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Laser Components
rofin
Toptica Photonics
TRUMPF
WHAT IS PHOTONICS?

Photonics is the generation, transmission, and utilization of light and other electromagnetic radiation. Photonics offers solutions to the global challenges of our time.

FUTURE

HEALTH
COMMUNICATION
INFORMATION
MOBILITY
ENERGY
SECURITY
CLIMATE
SUSTAINABILITY
Light can be focused on extremely small diameters.

- Outer sheath: 100 µm
- Core: 10 µm
- Pin human hair
- Optical fiber core diameter: 1,000 µm = 1 mm
- Paper clip wire: 1,000 µm
- Focus in laser cutting: 100 µm, 50 µm, 10 µm
- 1,000 µm = 1 mm

**BASICS**

**SMALLEST POINTS**
HIGHEST VELOCITY

Nothing is faster than light. The speed of light is 299,792,458 m/s.

- 1.5 m courier by foot
- 20 m carrier pigeon
- 250 m aircraft
- 10 km Apollo moon rocket
- 200,000 km optical fiber cable
- 300,000 km light in space

Distance Earth – Moon 384,400 km

5 times around the Earth in an optical fiber cable

How far does a message travel in one second?
Light makes even the fastest events measurable.

- **Second** ($1s$): Blink
- **Millisecond** ($1ms$): Athlete in action
- **Microsecond** ($1\mu s$): High-speed camera
- **Nanosecond** ($1ns$): Electric impulses in a computer
- **Picosecond** ($1ps$): Chemical processes such as the splitting of DNA
- **Femtosecond** ($1fs$): Processes inside an atom
- **Attosecond** ($1as$): Only measurable with light
With the pulsed operation of lasers, a power orders of magnitude greater than anything we have known so far can be achieved. This is made possible through the concentration of laser power to very short femtosecond pulses.

**COMPARISON OF POWER**

Worldwide power generated by electric power plants

2.6 terawatts = 2,600 gigawatts

around 400 times

Generated power of the Berkeley Lab Laser Accelerator

1 petawatt

= 1,000,000 gigawatts

laser pulse width:

40 femtoseconds

1 second

Peak powers are reached periodically for very short time intervals.
Dozens of data signals can be coupled into one single optical fiber and be separated again at the receiver’s end. The signals can be very finely distinguished based on their wavelength (spectral color), polarization, and phase.

Over 40 channels with data signals can be superposed in one fiber.

transmission rate:
100 gigabits per second
Light is the very small part of the electromagnetic spectrum visible to the human eye in the wavelength range of 380 to 780 nanometers.

**Spectral Sensitivity of the Eye at Daytime**

Range visible to humans: 380 to 780 nm

**Spectral Distribution of Sunlight on Earth**
Photonic applications use a broad portion of the electromagnetic spectrum that is predominantly not visible to humans.

**NUCLEAR TECHNOLOGY**

<table>
<thead>
<tr>
<th>PHOTONICS</th>
<th>GAMMA RADIATION</th>
<th>X-RAY</th>
<th>ULTRA-VIOLET</th>
<th>INFRA-RED</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMIC RADIATION</td>
<td>1 femtometer</td>
<td>1 picometer</td>
<td>1 nanometer</td>
<td>1 micrometer</td>
</tr>
<tr>
<td>high frequency frequencies</td>
<td>1 zettahertz</td>
<td>1 exahertz</td>
<td>1 petahertz</td>
<td></td>
</tr>
</tbody>
</table>

- **NUCLEAR TECHNOLOGY**
  - radiocarbon dating
  - material testing
  - X-ray machines
  - ultraviolet lamp

- **Visible Light**
  - full-body scanner
  - ultrasound

- **Heat**
  - lamp
  - heat lamp

- **Radiation**
  - cosmic radiation
  - gamma radiation
  - X-ray
  - ultraviolet
  - infrared

- **Wavelengths**
  - short wave
  - long wave
Photonic applications use a broad portion of the electromagnetic spectrum that is predominantly not visible to humans.

