measurement points on the emissions strand at the same time.

The newly developed QCL analyser is designed for measuring cabinet applications and therefore has a much more compact design. Over the next two stages, it will be able to simultaneously record two gas components. The QCL analyser has not only been used successfully in a research and development capacity, but increasingly for certification measurements of low-emission engines.

SUSTAINABILITY

The greenhouse gas effect of nitrous oxide (laughing gas) is around 300 times that of CO_2. Even if the emissions primarily originate from agriculture, emissions from combustion engines are also a significant factor.

The new, ultraprecise measurement method can broaden our understanding of the processes involved and can therefore help with reducing harmful emissions even during the engine development phase.

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APPLICATION EXAMPLES

ENERGY GENERATION AND STORAGE

Environmental sustainability through photonics in energy generation and storage

Germany has set itself ambitious targets for redesigning its energy system. According to the specifications of the Federal Government, by 2050 demand for primary energy should be half of that in 2008. Additionally, the proportion of renewable energies should be systematically increased to 60 percent of gross final energy consumption by 2050. This assumes that, in addition to the many construction-related updates that must be carried out, resource-efficient recycling strategies, the daily behaviour of consumers, technological innovation to increase energy efficiency, the use of new energy sources and expanded recycling measures will also be realised.

Laser technology will play a key role in increasing the efficiency of energy production, increasing productivity in the manufacture of components for energy conversion or a better selection of valuable materials in the field of recycling. Laser technology opens up new horizons in all energy-related areas, such as photovoltaics, solar thermals, energy storage technology, turbine construction and recycling.

Solar energy will be indispensable in the future energy mix, made usable primarily by photovoltaics. Laser processes in highly productive plants enable the cost-effective production of high-quality organic and inorganic solar cells. New energy storage systems are needed in the e-mobility sector, where lasers have proven their worth along the entire production process chain, from efficient cell production and high-performance inter-connection technologies through to packaging bonding.

In the field of stationary energy generation, laser methods can be used to manufacture, optimise and repair highly precise, temperature-resistant, long-life turbo engine parts. The further development of energy generation systems with stationary turbo engines is focused primarily on increasing efficiency and reducing CO_2.

Photonics offers varied solutions for more sustainable production methods in the areas of energy storage and generation. Laser processes make production more precise and efficient compared to conventional techniques, and the increasing requirements of cost-effectiveness and environmental friendliness are not a problem thanks to scaleable, clean processes. Laser technology offers important momentum for next-generation energy storage and innovative systems engineering.

APPLICATION EXAMPLES

Laser technology in photovoltaics: Sustainable electricity generation through efficient solar panels → **Page 64**

Laser processes for sustainable energy storage → **Page 66**

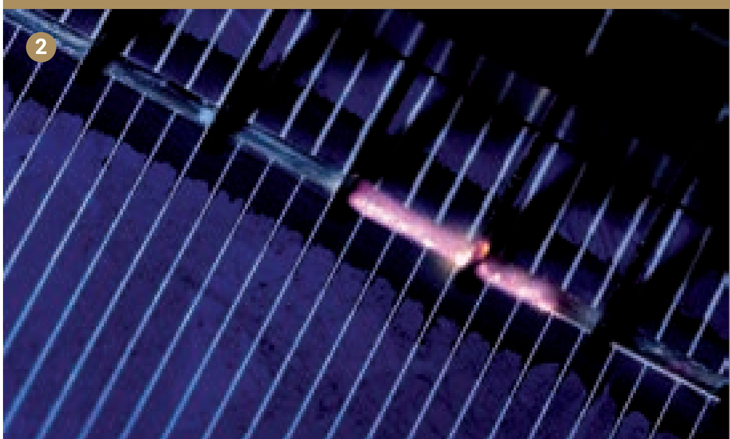
Laser technology in photovoltaics: Sustainable power generation through efficient solar panels

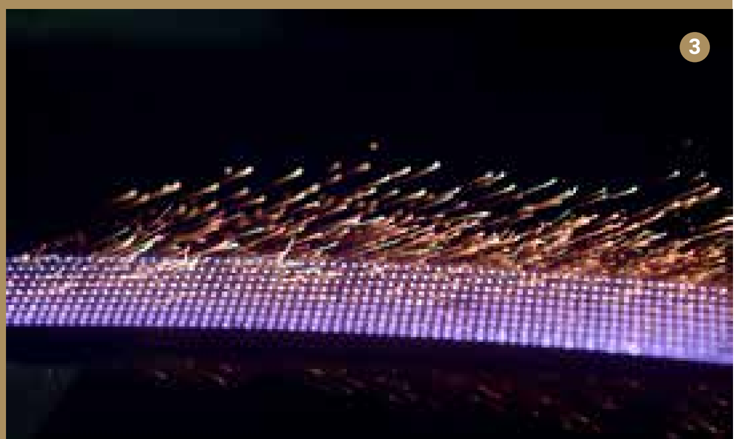
Solar energy is already an indispensable component of the energy mix. In order to ensure that photovoltaics plants remain competitive compared to conventional, fossil-fuel-based energy sources, laser processes are used to reduce the production costs of the modules and increase the efficiency of the solar cells.

1 Photovoltaics plant

2 Laser welding to connect solar cells

3 EWT cell with drill diameters of 50 µm at a distance of 0.5 mm





APPLICATION AREA

Laser technology has enabled a variety of processes to increase the efficiency of solar cells and solar modules through contactless, thermally minimised processing. In particular, the use of ultrashort pulse lasers can be used to process the usually very thin functional layers in the nanometre range with high precision and reproducibility. These include the ablation of thin dielectric layers for contact openings (LCO), such as for PERC, n-PERT and IBC solar cells, as well as the ablation of diffusion and etching barriers in the form of dielectric layers (silicon nitride, aluminium oxide, silicon oxide). For the production of new types of innovatibe, highly efficient solar cells with full unilateral bonding, laser processes are used in which electrical (LFC) and/or mechanical (AMELI) bonding is achieved by fusing together metal or metal-containing layers and layer composites. Adapted dopant profiles in solar cells can be created using laser radiation to form the selective emitter or the front surface fields on PERC and n-PERT solar cells. Finally, laser processes enable the highly flexible assembly of solar cells by the cutting, drilling and marking of silicon, glass and metal sheets.

In addition to the silicon solar cells commonly used today, thin layer solar cells are also produced – albeit on a much smaller scale – which offer a significant cost saving compared to crystalline silicon systems. Here, the individual strip-type cells are manufactured by selectively removing the thin absorber and conductor layers applied in continuous hot-dip galvanising. In addition to CIGS cells, organic solar cells and perovskite cells, are increasingly being used, and which promise a further significant reduction in manufacturing costs alongside greater efficiency.

TECHNOLOGY

Using laser processing to increase the efficiency of solar cells: Laser technology offers many technical solutions with a high energy savings potential for the production of solar cells, as well as new processes to reduce processing times and shorten process chains as well as improve product properties.

In the production of thin-layer solar cells – such as CIGS, perovskite or organic solar cells –, the layers added in wet or dry chemical processes are structured using selective laser removal in such a way that the two-dimensional material composite creates individual cells. The laser’s ability to work without requiring contact, its high intensity and the fact that it can be controlled precisely are important criteria which enable high quality and reproducibility when removing layers with a thickness of only a few 100 nanometres.

Laser removal methods are employed when bonding silicon solar cells so as to structure nano-scale passivation layers. In order to avoid damaging the underlying structures and the functionality of the material, ultrashort pulse lasers are used for this. Alternatively, selective melting methods can be applied, where metal backcoating is bonded with bulk silicon through nanosecond laser pulses. Short-term radiation with high laser intensities can significantly improve the conductivity and grain structure of the functional layers added through wet chemistry without the need for extreme temperatures or complex process chains.

SUSTAINABILITY

Photovoltaics play a highly significant role in the energy mix, which is on the rise again after a period of price pressure originating in the Far East. Today, efficiency and durability are more than ever considered to be pure cost factors. Accordingly, new processes, including laser processes, are increasingly in demand for the production of efficient solar cells. This is especially true for new perovskite cells, which are produced using coating processes in which large-scale, efficiency-increasing radiation techniques are used in addition to the traditional circuit technologies. In the future, laser methods which will save on costs and production resources can be expected to achieve efficiencies of over 20 percent under production conditions.

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Laser processes for sustainable energy storage

Competitive electrical energy stores require higher battery cell performance and significantly lower production costs. Photonics offers solutions for both of these challenges, which can speed up the processes as well as lower energy consumption.

1 Copper connector plate bonded using laser impulse melt bonding (LIMBO)

2 Laser-joined battery module containing type 18650 battery cells

3 Battery cells

APPLICATION AREA

Lithium ion batteries, currently the most powerful energy storage devices, consist of conductive layers and active materials on the cathode and anode sides. To achieve a cost-effective production process, the active layers are applied to large areas of conductive copper and aluminium strips and then conditioned and assembled over several process steps. One promising approach is to substitute conventional oven processes with innovative laser methods. By using laser-based drying and conditioning steps, the performance of lithium ion cells could be significantly increased in the future. In addition, the drying and sintering of battery electrode layers using laser processes opens up new opportunities for electrode manufacture, particularly for solid-state batteries.

