POLISH

OPTICAL FIBERS

Industry 4.0

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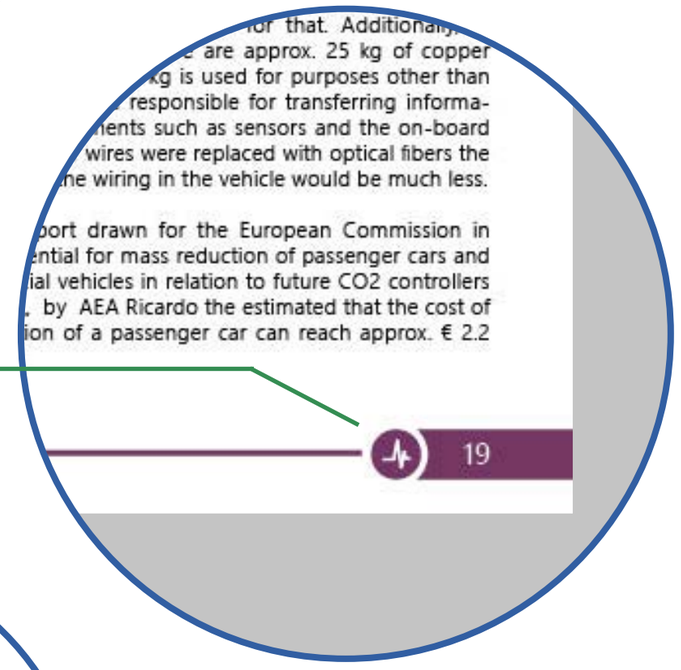
For your convenience we have created an interactive version.

You can easily move around the brochure using the list of contents – just click on the chapter you want to read.

There is an icon in the corner of each page – if you click it you will return to the list of contents.

The last page contains the logos of the companies which participate in the Cluster for Photonics and Fibre Optics – some of the logos link to the companies` webpages.

Cluster for Photonics and Fibre Optics



This document is a comprehensive study on the enormous potential of Polish optical fiber solutions and their impact on the development of modern industry 4.0. It was drawn up by scientists, specialists and enterpreneurs participating in the Cluster for Photonics and Fibre Optics.

Cluster for Photonics and Fibre Optics

TABLE OF CONTENTS

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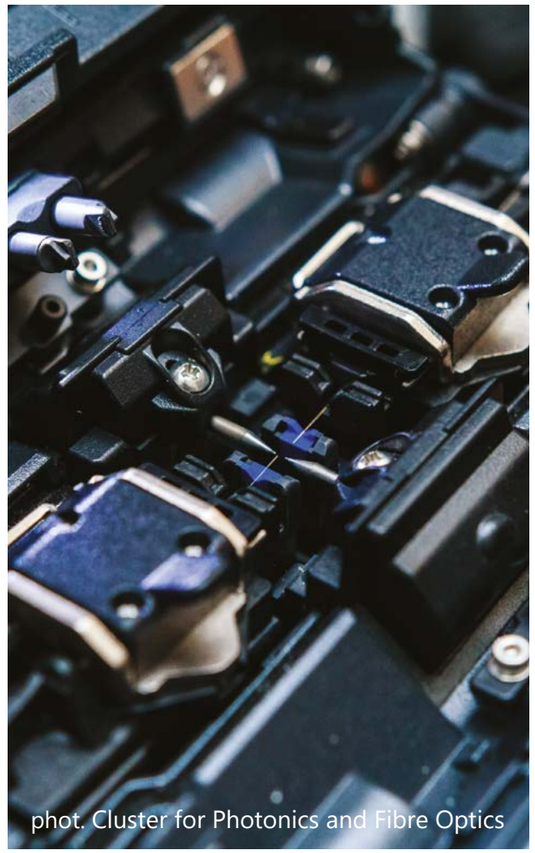
Abstract

The fourth industrial revolution, based on digitizing, obtaining and analyzing large amounts of data cannot take place without photonics. Whilst we are often unaware of its existence, photonics can be used to manage and make use of the light so that it serves us. In other words, photonics is a key technology for acquiring, processing and transmitting information. It started with the use of two pioneering inventions: the optical fiber and the laser, which helped us to manage the particles of light - photons. Now photonics constantly changes the world and penetrates all branches of industry. Just as electronics dominated the development of civilization in the twentieth century, the twenty-first century will belong to photonics.

Polish optical fibers have been independently developed for more than 40 years and can certainly be called a Polish specialty in the field of advanced technology. It is in our country that the first modern commercial multi-core optical fiber is being created, as a basic element for digitization and the new generation of telecom, as well as for development in the space sector. Intelligent sensor systems based on optical fiber technology do not need a power supply at the measuring point, are energy efficient, and can work in extreme temperatures and under the difficult conditions of an explosive or radioactive environment. Optical fibers are already providing a stimulus for development in various key industries, including energy, mining, construction, automotive and many others. In medicine, probes based on optical fibers will allow for extremely accurate blood, breathed-out air or blood pressure testing, and will lead to incredibly fast development of medical diagnostics that will help to prevent the spread of civilization diseases. A solution that will replace biopsy and revolutionize the diagnosis of cancer is already being developed in Poland.

High-power optical fiber lasers are another extremely important element in modern medicine, material processing and defense. These are just a few examples, and there are many more fields where the technology can be applied, and most importantly, provide a real opportunity to achieve a technological advantage over many competitors in highly developed countries. Above all, optical fiber technology turns the concept of Industry 4.0 into a reality. Optical fibers are significant in enabling the development of several components of this idea, such as: the Internet of Things (IoT), CPS systems (Cyber-Physical Systems), and handling large volumes of data or the infrastructure necessary for its transmission. The Polish optical fiber industry, which is still in the early stages of development, has seen several fold increases in its income and employment levels in the past five years. **Can you find any other innovative sector of the economy with such dynamic development? There is no other field, so important for the development of our civilization, in which we possess such huge potential and a solid base in a still growing industry.**



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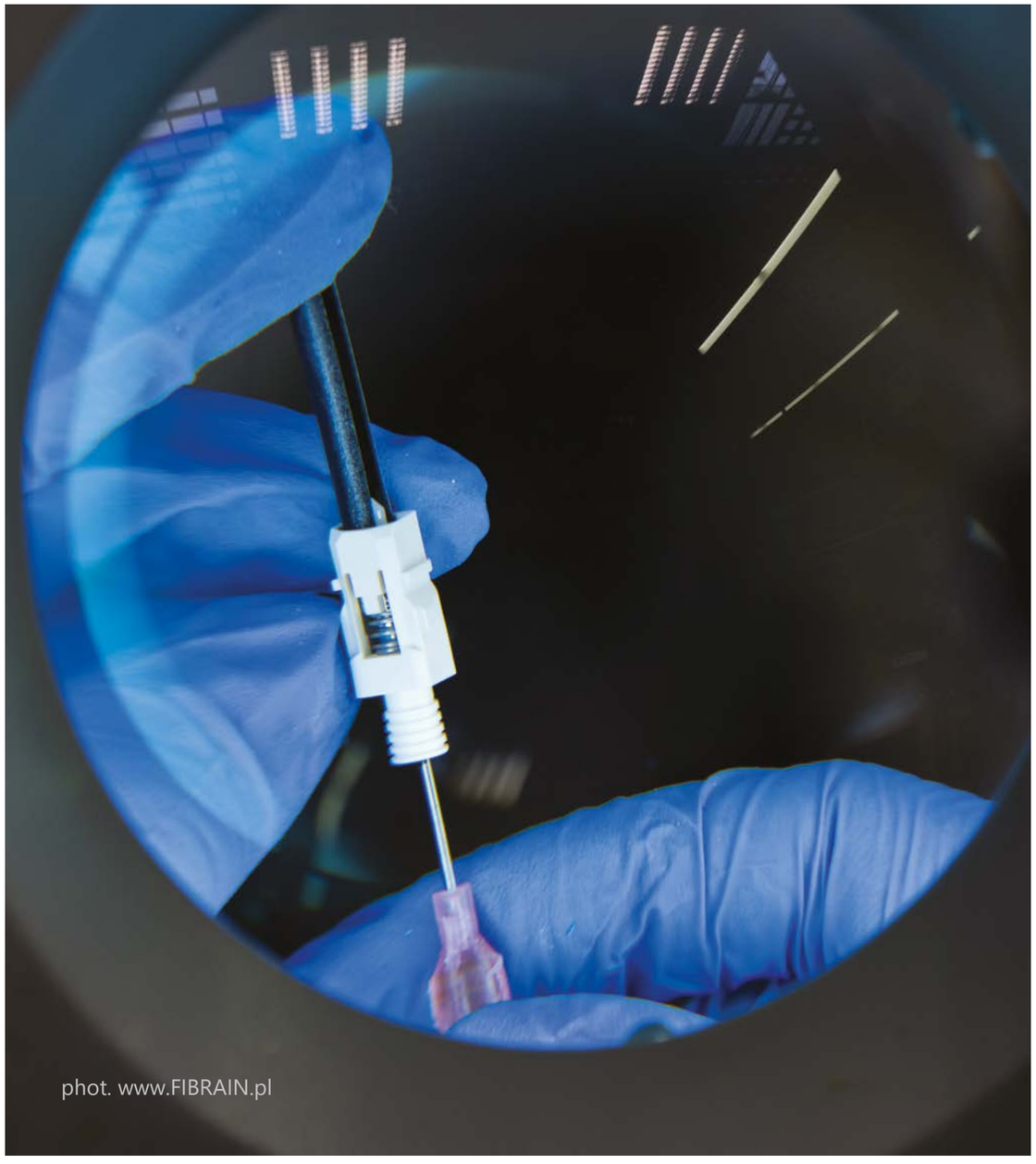
Introduction

Economy based on photonics

Investing in domestic optical fiber solutions, which are also innovative on a global scale, provides Poland's high-tech industry with an opportunity to achieve sustainable development and growth.