- 1 terahertz
- 1 gigahertz
- 1 zettahertz
- 1 exahertz
- 1 petahertz

- 1 picometer
- 1 nanometer
- 1 femtometer
- 1 micrometer

### Basics

#### Electronics

<table>
<thead>
<tr>
<th>TERAHERTZ</th>
<th>MICROWAVES</th>
<th>RADIO WAVES</th>
<th>ALTERNATING CURRENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 millimeter</td>
<td>1 meter</td>
<td>1 kilometer</td>
<td>1 megameter</td>
</tr>
<tr>
<td>1 terahertz</td>
<td>1 gigahertz</td>
<td>1 megahertz</td>
<td>1 kilohertz</td>
</tr>
</tbody>
</table>

- full-body scanner
- cell phone network
- identification system RFID
- power line
- television
- wireless LAN
- radar
- broadcasting

#### Nuclear Technology

- radiocarbon dating
- visible light
- X-ray machines
- full-body scanner
- lamp
- ultraviolet lamp
- material testing

#### Cosmics Radiation

- gamma radiation
- cosmic radiation
- x-ray ray
- ultraviolet ray
- visible ray

#### Heating

- lamp
- heat
- lamp
- visible light

#### Radio Frequency

- broadcasting frequencies
- high frequency
- low frequency
- wavelengths
- short wave
- long wave
Wavelength has a great influence on the performance of optical systems. Shorter wavelengths can produce smaller focus diameters making greater recording densities possible on optical storage media.

**WAVELENGTHS USED TO READ OPTICAL DISCS**

<table>
<thead>
<tr>
<th>CD</th>
<th>DVD</th>
<th>Blu-Ray Disc</th>
</tr>
</thead>
<tbody>
<tr>
<td>infrared</td>
<td>red</td>
<td>violet</td>
</tr>
<tr>
<td>780 nm</td>
<td>650 nm</td>
<td>405 nm</td>
</tr>
</tbody>
</table>

Increasing recording density
WINDOW GLASS vs OPTICAL FIBER

Glass is the most important component of optical systems. However, common window glass and glass used in photonics applications are worlds apart.

LIGHT TRANSMISSION OF GLASS

How thick can different glass types be so that 1% of the emitted light is still transmitted?

WINDOW GLASS

- glass thickness: 80 cm
- 1% of light

OPTICAL GLASS

- glass thickness: 29 m
- example: camera lens

OPTICAL FIBER

- glass thickness: 100 km (only valid for infrared light)
MIRRORS vs LASER MIRRORS

Many optical components can be found in their basic forms in the home. The components used in photonics, however, are characterized by the highest accuracy and technical finesse.

HOUSEHOLD MIRROR CONSTRUCTION

1 glass plate
2 back silver coating
3 protective layer

86% reflectance
Many optical components can be found in their basic forms in the home. The components used in photonics, however, are characterized by the highest accuracy and technical finesse.

### Household Mirror Construction
- Glass plate
- Back silver coating
- Protective layer

### Laser Mirror Construction
- Glass substrate
- 99.9% reflectance
- Layers of varying materials
- 99.9% reflectance

Usually, at least 20 to 50 layers of 100 to 200 nanometers thickness are applied on the front of a substrate. The result is an extremely high reflectance.

Laser mirror in kinematic mount
Lasers are the central component of many photonics applications. The numerous laser types always consist of the same basic elements although their shape strongly varies.

**Basic Elements**

- **Active medium = excited atoms or molecules**
- **Energy supply = pump**
  - Optical
  - Electrical
- **Resonator (end mirror or output coupler)**
- **Laser beam**

**Lasers**

- **Diode Laser**
- **Fiber Laser**
- **Disk Laser**
- **Gas Laser**
LASERS vs THE SUN

While conventional light sources emit their energy in all directions, lasers bundle the emitted light very efficiently into almost parallel light beams of small diameters.