High-speed laser processes can be used for cutting and structuring during the necessary assemply steps required for a lithium ion cell. This renders conventional punching tools redundant, while significantly increasing flexibility. The precise removal of active layers from the electrode without affecting the active layer material can replace previous masking steps, while at the same time achieve greater design flexibility. Laser cutting processes which isolate the coated battery sheets to prevent short-circuiting achieve maximum battery cell output.

Battery module and battery system production requires efficient assembly and joining processes which offer a high level of process reliability and are suitable for high transmittable power.

Laser beam microwelding is the main method used for joining battery cells, which allows different connection geometries, current load capacities and mixing ratios to be realised.

Different materials ranging from aluminium copper through to copper steel composites can be joined in a reproduceable process. The process is suited to creating electrically and mechanically safe connections between cells and for the production of modules from cell compounds and larger battery packs from individual modules.

TECHNOLOGY

High-quality battery cells using lasers: Laser technology offers many technical solutions for the production of batteries with a high energy savings potential, as well as new processes to increase performance and energy. The selective drying and heating of electrode layers after the deposition process can, on the one hand, shorten the process chain and reduce energy consumption compared to conventional processes. On the other hand, this may result in performance-enhancing sinter phenomena due to the high local temperatures. Laser processes based on high-performance ultrashort pulse lasers subsequently help to ensure defect-free assembly of the cells, providing high-quality processing of thick and thin-layer cells. Large-scale vaporisation processes prevent short circuits and edge melting of the cell sheets.

Finally, high brightness fibre lasers or frequency-converted disc lasers in the green spectral range can be used to combine the highly reflective materials copper and aluminium at cell level, while ensuring process reliability to produce round cells, pouch cells and prismatic cells.

SUSTAINABILITY

During the drying and sintering of battery electrode layers, laser processes open up high energy savings potential in hot-dip galvanising ovens thanks to their efficient energy input compared to conventional drying. The compact design of the laser also significantly reduces the space required. In the further course of battery production, laser cutting saves on tools and materials, which in turn reduces the energy required for production.

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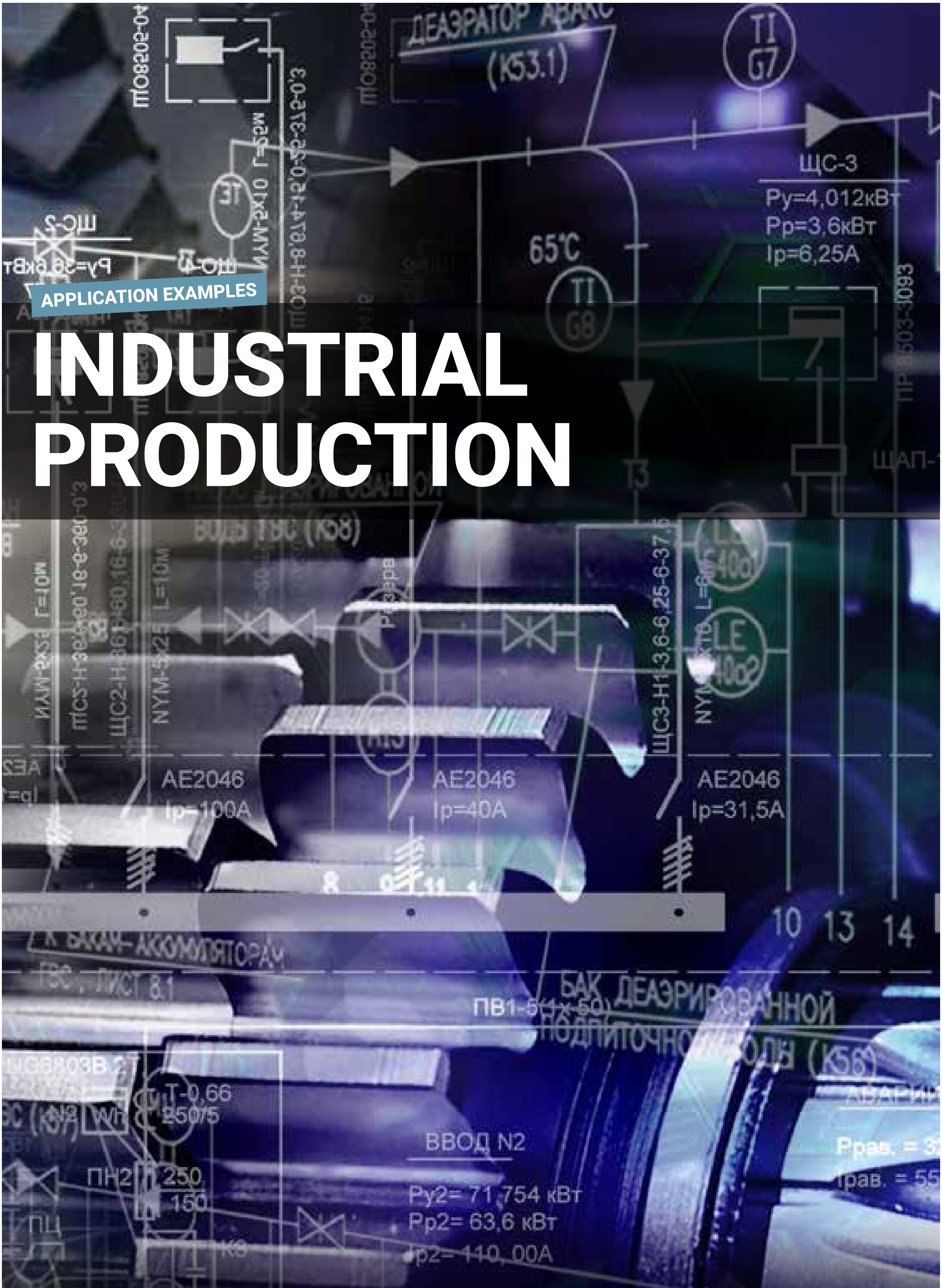

APPLICATION EXAMPLES

INDUSTRIAL PRODUCTION

Photonics for environmental sustainability in industrial production

According to a report by the Federal Environment Agency from 2018, the resulting costs of climate change in 2050 may amount to around a quarter of the global gross domestic product. The economy must rapidly adapt to become a more environmentally friendly green economy, that positively combines ecology and economy. To achieve this, the current economy must be modernised, for example through more efficient resource consumption, reduced emissions, intelligent product design and improved value chains. The digitisation of process chains can make an active contribution in this area. Laser technology in particular is ideally suited to networking between information and production technologies.

High-performance sources and optical systems, as well as highly efficient laser processes, help the industry to achieve flexible, environmentally friendly production. At the same time, lasers are the chosen method for meeting the rising demand for tailored, more complex components – even in small or medium quantities. For instance, laser-supported 3D printing can be used to produce components for end customers based on demand in a resource-efficient manner. The virtual replacement parts store is one result of this digitisation process. With the precise interaction of laser processes and the world of digital networks, Digital Photonic Production makes a key contribution to sustainable Industry 4.0 concepts.

For many applications, components must be protected against extreme environmental influences or equipped with functionalised surfaces. Tailor-made and locally selective laser processes can be used to efficiently create coatings whichincrease the temperature resistance of components, reduce friction or protect against wear and corrosion.

In this context, lasers often makes the use of environmentally damaging substances redundant – such as during "extremely high-speed laser deposition welding (EHLA)", which offers a sustainable alternative to to hard chrome plating with environmentally damaging chromium(VI).

Photonic technologies are paving the way for the next generation of industrial production. They create intelligent value chains which offer more resource-efficient and environmentally-friendly manufacturing concepts. In light of changing market structures, the use of innovative laser processes opens up new application areas and markets.

APPLICATION EXAMPLES

Environmentally friendly manufacture with extremely high-speed laser deposition welding ➔ **Page 70**

Sustainable manufacture using additive manufacturing ➔ **Page 72**

Energy-efficient laser functionalisation of surfaces ➔ **Page 74**

Photon-induced, large-scale thermal activation and structuring of energetic functional layers ➔ **Page 76**

Digital holography in production control ➔ **Page 78**

Environmentally friendly manufacture using extreme high-speed laser deposition welding

Extreme high-speed laser deposition welding (EHLA) can be used to coat, repair or additively manufacture components in a process that is both environmentally friendly and economically efficient.