Photonics is often referred to as the technology of the twenty-first century since it can accelerate the development of civilization, just as electronics did in the twentieth century.

Photonic solutions can be used wherever electronics reaches the limits of its capacity or is inefficient - in extremely high and low temperatures, and in particularly disaster-prone and difficult external conditions. Devices based on photonics are smaller, more precise and energy-saving. Photonic solutions can be applied to virtually all industries and they are having an increasing influence on all aspects of human life. The global photonics market is growing at a tremendous rate. With its potential in photonics, Poland can significantly accelerate its economic development.



phot. www.FIBRAIN.pl

Photonics and Polish optical fibers

The main pillar of photonics is an optical fiber technology. There is a saying that information is power. Its availability and transmission speed as well as the progress of the entire digitization depend on the development of optical fiber technology.

Optical fibers and their components also open up great opportunities for other areas of the economy, such as medicine, transportation, energy, construction, mining, defense, space and many others. This wide range of applications will **allow for considerable development of the economy due to the modernizing effect of photonics on industry, thus creating new jobs, new enterprises and gaining a competitive advantage for Poland in relation to highly developed countries.**

In spite of the highly developed Western research centers, Polish scientists were among the first in the world to create the basis for an independent optical fiber technology as early as the 1970s. This technology cannot be blocked with foreign patents, and thus it is a Polish national specialty in the area of advanced technology.

As a result, various types of innovative optical fibers are being developed and manufactured in Poland. We have excellent scientific facilities and, with the number of publications on optical fibers, we rank among the world leaders. Also there is dynamic, effective cooperation between Polish universities, research institutes and enterprises in the photonics industry as a whole, and especially in the optical fiber sector. This happens through innovative small and medium-sized enterprises which transfer technology from the science to industry, and this greatly increases the effectiveness of relations between scientific research centers, administration and business.

Due to the experience gained through years of research work, a unique Polish technology of special optical fibers has been created with remarkable industrial implementation potential. In recent years some of the world's most modern production plants have been built in Poland, and technology companies that compete effectively with the world leaders have been set up. This is a solid foundation for the development of a modern Polish optical fiber industry based on indigenous, and worldwide innovative technologies.

NEW GENERATION **DIGITIZATION**

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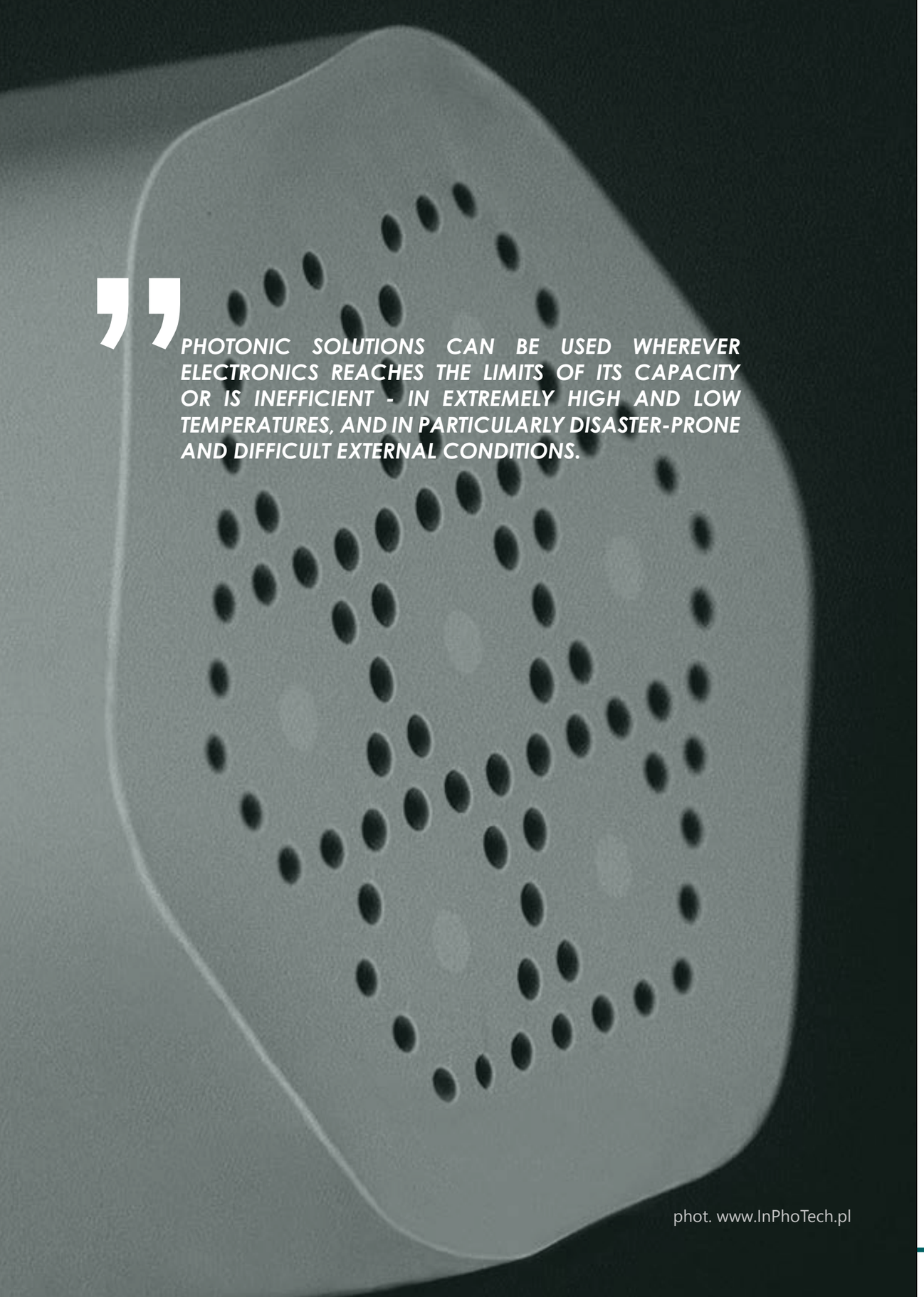

PHOTONIC SOLUTIONS CAN BE USED WHEREVER ELECTRONICS REACHES THE LIMITS OF ITS CAPACITY OR IS INEFFICIENT - IN EXTREMELY HIGH AND LOW TEMPERATURES, AND IN PARTICULARLY DISASTER-PRONE AND DIFFICULT EXTERNAL CONDITIONS.

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NEW GENERATION **DIGITIZATION**

Optical fiber technologies are primarily associated with modern telecommunications. The twentieth century was hallmarked by revolutionary communications solutions now commonly used worldwide, which involved replacing copper wires with optical fibers. This not only resulted in an increase in network capacity and consequently the speed of information transmission, but also a reduction in electric energy consumption. However, the continuous development of our civilization and technological progress mean that the techniques used previously are no longer efficient, putting us at the threshold of a telecommunications crash.

Developing innovative approaches to the process of transferring information is now a major challenge for digitization and telecommunications, where the data transfer rate is an actual barrier of a global nature.

The limited space for optical fibers is also a key problem that needs to be addressed when seeking new technological solutions. The number of optical fibers in a given cable or the number of cables themselves can only be increased to a certain extent since large urban agglomerations and data centers do not offer extra room for the optical links which transfer information.

There is ongoing competition in the world between many research centers cooperating with the corporations involved in the field of digitization, mainly from Japan and the USA. All of them are working on new special optical fibers which would increase the capacity of optical fiber lines.

The greatest expectations for digitization are placed on new generation modern optical fibers which are multi-core. The basic idea is simple – as many cores as possible are placed in the smallest possible cross-section of the fiber, and each of them is an independent channel for information transmission. These fibers allow an enormous boost in the bandwidth of data transfer.