PERFORMANCE COMPARISON

Sun

174 petawatts

Sun

Earth

button hole Ø1.5 mm

1

700 watts per m²
solar radiation intensity on the Earth (central European summer)

1.5 mm
beam diameter

5 milliwatts (max.)

5

laser pointer

PERFORMANCE BEHIND BUTTON HOLE
in milliwatts

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Modern technology requires efficient electronics in the smallest spaces. Thanks to optical technologies it is possible to organize increasingly smaller electronic components on semiconductor chips.

DEVELOPMENT OF SEMICONDUCTOR PRODUCTION PROCESSES

The image of increasingly smaller structures requires light sources with very short wavelengths.

OPTICAL BEAM PATH

Extreme ultraviolet (EUV) light, which is already in use and which has a wavelength of only 13.5 nanometers, requires the application of purely reflective optics with extremely accurate geometry.
PRECISE LASER DRILLING

Ultrashort pulse lasers drill differently sized, accurately shaped injection nozzles that distribute the fuel in the best way possible. Thanks to laser precision machining, up to 30% of fuel can be saved.

The lens focuses pulsed laser beams on a 10-micrometer diameter.

The heating of adjoining material is avoided by laser pulses shorter than 10 picoseconds.

Nightmarishly different sized injection nozzles optimally distribute the fuel.
LASER CUTTING

Laser cutting enables very quick processing of materials with a low loss of material, which makes this method extremely energy-efficient.

EFFICIENCY AND PERFORMANCE COMPARISON OF CONVENTIONAL MILLING AND LASER CUTTING

*cutting a 5-millimeter-thick steel plate for one meter*

<table>
<thead>
<tr>
<th>METHOD</th>
<th>CUTTING WIDTH (millimeters)</th>
<th>TOOL PERFORMANCE (kilowatts)</th>
<th>DURATION (seconds)</th>
<th>ENERGY CONSUMPTION (kilowatt hours)</th>
<th>WASTE (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONVENTIONAL MILLING</td>
<td>10</td>
<td>0.4</td>
<td>14</td>
<td>0.10</td>
<td>0.4</td>
</tr>
<tr>
<td>LASER</td>
<td>0.4</td>
<td>20</td>
<td>12</td>
<td>0.14</td>
<td>2.05</td>
</tr>
</tbody>
</table>

TOTAL ENERGY CONSUMPTION taking into account material savings (kilowatt hours): 390

PRODUCTION TECHNOLOGY
## Efficiency and Performance Comparison of Conventional Milling and Laser Cutting

<table>
<thead>
<tr>
<th>Cutting Method</th>
<th>Cutting Width (mm)</th>
<th>Tool Performance (kW)</th>
<th>Duration (s/m)</th>
<th>Energy Consumption (kWh)</th>
<th>Waste (g)</th>
<th>Total Energy Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Milling</td>
<td>5</td>
<td>0.07</td>
<td>14 minutes</td>
<td>2.05</td>
<td>390</td>
<td>0.14</td>
</tr>
<tr>
<td>Laser Cutting</td>
<td>5</td>
<td>0.10</td>
<td>12 seconds</td>
<td>0.07</td>
<td>15</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Laser cutting enables very quick processing of materials with a low loss of material, which makes this method extremely energy-efficient.

### Production Technology

16
SMARTPHONES THANKS TO THE LASER

Hundreds of thousands of smartphones are manufactured daily. Quality and efficiency of production are of crucial importance to the manufacturers in this competitive market. Lasers are the key to success here.