1 Extreme high-speed laser deposition welding EHLA

2 EHLA can be used to apply metal protective layers at extremely high speeds

3 Piston rod coated and finished using EHLA

WINNER OF MULTIPLE AWARDS

EXTREME HIGH-SPEED LASER DEPOSITION WELDING (EHLA)

After receiving the 2017 Joseph-von-Fraunhofer Award in Dresden and reaching 2nd place at the 2018 Steel Innovation Award in Berlin, the EHLA team consisting of Dr. Andres Gasser, Thomas Schopphoven (Fraunhofer ILT) and Gerhard Maria Backes (Lecturer for Digital Additive Production DAP, RWTH Aachen) reached 1st place at the renowned Berthold Leibinger Innovation Award for 2018 in Ditzingen in September 2018.

APPLICATION AREA

Metal coatings are often used to protect large components against wear and corrosion, for example components in the oil and gas industries or rollers in the steel and paper industries. Previous coating processes such as hard chrome plating or thermal spraying have disadvantages, including the use of chromium(VI) or a high consumption of fuel and material.

Scientists at Fraunhofer ILT and RWTH Aachen have now developed an economical, environmentally friendly alternative based on laser light: extremely high-speed laser deposition welding (EHLA). For the first time ever, thin metal layers made from innovative materials with a layer thickness in the micrometer range can be applied to many different base materials in a resource efficient manner.

In cooperation with machine manufacturer, this process has already been implemented in numerous industrial applications. For example, since 2015 the Dutch IHC Vremac Cylinders B.V. have coated several hundred hydraulics cylinders with lengths of up to ten metres and diameters of up to 500 millimetres for global offshore use using EHLA. In the Chinese market, several EHLA systems have also been used to coat offshore hydraulics cylinders.

The EHLA process is also suitable for applications in the automotive industry, for example to coat brake discs, which were previously difficult to coat due to heavy strain and high economical and environmental demands. With its firm bonding and cost-effectiveness, the EHLA process is a promising possibility when it comes to additive manufacture and repairs. Using a hybrid approach, conventionally manufactured components can be modified by the precise application of multiple layers of coating. Tailored products with functional elements can be manufactured with just one system technology.

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Since it can be easily adapted and integrated into existing process chains, this method is also attractive to small to medium-sized enterprises where its use threshold is low.

TECHNOLOGY

Coating at speed and with precision: in the processes used to date for laser deposition welding, the laser is used to create a molton pool on the surface of the component. At the same time, the powdered additive is deposited in the molten pool using a powder feed nozzle where it is completely melted down. After the material is solidified, the layer is formed.

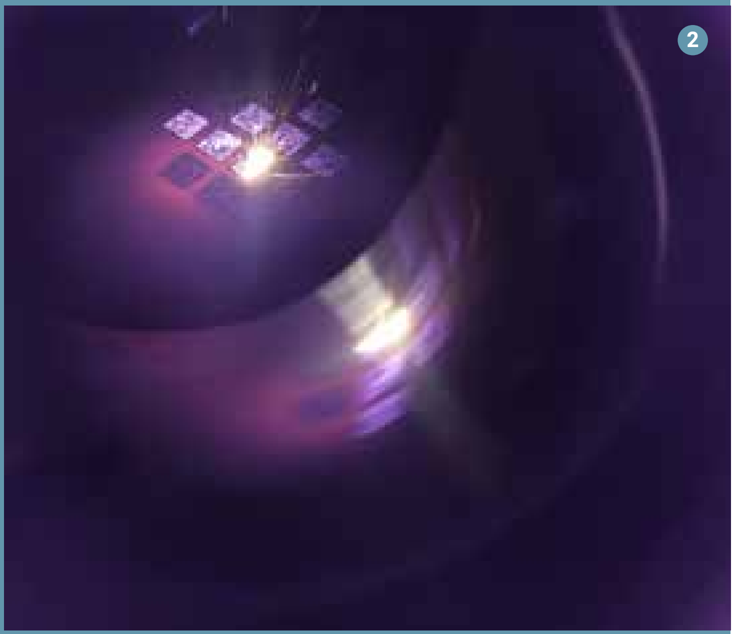
What makes EHLA so innovative is that the powder is already fully melted down above the molten pool through the targeted interaction of laser radiation and powder particles so that it can be deposited on the surface in liquid form. Since this removes the time required to melt down the powder particles in the molten pool, the time required to create the layer is drastically reduced. Previous process limits are therefore shifted or improved, including an increase in processing speeds (by a factor of 100-250), the reduction of processing times (by a factor of 10-20), the layer thickness (by a factor of 50) and the surface roughness (by a factor of 10). While the heat impact zone of laser deposition welding extends into the millimetre range, EHLA only thermally influences the material in the micrometre range. This makes it possible to coat heat-sensitive components and enables new material combinations, such as coatings and repairs on aluminium or cast iron alloys.

SUSTAINABILITY

The EHLA process utilises around 90 percent of the material deployed to produce the layer, meaning the process is much more resource-efficient than thermal spraying. Since EHLA does not employ any chemicals, it is much more environmentally friendly than hard chrome plating using chromium(VI) composites. While layers created with this processes are porous and have tears, layers made using the EHLA process are impervious, without fault, and protect the component much more efficiently and longer-term. The high layer quality makes it possible to use thinner layers in many applications and therefore save valuable coating material resources.

Sustainable production using additive manufacturing

Laser-based additive manufacture offers new opportunities to use materials more efficiently. The process is able to manufacture, repair or coat even complex components made from a range of materials, such as metals, ceramics or plastics, in an environmentally friendly way.



1 Three-jet powder nozzle for laser deposition welding

2 Exposure during local pre-heating using VCSEL

3 With laser powder bed fusion (LPBF), additive manufacture is even possible for pure copper components

APPLICATION AREA

Additive manufacture can be used in particular where there are high requirements regarding design and material properties for tailored or complex components. Laser-based processes prove to be very beneficial here because they provide high-quality component properties, can be flexibly tailored to the layers and materials to be generated, and are both productive and resource-efficient.

Since the mid-1990s, Fraunhofer ILT has been driving additive manufacture – particularly for metal components –, for example, using the powder-bed-based Laser Powder Bed Fusion (LPBF) or powder- or wire-input-based laser deposition welding. The focus is on optimising cost-effectiveness by taking a holistic approach to process chains – from component design, process management and systems engineering through to final processing. In order to improve robustness and reproducibility, the impacts of the powder materials, system components and exposure strategies on process stability and component quality are determined.

Inline process monitoring methods can be used to increase energy efficiency and reduce rejections. By implementing digital images – so-called digital twins –, makes it possible to define component properties before production and to simulate adapted process strategies.

Component properties can be optimised in a targeted way by developing new materials for additive manufacture, such as ODS tools or eutectic alloys. Exposure strategies and temperature control that are adapted to the material in question ensure that cracks can be avoided in materials that are difficult to weld, and stresses and distortions in high-quality components can be reduced.

TECHNOLOGY

Layered deposition in laser powder bed fusion reduces a three-dimensional manufacturing task to two dimensions. The process makes it possible to integrate functions or lightweight structures into complex components and manufacture topology-optimised components. LPBF can be scaled using movable processing heads in large installation spaces as well as tailored radiation sources. In the metal area, the process can be deployed in medical technology for individualised dental prostheses; in aviation technology for topology-optimised light components, and in tool engineering and mould construction to increase the productivity of tools with form-fitting cooling channels.

Laser deposition welding has been shown to be beneficial when coating materials to protect them against wear and corrosion as well as during repair and maintenance. Depending on the process variant, form-fitting, bonded, high-quality, flawless layers can be applied to components at low heat input and with layer strengths of between 0.01 mm and 1.5 mm. By applying several layers, geometries of great complexities and dimensions can be produced. Typical applications are found in tool, turbine and plant construction.

SUSTAINABILITY

Additive laser-based processes are beneficial in that even complex geometries can be produced and processed quickly, while the materials deployed can be used efficiently. This means that in industrial production, components with improved functions and properties can be produced, which significantly increase energy efficiency. In addition, lasers can be used to economically coat or repair components, in turn increasing their shelf lives. Since lasers are a contactless tool, they basically experience no wear. In many cases, chemicals that are harmful to the environment are no longer required.