Multicore optical fiber technology is also dedicated to space applications. Innovations in the field of space satellites must be a breakthrough in the broadest sense of the word. Currently, satellites are covered with outdated copper wiring, because the optical fibers developed previously turned out to be sensitive to destructive space radiation. Thanks to Polish technology which makes multi-core optical fibers insensitive to cosmic radiation, satellites will enter the twenty-first century.

Developing efficient systems for innovative information transfer infrastructure will allow large amounts of data to be processed, which is a key requirement for making Industry 4.0. a reality. Polish scientists have been working on multicore optical fiber technology since the 1990s. Thanks to their research results and the pioneering achievements of specialists from Polish technology companies, we now have an advantage over the majority of global competitors.

This is possible because in addition to developing innovative multi-core optical fibers, wherein each core meets all the necessary standards for information transmission, a compatible device has been created which separates the signal from each core of a multicore optical fiber and transmits it to a classic single-core fiber. As a result, it is possible to use all the currently existing transmitting and receiving devices, thus bringing significant savings, as well as shortening the lead time for implementing this innovation into industry.

Polish optical fibers in global **digitization**

IT SHOULD BE EMPHASIZED THAT DIGITIZATION AND DATA TRANSFER IS A STRATEGIC AREA FOR MANY OTHER BRANCHES OF THE ECONOMY AND ITS IMPROVED PERFORMANCE WILL PROVIDE A GOOD PACE OF INNOVATION BASED ON MODERN TECHNOLOGIES AS WELL AS ENTERING THE ERA OF INDUSTRY 4.0.

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It seems that from a user perspective, this small glass tube called an optical fiber, found in every home in order to enable an Internet connection, entirely meets customer expectations.

However, on global scale there is a growing demand for data transfer, which results from the development of industries based on data collection and transmission (e.g. cloud computing). The optical fibers in use today have their limitations, in particular the maximum data transfer speed, which makes the current technology insufficient.

The Polish multicore optical fiber technology is unique worldwide, and gives the answer to this problem. The first product of its kind in the world – the multicore optical fiber will facilitate a technological jump similar to replacing copper wires with optical fibers. Multicore optical fibers provide many benefits for the development of digitalization and optical data transmission, namely: increasing the amount of data transferred, and decreasing the amount of protective materials used for protecting optical fibers cables.

Furthermore, the use of multicore optical fiber technology also means shorter production processes, thus saving energy and raw materials as well as providing much lighter cables, resulting in easier and cheaper transportation thanks to significant savings on fuel and packaging.

The efficiency of data centers can also be significantly improved. Now they resemble a tangle of hundreds or thousands of cables, occupying large areas, so multicore optical fibers are also a breakthrough solution in this case. However, the data centers struggle with a wider range of problems related to a number of factors including a high noise level, the curbing of which is highly energy consuming.

In addition to developing this new generation medium (the multicore optical fiber) there is huge demand for a whole set of photonic devices for data transmission which together will result in faster transfer, lower energy consumption, and last but not least, reduced cost.

It should be emphasized that digitization and data transfer is a strategic area for many other branches of the economy and its improved performance will provide a good pace of innovation based on modern technologies as well as entering the era of Industry 4.0.

The FTTH - „Fiber To The Home" concept which is about connecting all infrastructure with an optical fiber network includes the idea of increasing the level of digitization across many regions, and in this way creating improved social opportunities through access to modern technologies. The very fact of such access will stimulate the creation of many new workplaces, even in less industrialized countries, since teleworking develops rapidly.

Modern telecommunication solutions based on special optical fibers are also applied in industries such as, for example, banking or defense (the development of secure communications systems resistant to data capturing).

It is worth mentioning that optical fibers can be found not only on the ground. Polish entrepreneurs are paving the way for the introduction of optical communication in space satellites. In this way Poland has a chance to mark its presence in the international space industry as a specialized and mature partner offering a technology of its own.

There are clusters in Poland bringing together entrepreneurs presenting different cells in the value chain: the companies developing know-how and co-operating with Polish optical fiber scientists (who developed an independent special optical fiber manufacturing technology), the companies supplying raw materials and semi-finished products, special service supply companies (e.g. developing an optical fiber network architecture), and businesses involved in the production of optical fibers and photonic devices.

The development of the Polish economy towards photonics, including that which is focused on collecting, processing and transferring huge amounts of data, fits perfectly with the global trends. At the same time, this idea is based on an existing industry, providing solid grounds for investing with a low level of risk. The legal basis of domestic technology and the existing enterprises create an excellent base for the development of the industry in Poland, which in terms of our know-how, puts us at the forefront of the industry worldwide.

Polish optical fibers in **cosmic space**

OPTICAL FIBERS AND RELATED PHOTONIC DEVICES OFFER A UNIQUE SET OF PROPERTIES THAT ARE VITAL FROM THE POINT OF VIEW OF THE VIABILITY AND PROFITABILITY OF SYSTEMS CARRIED AWAY INTO SPACE.

phot. www.spacex.com

The space sector is not only a purely cognitive scientific exercise, but mainly it is an important part of the economy supporting the safety and prosperity of the country as well as fighting climate and migration threats.

It has a significant impact on developing high-tech technology as it gives companies the challenge of solving unusual technical problems and applying high quality standards with regard to both the devices and the specialists. All that makes the space sector an essential component of any developed economy and an important area for competing in the development of technology worldwide.

It has also been acknowledged in Poland that the space sector is pro-innovative and strategic for the autonomy of the State. Recently Poland became a full member of the European Space Agency (ESA).

At the moment, the space sector worldwide is undergoing a transformation. **The devices and satellite communications standards** based on electronics and radio technologies **which have been used for many years are proving to be insufficient now.** New solutions are being sought to increase the data transmission bandwidth and at the same time reduce the weight and the amount of cabling inside satellites and spacecraft, to minimize energy consumption and increase the reliability of the systems sent into space. **The solution corresponding to these needs is the wide application of photonic devices, and optical fibers in particular.**

Optical fibers and related photonic devices offer a unique set of properties that are vital from the point of view of the viability and profitability of systems carried away into space. These properties are:
• small size and weight (launching into space is extremely expensive)
• low power consumption (power supply in space is difficult and expensive)
• lack of electricity in the optical fiber (important from the point of view of interference with other precision devices and explosion hazard,
which is important in monitoring fuel tanks systems, for example)
• reduction of the amount of cabling (very important for managing the narrow space inside spacecrafts and assembly speed).

Polish optical fiber technologies bring about innovative solutions such as:
• passive and active optical fibers which are insensitive to cosmic radiation, carrying a signal to and from the transceiver, and transmitting light between other devices such as lasers, detectors, telescopes, and mirrors
• active multicore optical fibers for optical fiber amplifiers for a new type of telecommunications satellite
• sensor systems which enable temperature, stress and pressure measurements, dedicated to monitor the equipment and construction elements (e.g. the housing and antenna) in the presence of cosmic radiation, high temperature and very rapid changes in temperature.

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INTELLIGENT OPTICAL FIBER **SENSORS**