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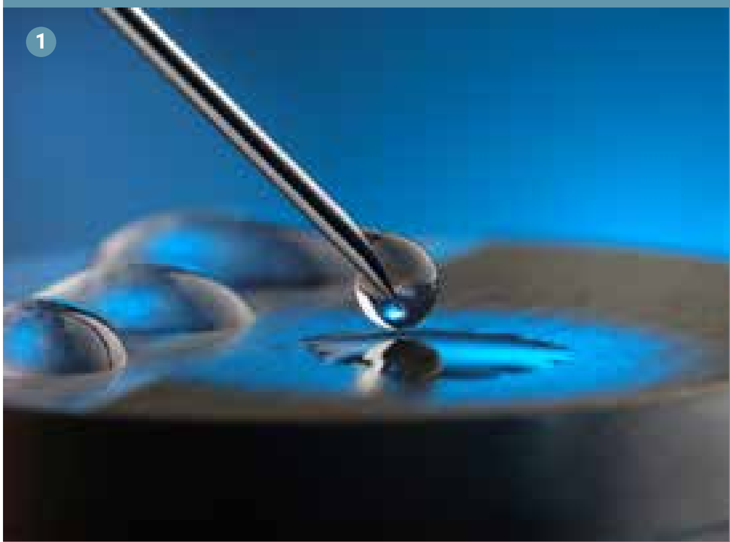
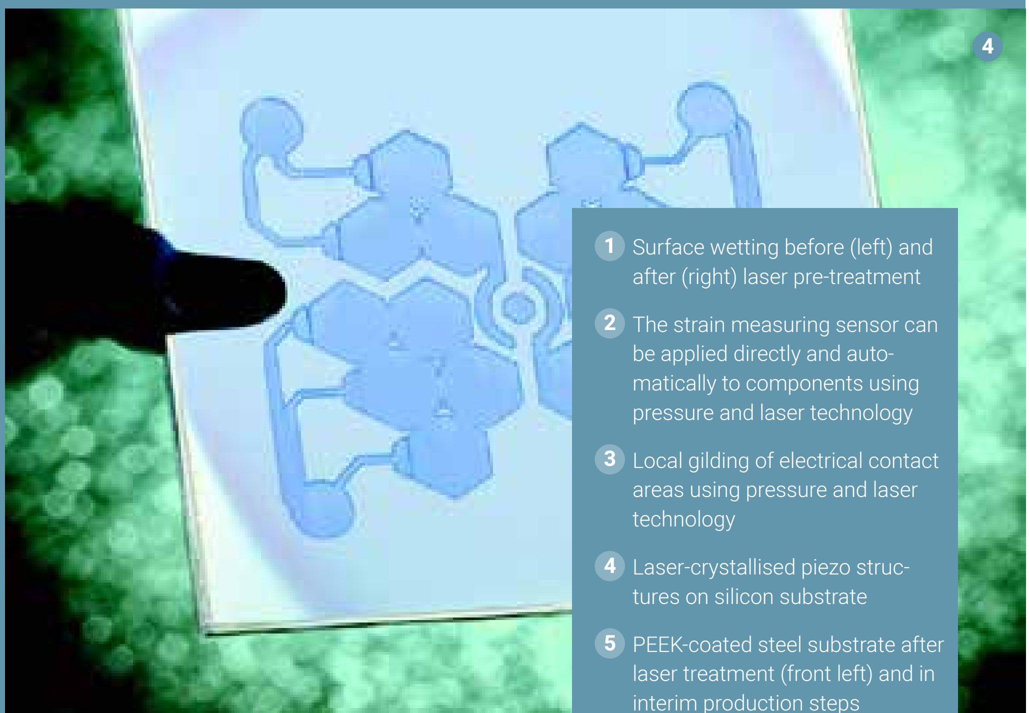
Energy efficient Laser functionalisation of surfaces

Optical technologies can be used to functionalise surfaces or thin layers in manufacturing processes and therefore optimise components in a way that is energy-efficient, while at the same time keeping thermal and mechanical strains to a minimum.





1 Surface wetting before (left) and after (right) laser pre-treatment

2 The strain measuring sensor can be applied directly and automatically to components using pressure and laser technology

3 Local gilding of electrical contact areas using pressure and laser technology

4 Laser-crystallised piezo structures on silicon substrate

5 PEEK-coated steel substrate after laser treatment (front left) and in interim production steps

APPLICATION AREA

The requirements for component surfaces are becoming increasingly more complex as part of the industry-wide trend towards functional integration. Functional surfaces and thin layers are used for electronic and optical applications, for protection from general wear and tear and corrosion, and in many other application areas. Laser-based processes offer sustainable processing concepts for components and products during drying, tempering, sintering, melting, crystallising or wetting of coatings, into which special functions can be integrated. The high local selectivity of lasers and the precision with which the energy input into the materials can be controlled offer major advantages so that even temperature-sensitive components can be coated.

Additive techniques such as printing processes, in combination with laser processing, have great potential, as they enable a resource-efficient and cost-effective deposition of structures on selected substrate areas. Laser processes are often more energy-efficient than conventional oven processes for the necessary thermal post-treatment of wet chemically applied layers because they primarily heat the layer, not the component as a whole. The significantly shorter interaction times (seconds compared to minutes or even hours) make laser processes predominantly more productive – especially when treating local coatings – while offering advantages such as a reduction in the diffusion processes required during processing. Since no templates are required, the digital processing of printing and laser technologies are predestined for a cost-effective, inline-capable, automated production of small and individual series with a range of variants. Harmful materials which would be required during traditional galvanic production can be avoided when creating local contact gold-plating.

In the area of electromobility, wet chemistry battery electrodes can be dried using laser radiation, which saves energy and, above all, space in the production hall compared to ovens.

Ceramic wear protection coatings are used in the automotive industry in order to increase the efficiency of the tribomechanical properties of heavy duty engine and transmission components.

TECHNOLOGY

The spectral, temporal and location controllability of the laser radiation means that the component's temperature profile can be modulated to adapt it to the given application. The high heating and cooling rates, which can be achieved in small volumes, mean that the energy input into the component can be reduced.

When functional coating is created using wet chemistry, this involves a process step with which the deposited materials are thermally functionalised, e. g. through tempering, sintering, melting or compacting. By using lasers, the coating alone can be heated so that it is no longer necessary to heat the entire component to the functionalisation temperature. This requires less energy and opens up a broader range of materials. The latter also includes temperature-sensitive components such as plastic sheets as well as bearing steels and aluminium alloys used in manufacturing.

Printed and laser-functionalised sensors for monitoring metal components can also be deployed in structural health monitoring to detect damage to structural components early on. After the steel surface has been cleaned and activated to create better wetting and adhesion properties, stacks of isolated, conductive or piezo-electrical layers can be built additively. These can be used for strain measurement and structure-borne sound sensors to monitor structural components, such as bearings for wind turbines and turbine blades.

SUSTAINABILITY

Lasers are ideally suited for the precise and rapid functionalisation of surfaces or the production of coatings to reduce component friction, protect against wear and tear and corrosion, and to integrate electronic functionalities. They can be flexibly adapted to manufacturing tasks, display local selectivity and inline capabilities, and as such increase energy efficiency compared to traditional methods, while at the same time allowing the processes to be scaled. In addition, environmentally harmful additives can often be avoided.

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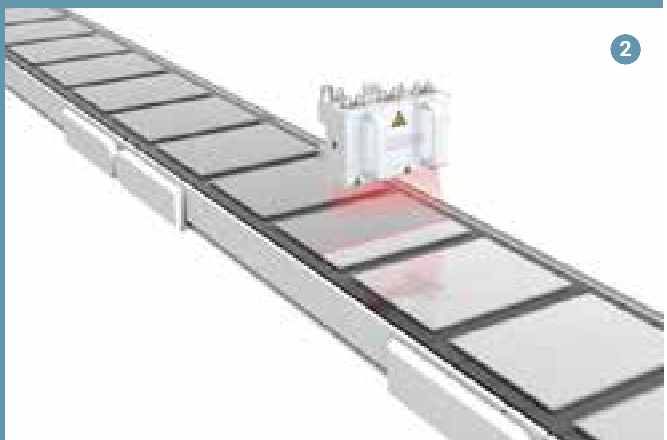
Photon-induced large-scale thermal activation and structuring of energetic functional layers

Electrical energy is typically generated and stored in thin layer systems with photoelectrical or electrochemical conversation layers. Due to the coating technologies available, the materials used still exhibit significant functional losses, which can only be reduced to a minimum through intensive, selective thermal treatment using laser light applied across the whole area.

1

2



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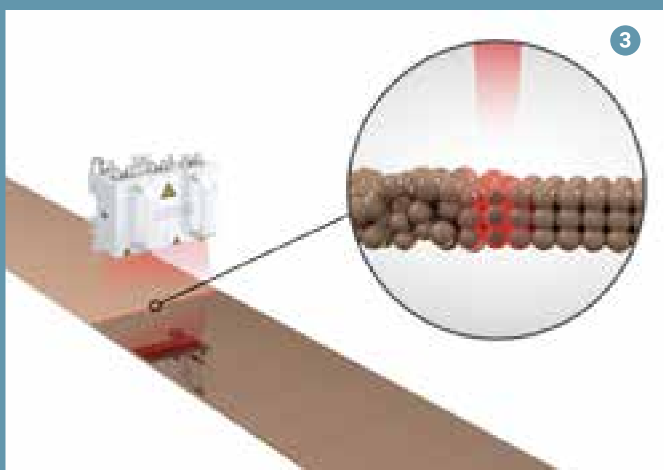

1 4 The LIMO Activation Line Laser System

2 Depending on the process (role-to-role/conveyor belt), thermal activation and structuring of energetic functional layers is possible on glass, paper, metal and semiconductor materials

3 Crystallisation/annealing of functional layers

APPLICATION AREA

The use of LIMO Activation Line Laser systems makes it possible to sinter, crystallise and anneal functional layers on glass, metal or sheets at rates of more than 30 m² per minute, and an electrooptic process efficiency of more than 50 percent making it one of the most energy-efficient heating processes. The use of laser light for the non-destructive heating and optimisation of material properties enables short-term high process temperatures on functional surfaces and coatings without changing the properties of the underlying materials or substrates.