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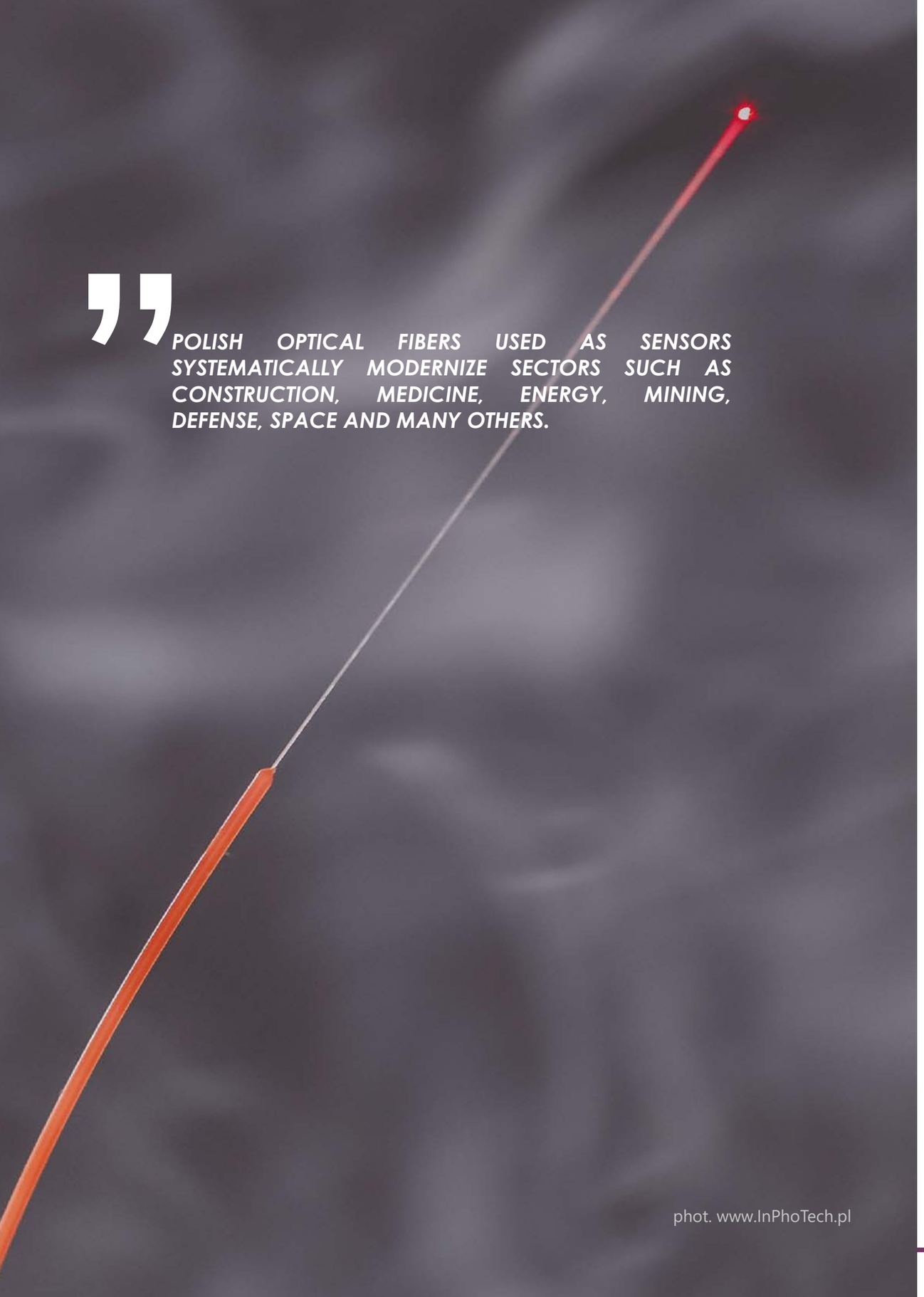

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INTELLIGENT OPTICAL **FIBER SENSORS**

The distinctive Polish technology of putting air-glass micro- and nanostructures inside an optical fiber opens up the path to creating special optical fibers for **extremely precise and reliable measurements carried out in very difficult conditions**, such as very low or very high temperatures or nuclear radiation.

Polish optical fibers used as sensors systematically modernize sectors such as construction, medicine, energy, mining, defense, space and many others.

Through analyzing the optical signal propagated in the optical fiber we can get information on the external conditions (pressure, vibration, stress, temperature, shape, electrical or magnetic field, and others) in each particular location or in any given point along the whole length of a fiber, even if it is 100 km long.

The main advantages of these sensors are their small size and weight, the ability to integrate them with other materials (e.g. composite), high safety in explosive zones, insensitivity to electromagnetic interference, and high resistance to very high temperature. These properties go far beyond what standard electronic sensors can achieve.

Applying sensors to testing blood pressure and the composition and the content of exhaled air would be a revolutionary step in medicine. Currently Polish scientists are working on an optical fiber probe for testing whether tissue treated under surgery is a tumor. This method of cancer diagnosis is a much more effective alternative to the more popular biopsy. The solutions in the field of medicine increase the effectiveness of the treatment of civilization diseases, thereby having a direct impact on the duration and quality of life.

A high-precision optical fiber sensor receives a vast amount of information. Since each metre of optical fibre is equivalent to one electronic detector, a 100km fiber would provide the same amount of information as 100 000 individual electronic detectors.
Such sensors can read technical condition, stress, and various parameters that determine the safety of building constructions, railways, pipelines or high voltage systems. Implementing optical fiber sensors for measuring conditions in nuclear power plants or in radioactive waste storage is a key factor for increasing safety standards.

The effectiveness of optical fiber sensors in spacecraft and satellites cannot be overstated. The use of accurate and innovative optical fiber sensors will lead to the creation of intelligent power systems, and intelligent mine monitoring systems, as well as intelligent pipelines.

Their use can be a breakthrough in the automotive industry, the designing of intelligent, energy-saving electric vehicles or the currently high profile autonomous vehicle. Therefore optical fiber sensors are an essential element necessary to achieve the objectives of the Internet of Things concept.

Intelligent electric **vehicles**

USING POLISH OPTICAL FIBERS IN INTELLIGENT ELECTRIC VEHICLES WHICH SELF-MONITOR ALL PROCESSES AND THE WEAR AND TEAR OF PARTS WILL LEAD NOT ONLY TO MORE EFFICIENT USE OF THE CAR BUT WILL ALSO MAKE IT SAFER FOR PASSENGERS AND OTHER ROAD USERS.

phot. www.pexels.com

Due to its geographical location and economic conditions **Poland is one of the largest manufacturers of automotive components in the region.** According to the Association of Distributors and Manufacturers of Automotive Parts automotive components, the value produced in Poland in 2014 amounted to over 60 billion PLN (15 billion euros), of which more than 50% is exported. If the economic prognosis is right this market is still going to grow by a few percentage points annually in the coming years.

Thanks to this market position and the steadily increasing potential of optical fiber photonics (both in universities and in R & D companies), Poland can surely aim at the implementation of modern technological solutions in modern electric vehicle manufacturing.

There is a constantly growing demand for optical fiber technologies and newer solutions (telecommunications, sensing, laser). As a result the photonics market is driven by innovative products and niche solutions.

Forecasts suggest that the optical fiber market will grow in the coming years with a CAGR (compound annual growth rate) above 10% for optical fibers in telecommunications and optical fiber lasers, and as high as 30% for optical fiber sensors! The increasing development of photonic technology in Poland provides an excellent opportunity to use optical fiber photonics in the automotive industry - including in the production of modern electric vehicles.

One of the main challenges in electric (and combustion) vehicle design is keeping their weight down. A low weight is desirable primarily due to the corresponding lower fuel and electricity consumption. **The use of light and strong composite materials instead of metal or steel (e.g. in the body, chassis, etc.) in electric vehicles could significantly reduce their weight, even by hundreds of kilograms, thereby reducing energy consumption and thus lengthening their range.**

However, such modern materials should be subjected to continuous monitoring of strength, stress and aging, and optical fiber sensors are the perfect tool for that. Additionally, in a modern passenger car there are approx. 25 kg of copper wires, of which approx. 18 kg is used for purposes other than power supply. They are responsible for transferring information between components such as sensors and the on-board computer. If copper wires were replaced with optical fibers the overall weight of the wiring in the vehicle would be much less.

Based on a report drawn for the European Commission in 2015, „The potential for mass reduction of passenger cars and light commercial vehicles in relation to future CO2 controllers requirements „ by AEA Ricardo the estimated that the cost of weight reduction of a passenger car can reach approx. € 2.2 per kilogram.

For vans however this cost rises to € 37 per kilogram. The report also points out that the savings resulting from lower fuel consumption may reach approx. € 6 per kilogram reduced, over the lifetime of the vehicle (€ 11 for vans).

In larger vehicles, such as buses, trains, aircraft and specialized vehicles, which contain a lot more copper wires the benefit flowing from the reduction in weight significantly increases. This is not the only advantage of optical fiber solutions - they can send a lot more data than copper cables. This creates the possibility to link most of the devices in the vehicle and moves us towards the extremely popular idea of autonomous vehicles.

Optical fibers do not carry electric flows, so there is no arcing in them. This reduces the risk of ignition and increases the safety of users. Additionally light is resistant to electromagnetic interference generated by, for example, an electric engine, electric starter motor etc., therefore optical fiber sensors are more reliable than electronic sensors and ensure proper functioning even in difficult conditions.

Optical fiber technology uses low-cost, semiconductor light sources with a high efficiency and low electricity consumption. This allows fuel consumption in combustion vehicles to be reducedand the life of batteries in electric vehicles to be extended, which is an advantage, both for economic and environmental reasons.

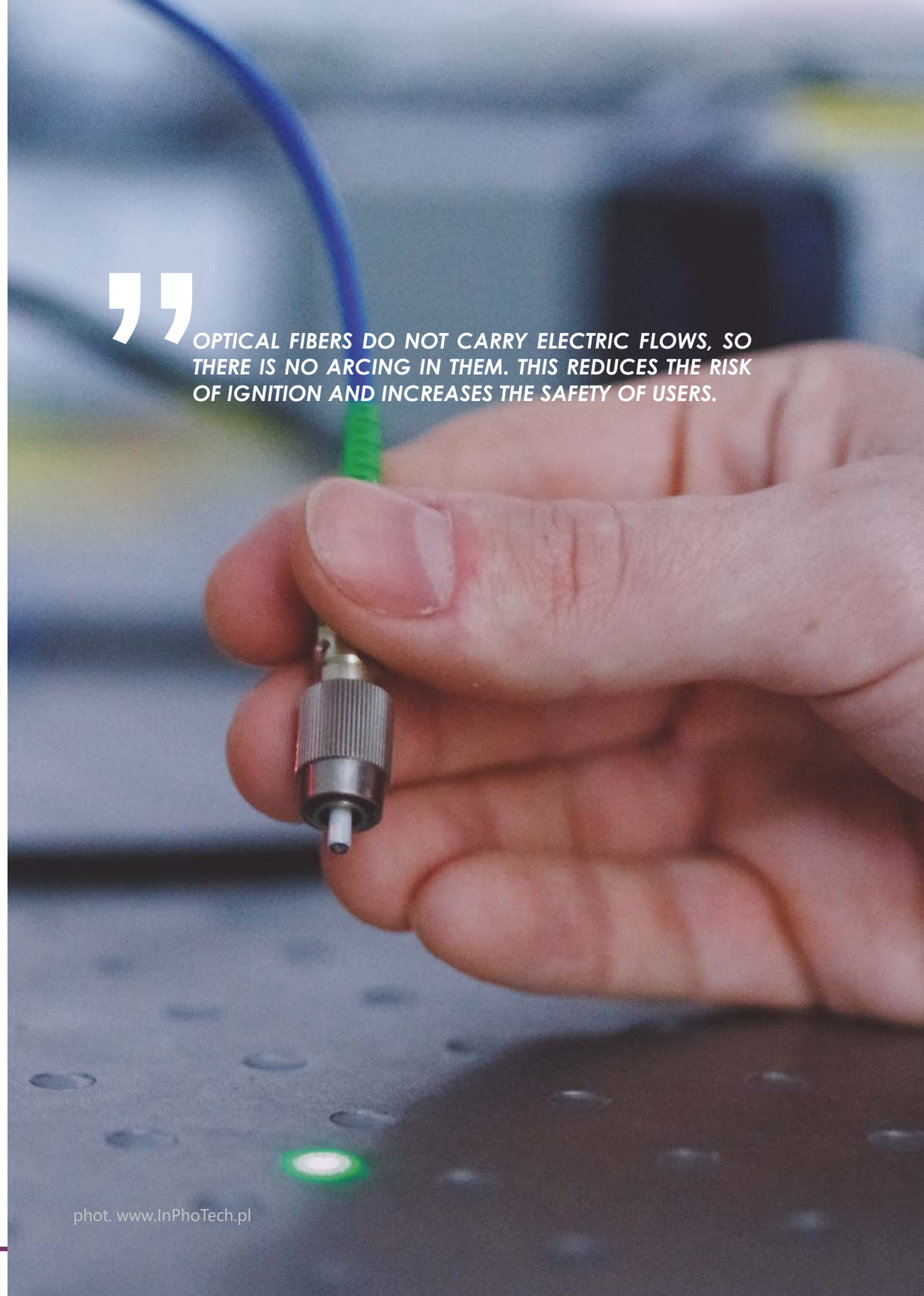
But above all, optical fibers sensors provide the highest measurement precision, which is essential for smart vehicles that are able to perform a series of tasks without human intervention. An example of an optical fiber application in vehicles is optical fiber sensors: gyroscopes and accelerometers which determine a vehicle's position and the direction in which it is accelerating. They can be also used in traction control systems or for automatic control of the vehicle, even in tunnels. Accurate flowmeters that measure the flow of liquids and gases are another good example of optical fiber sensors. They give very accurate level measurements as well as measuring the consumption of fuel or other liquids.

Most importantly, it is also possible to accurately measure temperature, which is crucial for the maintenance and proper operation of batteries, leading to another application for optical fiber sensors in electric vehicles. Thanks to sensors based on optical fibers, electric current transmitted, for example, from the batteries to a particular component in an electric vehicle can be precisely measured. By combining the activity on two markets - automobile and photonics - technological and economic advantage can be achieved in Poland. Apart from the economic benefits, optical fiber technology is distinguished for its ecological advantages.

First of all, the development of semiconductor light sources, with high efficiency allows electricity consumption to be reduced. This is particularly important in automotive and telecommunications applications. Moreover, in electric vehicles, this also allows the battery charging frequency to be reduced.

It is also worth noting that the majority of optical fiber is made of silica glass, which is a natural and non-toxic material. Furthermore, light propagation in an optical fiber is not accompanied by an electromagnetic field which in some cases has a detrimental effect on human and animal health.

Using Polish optical fibers in intelligent electric vehicles which self-monitor all processes and the wear and tear of parts will lead not only to more efficient use of the car but will also make it safer for passengers and other road users. Implementation of such a strategic horizontal project will help us to create highly innovative advanced technologies of Industry 4.0.



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Intelligent **power systems**

PHOTONIC SOLUTIONS ARE VERY ADVANCED TECHNOLOGICALLY, AND OPTICAL FIBER SENSORS, AND OPTICAL FIBER SYSTEMS IN PARTICULAR, ARE SUITABLE FOR SMART ELECTRICAL POWER DISTRIBUTION SYSTEMS.

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Modernizing the energy sector is absolutely crucial for ensuring energy security as well as a competitive and efficient economy in Poland. With this in mind, new technological solutions for modernizing power systems must be developed. In particular, transmission and distribution grids are key factors for the smooth operation of power systems. This involves introducing smart interconnected grids and carrying on working on the implementation of nuclear energy.

Photonic solutions are very advanced technologically, and optical fiber sensors, and optical fiber systems in particular, are suitable for smart electrical power distribution systems. An excellent example of such an application is the placement optical fibers inside transmission cables in high voltage networks. This type of optical fiber sensor takes many measurements and determines the actual current and electric energy exploitation.

When transmission optical fibers are inserted into electric cables, they are able to deliver high-speed Internet together with electricity. Moreover measuring the temperature around an optical fiber inside an electric wire enables the measurement of local changes in the resistance of the transmission cables and can send information about any possible defect. Such solutions will make it possible to **monitor a transmission network continuously, and gather information about changes in transmission and electricity demand in its individual sections as well as making it easier to locate spots with increased risk of failure.**

Optical fiber sensors applied in the energy sector result in intelligent transmission systems which can **make rapid decisions about the choice of production priorities in electric power plants.** This considerably enhances their productivity and at the same **time reduces production costs.** Moreover, the application of optical fibers leads to an acceleration in the process of setting up companies and institutions with highly qualified staff to deal with implementing optical fiber technology into the market.

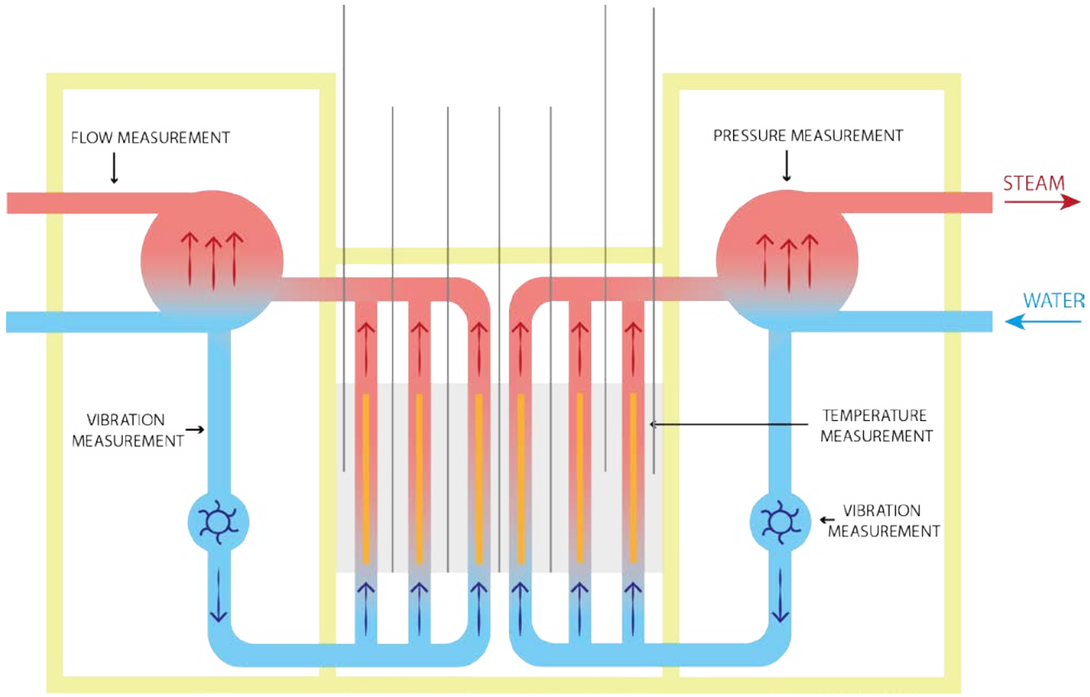
Due to their insensitivity to electromagnetic interference optical fiber sensors are an ideal solution for monitoring the condition of electrical switchgears, and transformers in particular. Optical fiber sensors, thanks to their small dimensions and lack of need for electricity, can be placed inside transformers with no risk of their damaging or interfering with the electric pole.