In other words, the light really only heats up the volume of material to be transformed. As a result, for the first time, the laser process makes it possible to conduct cost-effective, high-temperature processes on surfaces and coatings for energy-efficient energy sources and energy stores to enable a global energy revolution. The combination of laser sources and light-forming micro-optic beam shaping systems is suitable for economical processing with high area processing rates. This allows for defined, simultaneous, uniform radiation in inline manufacturing processes using line beam shapes. Traditional isothermal ovens only reach low process temperatures at which the non-active base material does not show any degradation or get destruction.

With the new laser processes, the conductivity of TCO layers and printed strip conductors can be significantly improved.Even thick silicon layers on glass substrates can be crystallised at 1,500°C without destroying the substrate material. By eliminating the need for long heating and cooling phases the laser heating process can generate a defined, controllable temperature within only a few 100 microseconds. It is therefore also suitable as a digitally adjustable heater for Industry 4.0.

TECHNOLOGY

In collaboration with the IPHT, the Helmholtz Centres in Dresden-Rossendorf and Berlin, along with users from the glass, photovoltaics and battery industries, the electrical properties of metals, semiconductors and electrically conductive layers were significantly improved through sintering, annealing and crystallisation processes.

The forming temperatures were above the destruction threshold of the substrate materials up to a factor of 3. Selective high-temperature laser heating with a scaleable line focus opens up completely new application areas and material properties for the smart, energy-efficient stationary and mobile applications of the 21st century.

4

SUSTAINABILITY

The sustainability of a photon-induced thermal activation of energetic functional lasers comprises three components:

- The selective and fast heating of absorbing layers within only a few hundred microseconds allows a high heat efficiency to be achieved. By using diode laser sources, more than 50 percent of the electrical energy can be used in the process
- High-temperature forming enables the use of new, cost-effective, and readily available material systems which could not be used with previous isothermal processes (e. g. silicon).
- Laser sources with a line focus and high area processing rate make it possible to achieve scaleable productivity.

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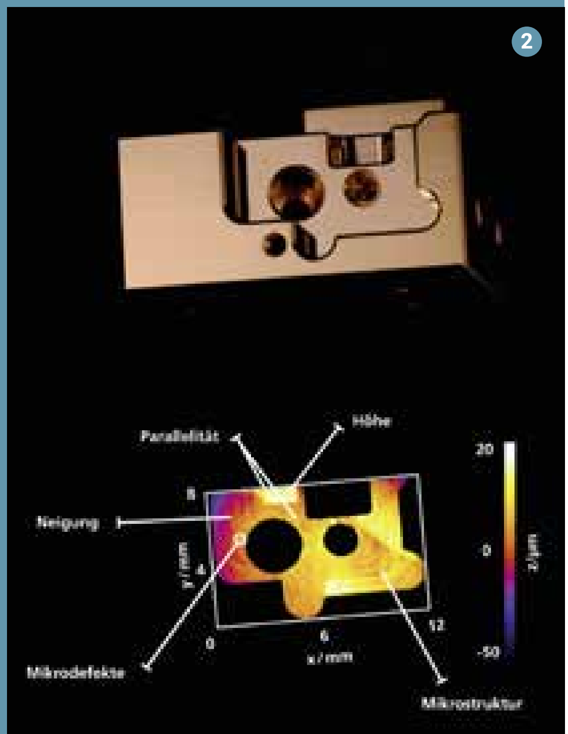
Digital holography in production control

Digital holography in the production process can be used to measure components quickly and with high precision. This allows for complete monitoring and there avoids any rejections.

1 Monitoring equipment in permanent use in a production line to measure precision swivel plates

2 Component measured in the machine tool using digital holography without removing the component

3 The 3D sensor HoloPort is the first sensor to be able to directly measure the topography of components in machine tools across their area to the precision of sub-micrometers



APPLICATION AREA

Measuring three-dimensional surfaces with small 3D structures is a challenge for industrial measurement technology. The most commonly used methods, such as strip reflection, laser triangulation or white light interferometry, are not precise or fast enough, nor sufficiently robust for many inline measurement tasks. The measurement system "HoloTop" developed at Fraunhofer IPM uses digital multiple wavelength holography for fast 3D inline monitoring. Today, holographic measurement processes are predominantly used in microscopy in laboratories.
By contrast, the systems developed by Fraunhofer IPM can be used to examine measuring fields of 20 x 20 mm^2. The sensors measure the surface topographies in the (sub-) micrometre to millimetre range at a measurement speed and robustness that was not previously possible.

Fraunhofer IPM has developed a fully automated inline monitoring system for precision turned parts for Werner Gießler GmbH, due to the company's customer requiring 100 percent checks of the parts. The system checks the sealing surfaces of precision turned parts, which are the size of a coin, in just seconds. These are used in 70 percent of all common rail diesel injection systems in lorries around the world.

TECHNOLOGY

Digital-holographic 3D measurement technology makes it possible to measure the 3D geometries of technical components, which are typically the size of matchboxes, both quickly (sub-seconds) and highly precisely (sub-µm range).

In contrast to photography, which records the spatial distribution of light intensity, holography also charts phase information. A prerequisite for this is a coherent light source – typically a laser. If the surface of a test piece is illuminated using laser light, the shape of the test piece is recorded in the phase distribution of the re-radiated light source. The interferometric capture and subsequent digital reconstruction make this information accessible and usable to measure the surfaces three-dimensionally.

By using several narrow-band lasers, different synthetic wavelengths can be generated. These different wavelengths provide a broad measurement range from the (sub-) micrometre to the millimetre range depending on the roughness of the surface. Modern graphics cards are used for the CPU-intensive digital-holographic reconstruction of complex wavelengths, which record the test piece topography. This process has been accelerated by several orders of magnitude in recent years. The 3D sensor "HoloTop" developed by Fraunhofer IPM evaluates more than 100 million measuring points per second and as such boasts unique performance in terms of precision as well as speed.

SUSTAINABILITY

Industrial quality assurance reduces rejections and ensures that components and devices remain functional for a long-term without faults. Optical measurement technology therefore makes a direct contribution to resource efficiency in this area. Often, complex 3D components must be checked at a high throughput rate and to a precision of micrometres. The new measurement system was able to massively reduce the pseudo-rejections of the company Gießler GmbH. In addition, the measurement system makes it possible to further optimise the manufacturing process. The quality of Gießler GmbH's precision-turned parts has directly influenced the efficiency of diesel engines and thus of fuel consumption and harmful substance emissions, with the measurement system also indirectly contributing to environmental improvement.

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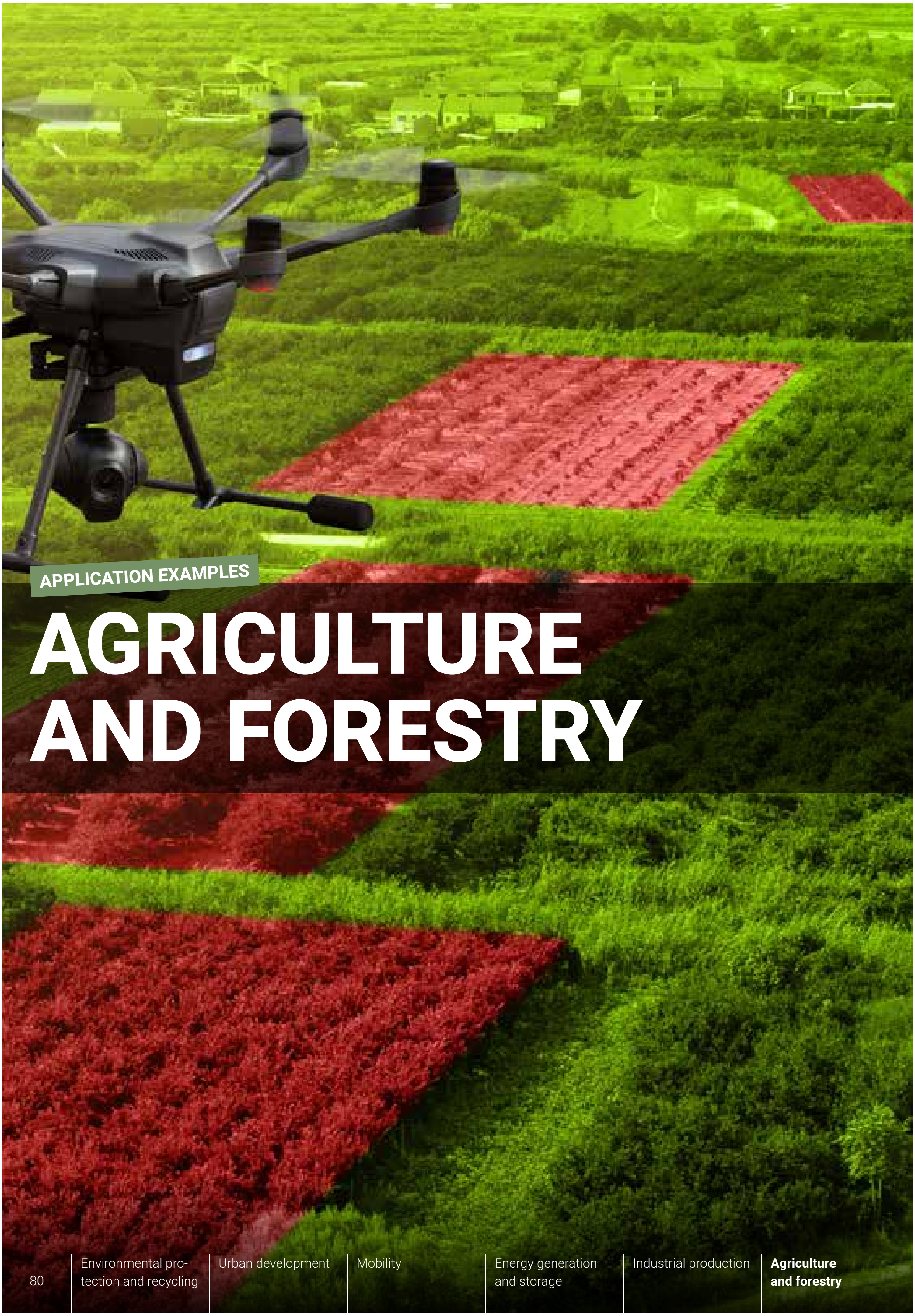