Optical fibers may also be used in nuclear technologies, like for example **high-temperature optical fiber sensors implemented in nuclear power plants. They measure gases and steam flows at temperatures of 500C or even 1000C in a radioactive radiation environment. Because of their high resistance to extreme conditions and the fact that they do not arc, optical fiber sensors may be placed in the direct vicinity of atomic reactors,** for example, in order to monitor fuel rod cooling systems, the distribution of temperature in the same fuel rods, or to control robots working close to the reactor and so on.

The development of optical fiber technologies will play **a crucial role in the growth of a modern and innovative economy, in particular in the energy sector.**

Their great market potential regarding intelligent solutions for energy transmission networks will provoke the industry to launch products and services that will satisfy market demand while at the same time increasing employment for qualified specialists.

OPTICAL FIBERS MAY ALSO BE USED IN NUCLEAR TECHNOLOGIES, LIKE FOR EXAMPLE HIGH-TEMPERATURE OPTICAL FIBER SENSORS IMPLEMENTED IN NUCLEAR POWER PLANTS.



Scheme of the nuclear reactor construction with optical fiber sensors. By www.PCFS.org.pl

Intelligent **pipeline systems**

> ***OPTICAL FIBER AND PHOTONICS SOLUTIONS WITH THEIR HIGH TECHNOLOGICAL POTENTIAL GIVE BIRTH TO A WHOLE RANGE OF SOLUTIONS WHICH IF JOINED TOGETHER FORM INTELLIGENT PIPELINES.***

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Modern industry is based on innovation, which should include all its key aspects. New breakthrough products and technologies, such as Polish optical fiber applications, allow on the one hand the digitization and advanced automation of production, and on the other hand smart chains linking producers, suppliers and consumers.

In those chains transportation systems play a vital role, which if constantly improved **will form intelligent transportation networks, which subsequently will contribute to the creation of an efficient, flexible and competitive Industry 4.0.**

Creating intelligent transportations networks is not possible without help from the newest, innovative photonics solutions. Only through the extensive integration of new and existing infrastructure chains with the most modern technologies can we find solutions unprecedented on a world scale.

One of the key technologies which will allow steps beyond the current technical limitations and offer innovative solutions for the transport sector is **optical fiber photonics. Intelligent raw material transportation systems** could be such an example. Optical fiber and photonics solutions with their high technological potential give birth to a whole range of solutions which if joined together form intelligent pipelines. Optical fibers fixed to pipelines permit stress measurement and leak detection, which in turn will **prevent potential cracks and the consequent loss of the valuable raw material, and eliminate the risk of ignition or explosion.**

Optical fiber technologies are also the basis for the creation of low-energy-intensive and spark-free optical sensors, which if applied in the expansion joints of pipelines will provide for **the continuous monitoring of their technical state without the need for excavation in the most sensitive spots. This also protects the natural environment and increases safety.**

Moreover, sensors can be arranged very densely along an optical fiber, as they are small. They can take measurements without electric power which allows the optical fibers to be placed inside the pipeline in order to measure vibration, local variations in pressure, temperature and the precise flow rate, and the total quantity the substance transmitted.

Such a solution not only **protects a pipeline from harm** (e.g. as a result of careless handiwork), but also from the theft of raw materials, and the threat of breakdown, accident or explosion.

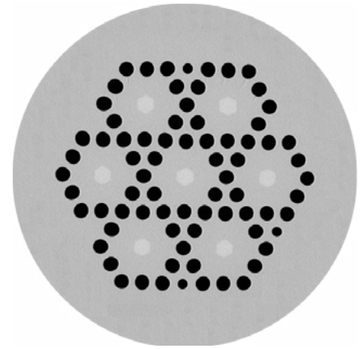
Polish optical fibers are the technology which allows the introduction of significant innovation in the extraction and transportation of natural resources, a traditional branch of industry that is also important for the Polish economy.

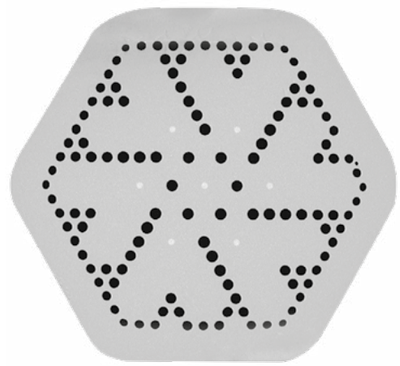
At the same time it engages other industries in the creation of new solutions, which in turn guarantees the creation of new jobs. The development of optical fiber sensors requires a symbiotic relationship between companies involved in optics, electronics, and IT as well as chemical technologies, robotics, mechanics, etc.

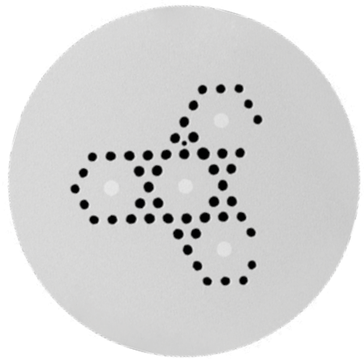
The solutions offered **will bring a new level quality, raising the technological standard of the products** and will allow them to compete on the global market. Integration of the technical infrastructure in the fossil fuels market by introducing switching systems for the transportation and storage of raw materials with sensors based both on photonic and ICT elements will contribute to the creation of new models of industrial management. This will provide for more efficient control over the movement of resources, and energy consumption in industry, which **will have a positive impact on the natural environment.**

The phenomenon of technical convergence requires coherent development planning, and **photonics, and especially optical fiber sensors, allow the development of new models of sensor networks.** These networks enable smart metering and transportation system management, such as for pipelines.

The strategic horizontal project of intelligent pipeline systems in which Polish optical fiber sensor systems are used is strictly in line with the program of technical infrastructure development for Industry 4.0, as well as with the global megatrend bound to the Internet of Things.







Intelligent systems for monitoring **mines**

A GOOD EXAMPLE OF INTELLIGENT REINDUSTRIALIZATION IS THE PHOTONIC OPTICAL FIBER SYSTEM FOR MONITORING MINES, WHICH COMPREHENSIVELY ANALYZES PARTICULAR SECTIONS OF A MINE.

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A good example of intelligent reindustrialization is the photonic optical fiber system for monitoring mines, which comprehensively analyzes particular sections of a mine. As photonics is a dynamically growing technology it is possible to make optical fiber sensors which due to their characteristics function smoothly in extreme conditions, such as in mines. Photonics is a technology that is boosting new mining industry sectors, which involves scientists and highly qualified staff who will create groundbreaking products stimulating other areas of the economy.

This also means the **development of traditional industries, which through the implementation of cutting-edge research and production technology, such as Polish Optical Fibers, will move them to a higher level in the value chain and will make Economy 4.0. a reality.**

This approach towards the intelligent industrialization of the mining sector will guarantee an increase in profitability, which in turn will have a positive impact on the economy of the whole country. Optical fiber technology paves the way for the use of optical sensors in mines, places where so far safety monitoring has not been possible because of the risk of ignition or explosion when using electronic measuring equipment.

Optical fibers sensors can be used for automatically measuring the temperature distribution in the corridors walls, stresses in the structural beams or monitoring the concentration ofgases, and controlling the operation of mining machines, etc.

Sensors arranged in mines, when connected to a common system of acquisition, processing, and analysis of data can provide the information necessary **to identify potential threats** and withdraw people from the dangerous area. Moreover, the signal conveyed by an optical fiber in a mine may play the role of **an early warning system.**

Appropriate optical fiber solutions immediately provide information about the danger in an affected area. Optical fiber solutions can also add value in terms of the production of equipment and machines for applications in the mines.

Optical fiber optic sensors may be applied as elements of intelligent machine condition monitoring systems. Due to their small size and high measurement accuracy they are able to provide information on the current state of given components.

It is possible to collect information about the vibrations of a subunit, its temperature, the stress affecting it, and so on. The appropriate analysis and the interpretation of these data facilitate a **prompt reaction, ensuring a minimization of losses resulting from equipment downtime.** Optical fiber technologies also contribute vastly to the economical use of energy in mines.

Optical fibers put along electric wires in a mine allow their temperature to be measured continuously, which if analyzed adequately enables us to determine the energy consumption in particular sections, and identify unnecessary transmission interferences or cable damage.

This considerably reduces the time spent on the analysis of the technical condition of many kilometers of cable, and enables the **creation of intelligent power supply plans**, aimed at optimizing the power consumption.

In addition, the latest solutions make it possible to transmit electricity overlong distances using optical fibers, which allows us **to build power supply systems in explosive and flammable environments**, where up till now such a power supply could not be used or was extremely expensive due to the possibility of rise in temperature or sparking.

If innovative photonic solutions are applied in mines, it will increase profitability by optimizing production efficiency as well as increasing work safety.

Optical fiber sensors for **medical applications**

ONE OF THE MAIN POTENTIAL APPLICATIONS FOR OPTICAL FIBER SENSORS IN MEDICINE IS DIAGNOSING CANCER.

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Contemporary medicine provides treatment for many diseases which has lengthened life expectancy and improved the standard of living in developed countries. However in many cases, the use of the most recent treatment methods is most effective in the early stages of the disease. Therefore the diagnostic tests that allow early treatment are extremely important. The very process of diagnosis is not an obvious thing and requires highly specialized and expensive equipment as well as staff who are experienced in interpreting test results.

In addition, the time needed for testing is often quite long, resulting in a deterioration of the patient's health while waiting for the diagnosis. An alternative to the existing diagnostic methods is the use of **optical fiber sensors and this has a number of advantages over traditional measurement methods.**

Sensors can measure minimal changes in various parameters and they may be used to detect trace amounts of identified substances. Moreover, **optical fibers are very small** - their diameter is comparable to the diameter of a human hair. **This means that very precise and minimally invasive examinations can be conducted**, whereas in conventional methods a complicated procedure must be performed in order to obtain test material.

One of the main potential **applications for optical fiber sensors in medicine is diagnosing cancer.** It is difficult to carry out this test in the early stages of the disease because cancer cells resemble the healthy ones. In general, in order to recognize neoplastic changes a biopsy is performed. The tissue is cut out and analyzed under a microscope, and because of the presence of specific substances in the vicinity of the tumor cells cancer is diagnosed. This technique is very inefficient, because interpreting the results is subjective.

The test performed with an optical fiber probe has several advantages over biopsy. First of all, the whole process of analysis can be completed in a single operation, during which doctors will find out whether or not the endangered tissue should be removed. In the case of a biopsy the analysis usually takes several weeks. This means that **the use of optical fiber probes will allow doctors to diagnose and operate on more patients faster and cheaper.**

Optical fiber probes can also be successfully used in medicine in the early detection of pathological conditions of the joints. When people are diagnosed at an early stage of the disease, they are less likely to suffer limited mobility or inability to work, so this method is of interest to many people. Late diagnosis has a negative impact on the economy, because those persons are prematurely excluded from the labor market. **The use of optical fiber probes could replace the expensive and not always effective methods of X-ray and ultrasound.**

Its small dimensions would allow the probe to be introduced precisely into the joint without the need for surgery, and the results would be more reliable, because they could also contain data on the chemical composition of fluids. This is not possible with the most commonly used methods which are also quite expensive. **Optical fiber sensors are much cheaper**, and therefore accessible for the majority of healthcare centers, which ultimately would result in the broader availability of this type of medical test for society.

The above-mentioned examples do not exhaust the possible applications of optical fiber sensors in medical diagnostics. If funds were gradually invested in this field new applications for this type of sensor could be developed. It is worth noting that unlike the use of optical fiber in telecommunications, its application in medicine is still a novelty.

The centers which are active in this area right now have a good chance of getting patents on key solutions, whilst becoming the leaders in this field. This is likely to assure them extensive growth and prosperity for many years. Companies and institutions which do not participate in this process will not have a chance to catch up with the leading centers in the future.

A similar situation is currently visible in the microprocessor industry and with other integrated circuits manufacturing. The development of the field of medical optical fiber sensors will enhance closer cooperation among various sectors of the economy, and further research on advanced devices for medicine and industry, which will also have a positive impact on the development of other sectors. Healthcare and diagnostics is one of the fundamental priorities of most developed countries.

THE DEVELOPMENT OF THE FIELD OF MEDICAL OPTICAL FIBER SENSORS WILL ENHANCE CLOSER COOPERATION AMONG VARIOUS SECTORS OF THE ECONOMY, AND FURTHER RESEARCH ON ADVANCED DEVICES FOR MEDICINE AND INDUSTRY, WHICH WILL ALSO HAVE A POSITIVE IMPACT ON THE DEVELOPMENT OF OTHER SECTORS.

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INNOVATIVE
LIGHT SOURCES

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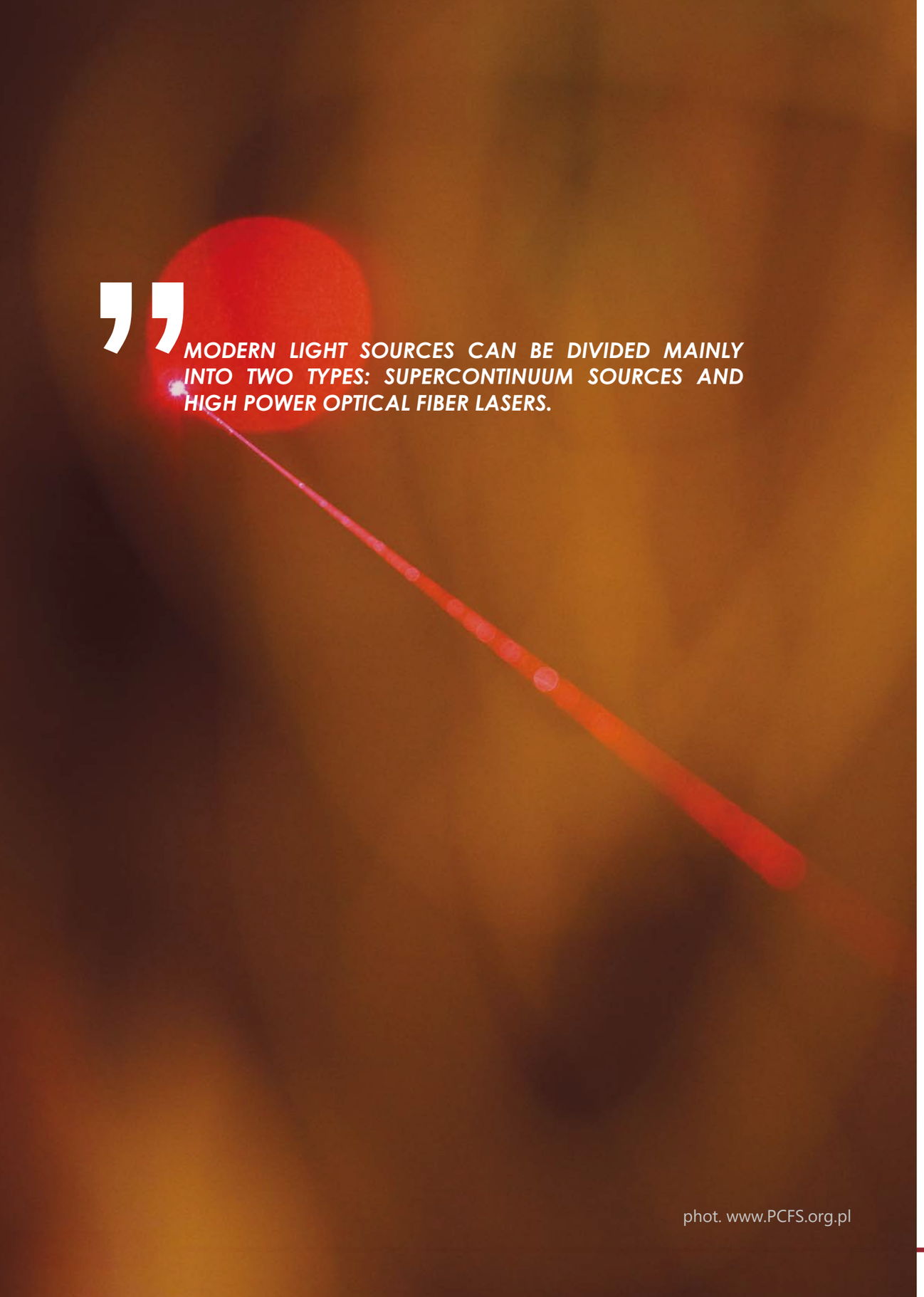

MODERN LIGHT SOURCES CAN BE DIVIDED MAINLY INTO TWO TYPES: SUPERCONTINUUM SOURCES AND HIGH POWER OPTICAL FIBER LASERS.

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INNOVATIVE **LIGHT SOURCES**

Another important area in which optical fiber solutions are used more and more often is the innovative light sources sector.