APPLICATION EXAMPLES

AGRICULTURE AND FORESTRY

Photonics for environmental sustainability in agriculture and forestry

Digitisation is being introduced into agriculture. Smart Farming and Agriculture 4.0 will increase resource efficiency and crop yields, and at the same time make agriculture more sustainable. Data-driven solutions and hardware are used for this purpose, which predominantly rely on optical sensors. Drones play an important role, performing some of these tasks through optical systems while functioning as a link within the system.

What may sound like science fiction is increasingly becoming reality. According to a Bitkom survey, more than 50 percent of agricultural businesses already use digital applications – and this is on the increase.

The potential is vast, ranging from capturing extensive weather data and field analysis, for example irrigation, fertilisation, weed control, protection against pests, or evaluating harvest conditions, through to linking up agricultural machinery and operating driverless vehicles. Modern methods such as precision farming to combat undesirable weeds use camera sensors to distinguish between crop plants and weeds and therefore allow herbicides to be applied precisely and at reduced volumes. Expensive substances such as bioherbicides, which are naturally broken down more easily constitute a genuine alternative.

Scientists at the Laser Centre in Hanover are now going a step further and are working on a solution which uses lasers instead of herbicides.

Another example of greater sustainability in agriculture through photonics is the use of special LEDs in greenhouses, which greatly reduce the use of electricity and fertilisers.

In forestry, optical solutions are also playing an ever more important role. Rising temperatures due to climate change are causing more and more dry conditions. As a result, the risk of forest fires is on the rise around the world. It is a trend which has left its mark in recent years, and one which in 2018 reached a new record for damage around the world. This has meant disastrous consequences for the environment: According to Greenpeace, fires in the environment are causing global CO_2 emissions of approx. eight billion tons per year. Digital terrestrial remote observation systems to detect forest and bush fires early on are capable of permanently observing large stretches of woodland in order to monitor smoke emissions and alert the emergency services.

Satellite-based systems such as the FireBIRD mission detect high-temperature events from space.

The data can be used by situation centres, authorities and aid organisations, and help to better predict the behaviour and development of large-scale fires in future.

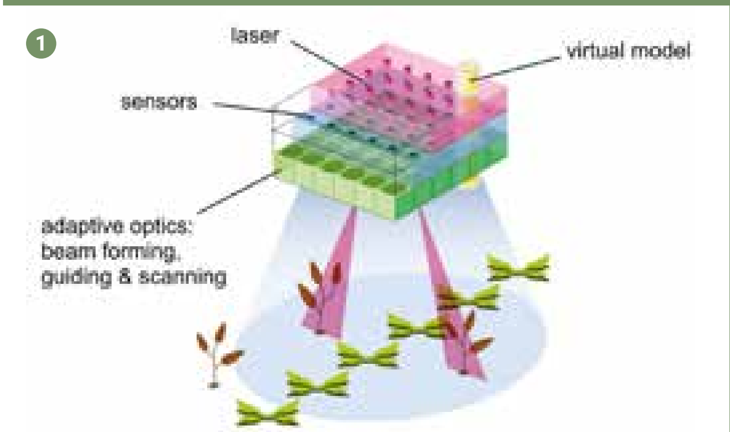
APPLICATION EXAMPLES

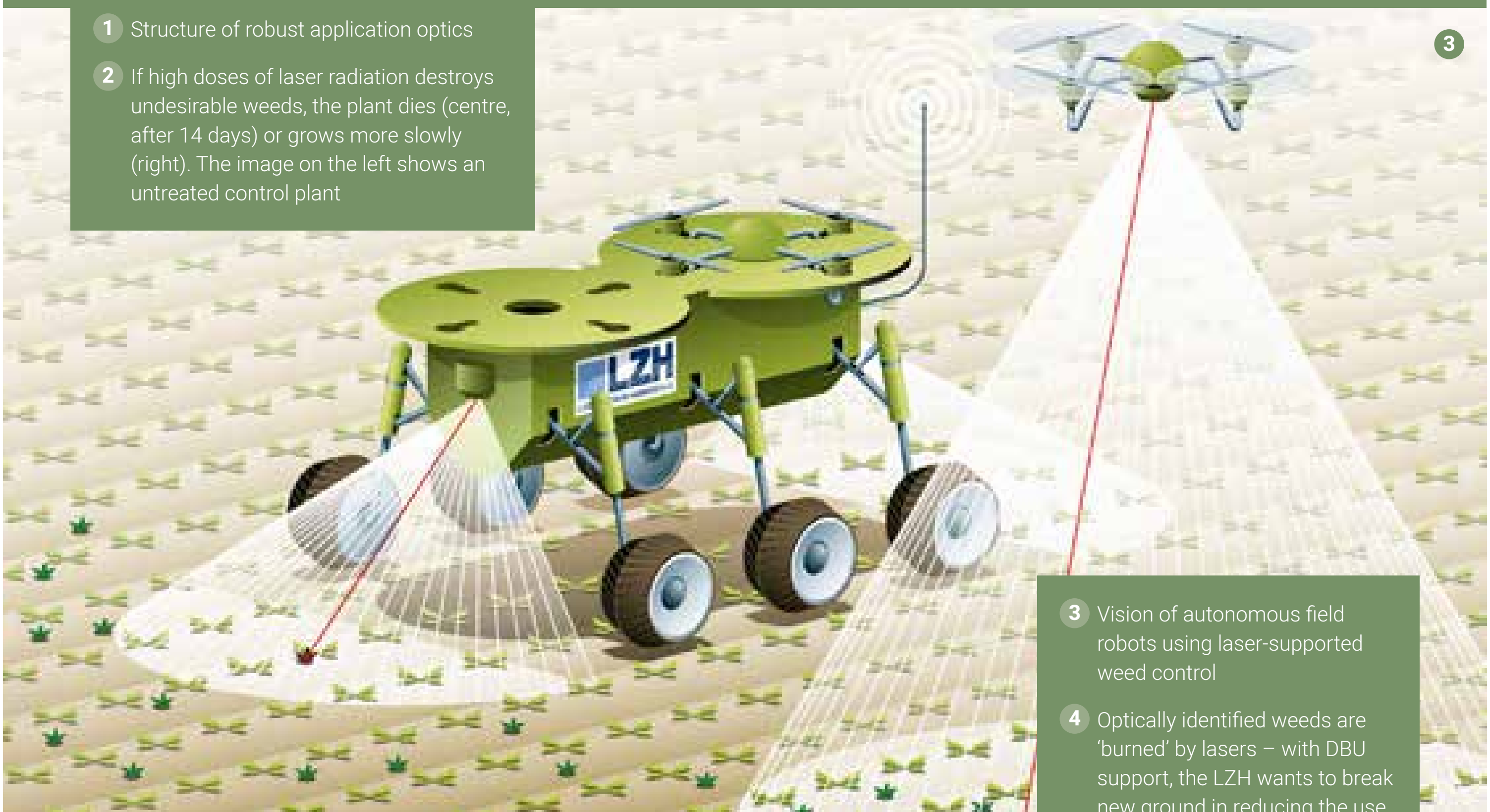
Lasers versus “weeds”:
Reducing herbicides in crop production ➔ **Page 82**

Optical early detection of
forest fires and wildfires ➔ **Page 84**

Lasers versus “weeds”: Reducing herbicides in crop production

The Hanover Laser Centre (LZH) is working on a new approach to combat undesirable weeds in crop production. Instead of applying herbicides using a scattergun approach, weeds are to be controlled physically.