Modern light sources can be divided mainly into **two types: supercontinuum sources and high power optical fiber lasers**. The former enable the generation of light in a wide range of spectra, which has invaluable applications in various fields, such as **medical diagnostics, sorting of waste, chemical production and so on.**

Precise laser processing is an example of an application for high-power laser devices, for which there is currently growing demand. This is because they meet the high standards required regarding cutting various materials precisely, for example in the production of photovoltaic panels, circuit boards and other things which have become popular recently.

The fully optical fiber high power laser is a device with an extremely wide range of applications ranging from medicine, through cutting and welding materials, accurate distance measuring, **to use in combat** (e.g. shooting down drones). The laser based on Polish optical fibers is distinctive for its relatively **small size and weight**, and resistance to vibration and shocks, which ensures its exceptional mobility and allows its use without involving additional mechanical power.

The development of lasers based on special optical fibers is also very important because it **activates and stimulates progress in other industries** that are directly or indirectly related to the market of light sources. The directly related industries include companies producing laser components, and marking and cutting laser devices, as well as CNC machine manufacturers.

The development of laser light sources will also indirectly benefit sectors such as the photovoltaic industry, automotive and the packaging industry, which thanks to the use of modern optical fiber lasers will significantly improve their manufacturing processes as well as the quality of the components they produce, whilst reducing the amount of material loss. At the same time the use of optical fiber devices **will increase the energy efficiency of technological processes and diminish the level of pollution.**

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High power optical **fiber lasers**

THANKS TO THE STRENGTH OF THE INDIGENOUS POLISH OPTICAL FIBER TECHNOLOGY WE ALSO HAVE ENORMOUS POTENTIAL TO GAIN A COMPETITIVE ADVANTAGE IN THE FIELD OF LASERS. THE REPLACEMENT OF STANDARD OPTICAL FIBERS WITH POLISH MICROSTRUCTURED OPTICAL FIBERS PROVIDES UNPRECEDENTED OPPORTUNITIES.

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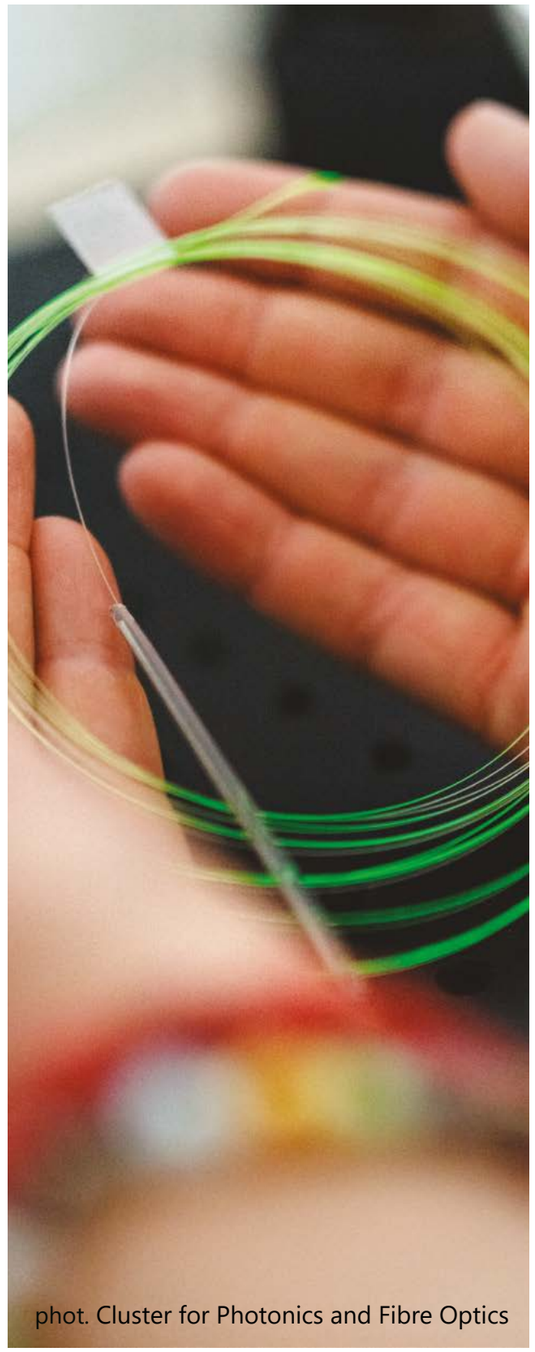
The revolution in laser technology has always related to the development of new materials and so it was with optical fiber lasers. Replacement of the materials used in solid state lasers with optical fibers opened a wide range of possibilities to manufacturers. Apart from achieving enormous optical power, **the construction of a laser exclusively with optical fiber technology** makes the laser insensitive to temperature fluctuations, humidity, vibration or extreme dust. This type of laser is specific for its smooth functioning and small size, which is crucial from the point of view of industrial applications. Optical fibers offer significant strengthening of power, very good thermo-optical parameters and excellent beam quality.

The use of lasers for materials processing carries a number of advantages, as noted and appreciated by the European Technology Platform „Photonics21," which found that application to be one of the priority developments in the European economy. **According to most experts the future of the global materials processing industry belongs to optical fiber laser technology.** The data on the laser materials processing market show a steadily growing trend: optical fiber lasers took a 4% market share in 2005, rising to 10% in 2008 and already at 23% in 2013.

Such intensive development of this field is possible thanks to the progress made in special optical fiber technology, as standard telecommunications optical fibers do not generate very high power. The various unique characteristics of high power optical fiber lasers are also suitable for other applications, for example in medicine – e.g. the construction of surgical instruments for fast and accurate tissue cutting; or in the military services industry – e.g. constructing laser weapons, for example for shooting down drones and missiles.

Thanks to the strength of the indigenous Polish optical fiber technology we also have enormous potential to gain a competitive advantage in the field of lasers. The replacement of standard optical fibers with Polish microstructured optical fibers provides unprecedented opportunities.



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Broadband **light sources**

ONE CANNOT UNDERESTIMATE THE ROLE OF SPECIALIZED WHITE LIGHT SOURCES, EMITTING RADIATION IN A BROAD SPECTRUM FROM ULTRAVIOLET THROUGH THE VISIBLE RANGE UP TO INFRARED. THEY ARE APPLIED IN MEDICINE, THE CHEMICAL INDUSTRY, FOOD PROCESSING, AUTOMATICS, BIOLOGY, WASTE STORAGE AND MANY OTHER AREAS.

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One cannot underestimate the role of specialized white light sources, emitting radiation in a broad spectrum from ultraviolet through the visible range up to infrared. They are applied in medicine, the chemical industry, food processing, automatics, biology, waste storage and many other areas.

Modern light sources which combine laser and Polish special optical fiber technology are the so-called "supercontinuum source type", and have great potential for practical applications in many sectors of the economy.

The supercontinuum type of optical fiber source is one of the most innovative breakthrough solutions in the field of photonics in the XX and XXI century. The source, made completely using optical fiber technology, offers miniature dimensions and is highly compact and mobile, which definitely raises its economic attractiveness. At the same time, these sources can work much more efficiently than conventional lighting systems (with negligible loss of energy). Because of its unique advantages, medical centers are currently primarily applying supercontinuum source type technology (tomography, microscopy, dermatology).

In rapidly developing economies, **the supercontinuum source type is increasingly used in interdisciplinary processes** on the crossroads of: precision mechanics, automatics and electronics, sensor technology, production quality control, and microscopy of ultra-high resolution.

Optical fiber technologies available in Poland would enable the production of such innovative supercontinuum type sources in Industry 4.0. At the moment, their exclusive producer is the Danish company NKT Photonics. The high innovation level of optical fiber white light sources gives an **extremely powerful impulse to the development of a wide range of industrial sectors.**

Cluster for Photonics and Fibre Optics

This brochure is a study made by scientists, specialists and enterpreneurs who are members of the Cluster for Photonics and Fibre Optics.

The Cluster for Photonics and Fibre Optics is a group of companies, scientific institutions and other organizations active in the same or related markets.

Our mission is to organize cooperation in the field of photonics, and in optical fiber technology in particular.

The enterprises that participate in the Cluster cooperate in areas where synergy may be attained from joint activities. These areas are:

- know-how diffusion and staff exchange within the Cluster
- increase in efficiency and production capability
- increase in absorption of innovation
- creating a favourable environment for the dynamic growth of new business players in the innovative area of photonics
- drawing in new members and resources
- executing joint projects

The basic condition for the synergy effect to appear is the readiness of all members of the Cluster for Photonics and Fibre Optics to cooperate. This readiness should be grounded on common trust, since membership in the group also means access to the common skills resources, training needs or marketing and R&D activities.

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Polish Centre for Photonics and Fibre Optics

PCFS Technology

ipt advanced

InPhoTECH INNOVATION PHOTONICS TECHNOLOGY

ipt applied

ipt fiber

ipt safety

ipt plus

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