1 Structure of robust application optics

2 If high doses of laser radiation destroys undesirable weeds, the plant dies (centre, after 14 days) or grows more slowly (right). The image on the left shows an untreated control plant

3 Vision of autonomous field robots using laser-supported weed control

4 Optically identified weeds are ‘burned’ by lasers – with DBU support, the LZH wants to break new ground in reducing the use of chemical pesticides

APPLICATION AREA

Society is putting a high demand on agriculture to develop and implement large-scale sustainable concepts for agricultural production. But this hasn't just been the case since the use of the weed control pesticide glyphosate has been intensively discussed in politics and law. The search for innovative alternatives to using chemical herbicides in agriculture is in full swing.

The Hannover Laser Centre (LZH) is working on a new photonics-centred approach to combat weeds in crop production. Instead of applying herbicides using a scatter-gun approach, the aim is to gradually reduce the sensitive growth centres of unwanted plants.

In the laboratory, the method's effectiveness has long been proven. But to achieve reliable results in the field, the current focus is on developing a robust, safe laser system or laser application suitable for use in the open air. The aim is for this technology to reach market maturity as soon as possible. The project "NUBELA" receives funding from the German Federal Environment Foundation (DBU) of approx. EUR 315,000. In addition to the LZH, the companies LASER on demand in Burgdorf, Lower Saxony, and IPG Laser in Burbach, North Rhine-Westphalia, are involved in the project as cooperation partners.

TECHNOLOGY

Weed control using lasers involves classifying the plants on the cultivated area as either beneficial plants or undesirable weeds based on images. A scanner then aims the laser beam directly at the weed. plants that are beneficial are not treated. Depending on the applied dose and localisation of the laser beam on the weed, the plants are either killed or initially their growth is only halted. By restricting their growth, the beneficial plants can get the growth advantage that they need so that competition with the surrounding weed does not reduce yield.

SUSTAINABILITY

The laser-based approach offers several benefits at the same time: Crop producers need less herbicide, the plants are unable to build up resistance to laser radiation and useful weeds and insects on the affected areas suffer fewer negative consequences. In this way, future crop production can be protected without the need for gene technology.

Laser Zentrum Hannover e. V.
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Optical early detection of forest and wild fires

IQ FireWatch is a terrestrial, automated system for the early detection of forest and wild fires. Modern in-situ sensors can monitor large stretches of forest and check for smoke emissions around the clock.

1 IQ FireWatch sensor in use in Spain

2 System findings during the day

3 Example of an installation on a former fire watchtower in Brandenburg

APPLICATION AREA

IQ FireWatch is a system to automatically detect forest fires early on across large distances, which includes data transmission to any centre for final visual control by an operator who normally monitors 12 - 16 towers at the same time.

The rotating multi-spectral sensor can continuously monitor around 700 km² on even ground in 4 - 6 minutes and works all day, all night and under difficult weather conditions.

The technology was developed in cooperation with the DLR and used as a key component during the Rosetta mission. Since then, IQ FireWatch has been optimised continuously, combining decades of experience with the latest technologies, for example, machine learning. More than 300 sensors protect around 6 million hectares of forest around the world.

In Germany, forests in Brandenburg as well as woodland areas in Mecklenburg-West Pomerania, Lower Saxony, Saxony-Anhalt and Saxony have been monitored successfully for nearly 20 years. The EU has certified these areas as being at a comparable risk to regions in Southern Europe for a variety of reasons.

TECHNOLOGY

The IQ FireWatch unit is installed on a tower, mobile phone mast or another suitable position, and rotates continuously at 360°. Three integrated sensors (monochrome, colour, NIR) supply high-resolution, uncompressed video data which is processed and analysed by a computer unit on site.

As soon as smoke or events resembling smoke occur, an operator is notified automatically. Visual final monitoring is needed to reach a deployment decision because smoke from a forest fire is no different from e. g. smoke from a charcoal grill.

SUSTAINABILITY

Even though forest fires form a natural part of our ecosystem, only 4 percent of them are due to natural causes. In all other cases, they are triggered by humans either directly or indirectly, due to negligence or intent.

In addition to economic factors and risk to life and limb, they also have disastrous consequences for our climate as forest fires contribute a gigantic proportion of global greenhouse gas emissions.

This speeds up climate change and drives global warming, which in turn promotes fires – a vicious circle which can be counteracted with early detection and control.

4 Forest fire in Wünsdorf/Brandenburg

5 IQ FireWatch sensor in use in Slovakia

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Messe München GmbH
LASER World of PHOTONICS

The global trade show and leading platform for the laser and photonics industry

The global trade show LASER World of PHOTONICS is the leading platform for the laser and photonics industry. The trade show provides a complete market overview – from optoelectronics and laser manufacture through to imaging, sensors and biophotonics. Many exhibitors develop not only optical components and systems for one application area, but are also active in the aviation and space travel industry, drive progress in the semiconductor and electronics industry, or contribute to quality assurance in the food industry through new imaging processes. More and more application areas are being added all the time.

In addition to the exhibition area, the trade show also offers a broad programme of awards, start-up programmes, live demonstrations, guided tours and much more.

WORLD OF PHOTONICS CONGRESS

Europe's largest World of Photonics Congress is held at the same time as the trade show. Participants can look forward to a foreward-thinking Congress comprising seven individual conferences by the world's leading organisations, as well as more than 5,000 experts from all over the world. In short: a fantastic event which provides a deep insight into the future of photonics.

Since 1973, The LASER World of PHOTONICS has been organised every two years by Messe München; the next event will be held in Munich from 24 until 27 June 2019, with the next World of Photonics Congress running parallel from 23 until 27 June 2019 at the ICM – International Congress Center Munich.

Messe München

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Industry Association SPECTARIS

SPECTARIS is the industry association for optical, medical and mechatronic technologies

ABOUT SPECTARIS

SPECTARIS represents more than 400 innovative companies. Well-known representatives include Carl Zeiss, Jenoptik, Leica, Rodenstock, Dräger, Sartorius, Karl Storz, Otto Bock and Eppendorf. But the majority of member companies are medium-sized manufacturers that are often considered ‘hidden champions’ in their fields on the global market.

SPECTARIS brings together fascinating, forward-looking and innovative industries: Consumer optics (ophthalmic optics), photonics, medical technology and analytical, bio- and laboratory technology. Together, these industries have generated total revenues in 2018 of close to EUR 72 billion and employed around 316,000 staff.

The medium-sized company structure, its vast potential for innovation and its clear focus on exports are the common factors of these industries, whose product solutions are used across a range of different industries, often as key technologies which provide people with a high quality of life.

SPECTARIS is a powerful network which facilitates a constant exchange between its members while providing a platform for discussions with politicians, other associations, important users and sales agents. As a service provider, SPECTARIS not only ensures that its members have access to valuable market and industry data but also provides targeted assistance for sales staff as well as information regarding permits, important legal amendments and economic matters.

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SPECTARIS
Verband der Hightech-Industrie

Fraunhofer Institute for Laser Technology ILT

Laser technology for tailored solutions

FRAUNHOFER ILT

With more than 540 employees and a net area of more than 19,500 m², the Fraunhofer Institute for Laser Technology ILT is one of the world's most important contract research and development institutes in the areas of laser development and laser application.

The core competences of Fraunhofer ILT comprise the development of new laser beam sources and components, laser measurement and monitoring technology and laser manufacturing technology.

This includes cutting, removal, drilling, welding and soldering, as well as surface tempering, micro production and additive manufacturing. Moreover, Fraunhofer ILT focuses on laser installation engineering, process monitoring and control, modelling and system technology in general. Its services range from feasibility studies and process qualifications through to the customer-specific integration of laser processes into the respective production line.

Fraunhofer ILT is part of the Fraunhofer Society, which has 72 institutes, more than 26,600 employees and a research volume of EUR 2.6 billion a year, making it one of the most important research associations in Germany.

1

2

Fraunhofer Institute for Laser Technology ILT
www.ilt.fraunhofer.de

Fraunhofer ILT

Fraunhofer Association Light & Surfaces

Competence through networking

LIGHT & SURFACES

The Fraunhofer Association "Light & Surfaces" is a cooperation between six Fraunhofer Institutes in the areas of laser, optics, measurement and coating technology. Based on fundamental work in various application areas, the association guarantees a fast and flexible realisation of customer-specific system solutions in these areas.

Coordinated strategies focused on current market requirements creates synergy for the customer. In cooperation with the respective local universities, the institutes offer the entire spectrum of student education, right up to doctorate level.

In this way, the Fraunhofer Institutes are not only innovation partners for technological developments, but also continuously function as a source of young scientific and technical staff.

1 Laser beam drilling of guide blade segments

2 Large-scale inline coating at Fraunhofer ISF

3 Non-linear frequency conversion can be used to generate adjustable laser light in previously unavailable spectral ranges

Fraunhofer Association Light & Surfaces
www.light-and-surfaces.fraunhofer.de

CORE COMPETENCES OF THE ASSOCIATION

The coordinated competences of the six association partners ensure that the research can be quickly and flexibly adapted to the different requirements of the areas:

- Laser manufacturing processes
- Beam sources
- Measurement technology
- Medicine and life sciences
- Material technology
- Optical systems and optics manufacture
- Micro and nanotechnology
- Thin layer technology
- Plasmatechnology
- Electron beam technology
- EUV technology
- Process and system simulation

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Fraunhofer Institute for Layer and Surface Technology IST
www.ist.fraunhofer.de

Fraunhofer Institute for Material and Beam Technology IWS
www.iws.fraunhofer.de

4 Surfaces with a hydrophilic, hydrophobic structure on a stainless steel sheet

5 Measurement of a mirror module with two free-from mirrors and reference structures in a computer-generated hologram

6 Flexible OLED as a design kit

Fraunhofer
LIGHT & SURFACES

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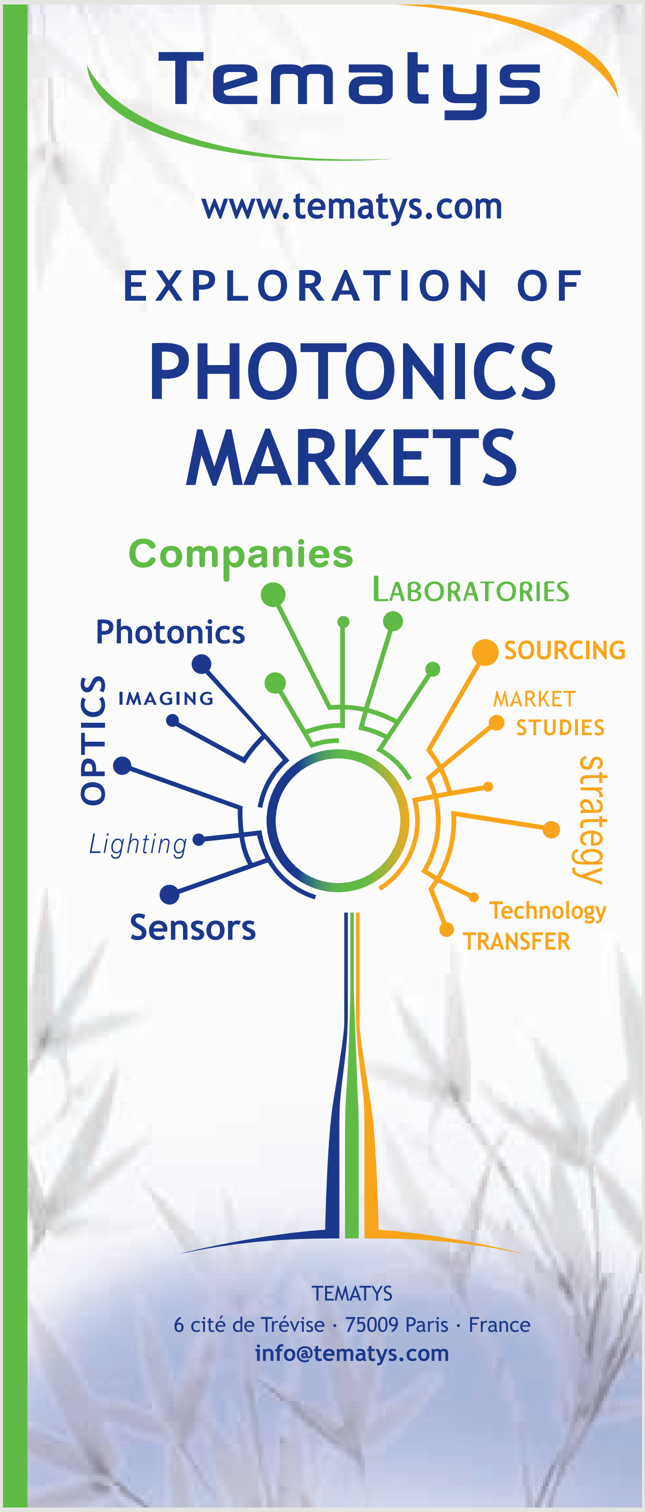

TEMATYS

Tematys is an independent, medium-sized consultancy firm which focuses on studies and strategies in the areas of optics, photonics, sensor technology, imaging, material technology and their applied markets.

We have a particular expertise in technology transfers, R&D exploitation and the marketing of emerging technologies.

We assist with the critical steps of the product development process and offer services which go beyond market studies. One example of this is customer needs analyses on the exact, demand-based development of products.

We offer end users tailored market updates and procurement services in numerous applied markets for the technologies described above. Examples include life science, security and aviation.

TEMATYS offers associations, industry clusters and public institutes information to facilitate strategic decision-making.

We have more than 150 international customers in Europe, Asia, and the USA, including research organisations, public institutions, company groups, industry consortia, SMEs and start-ups.

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Exploration of photonics markets

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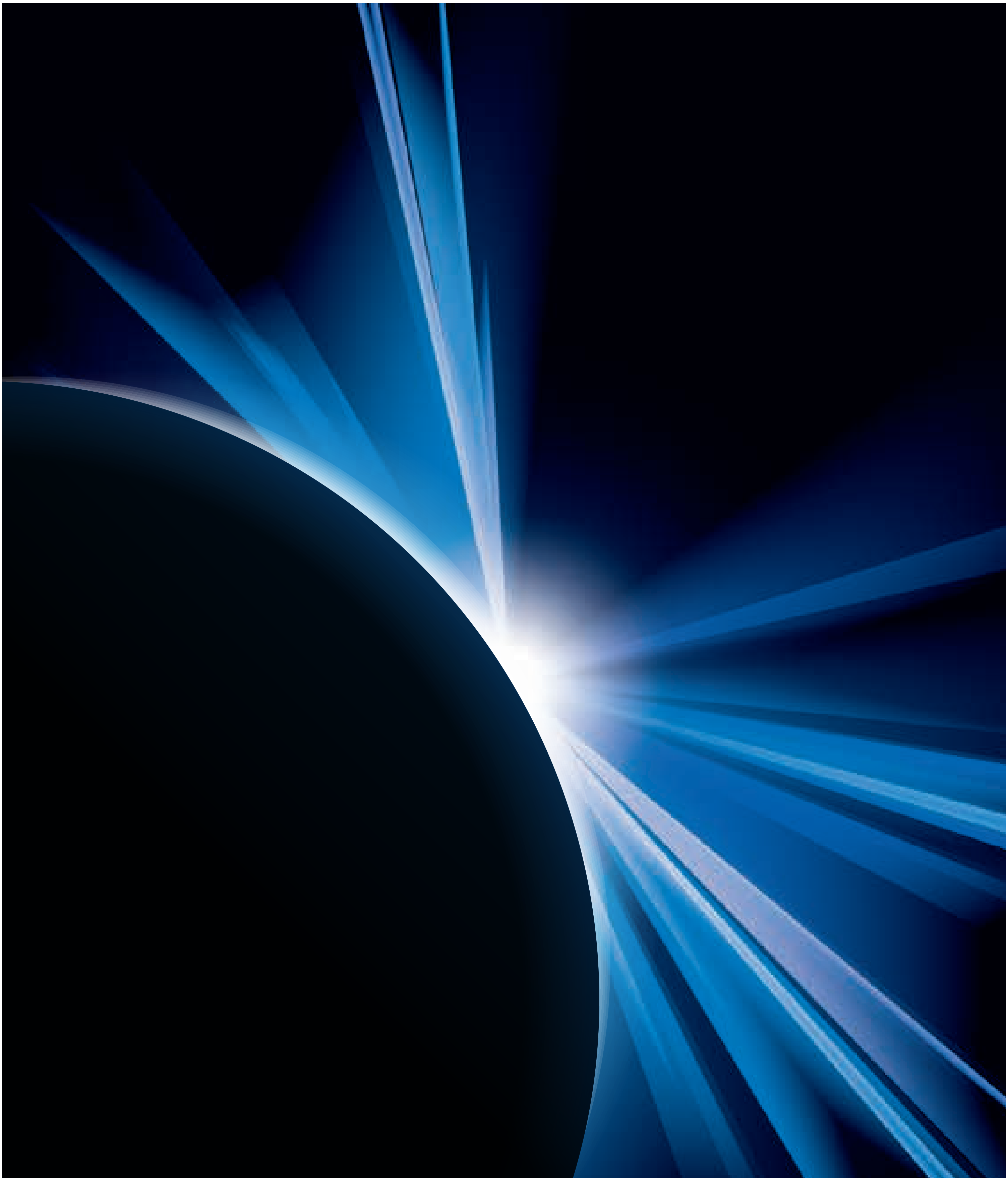

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