**LASER TYPES**
- fiber laser
- UV solid-state laser
- solid-state laser
- CO₂ laser
- ultrashort pulse laser
- UV excimer laser
- IR diode laser

**MACHINE PROCESS**
- edge
- area
- pattern
- holes

**Housing**
- cutting of housing
- marking logo and serial number

**Circuit board**
- structuring of conductor tracks
- cutting of foil circuit boards
- drilling of contact holes

**Battery**
- welding of battery case
- marking logo, data-matrix-code, and serial number

**Screen**
- cutting of extremely thin, hard cover glass
- cutting of touchscreen foil
- structuring of conducting layers

**Touchscreen**
- generation of polycrystalline layers
- encapsulation of laminated glasses

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3D PRINTING

Based on a computer drawing, complex structures can be produced from plastics, ceramics, and metals with the help of selective laser melting. Dentures and implants are among the rapidly growing number of applications.

GENERAL OPERATING PRINCIPLE

The digital model of an object is transformed into a model made of a series of thin layers.

1. A layer of powder is applied.
2. The application, melting, and lowering repeats itself until the object is finished.
3. The powder melts in the component's cross section according to the specifications of the layer model.
4. At the end, the material that has not melted will be removed. The actual object is all that is left.
DATA TRANSFER
OPTICAL FIBER NETWORKS

In 1988, the first transatlantic optical fiber cable, the TAT-8, went into operation. Optical fiber quickly replaced copper cables to meet the fast-growing need for greater capacity. Today, submarine cables with capacities of up to several terabytes per second connect the whole Earth.

Optical fibers offer substantially higher transmission rates, while simultaneously providing large ranges. Other advantages are lighter cables, lower space requirements, and fewer repeaters. The operation and maintenance costs are also significantly reduced.

Data cable in city area

<table>
<thead>
<tr>
<th></th>
<th>transfer speed</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in Mbit/s</td>
<td>in km, without repeater</td>
</tr>
<tr>
<td>optical fiber cable</td>
<td>1000</td>
<td>100</td>
</tr>
<tr>
<td>10 µm (0.01 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cladding</td>
<td>0.6 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>transfer speed</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in Mbit/s</td>
<td>in km, without repeater</td>
</tr>
<tr>
<td>copper cable</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>1.1 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cladding</td>
<td>6.9 mm</td>
<td></td>
</tr>
</tbody>
</table>
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**DATA TRANSFER**

<table>
<thead>
<tr>
<th>shelf life (in years)</th>
<th>weight (100 m cable in kg)</th>
<th>energy consumption (in watts per user)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.6</td>
<td>2</td>
</tr>
</tbody>
</table>

In 1988, the first transatlantic optical fiber cable, the TAT-8, went into operation. Optical fiber quickly replaced copper cables to meet the fast-growing need for greater capacity. Today, submarine cables with capacities of up to several terabytes per second connect the whole Earth.
Free space optical communication between near-Earth and geostationary satellites enables the fast transfer of data to a ground station. Vital data during natural catastrophes or in emergencies at sea can be received almost in real time in this way.

ADVANTAGES OF THE LASER

- **LARGE DATA VOLUMES**
  - 1.8 gigabytes per second corresponds to around 500 songs per second

- **NO LIMIT** due to frequency allocations

- **LOWER ENERGY CONSUMPTION** expands shelf life

- **LESS MASS** saves costs

THE LASER AND OPTICS MEET THE HIGHEST REQUIREMENTS

- **SMALLEST TOLERANCE** for generating a bundled laser beam across largest distances

- **stable** despite great **TEMPERATURE DIFFERENCES**

- **survive strong VIBRATIONS** and **ACCELERATIONS** during rocket launches

- **over 15 years MAINTENANCE-FREE**

- **RESISTANT** against UV and gamma radiation in space
ADVANTAGES OF THE LASER

EARTH

NO LIMIT due to frequency allocations

LARGE DATA VOLUMES

1.8 gigabytes per second corresponds to around 500 songs per second

LESS MASS saves costs

LOWER ENERGY CONSUMPTION expands shelf life

SMALLEST TOLERANCE for generating a bundled laser beam across largest distances stable despite great TEMPERATURE DIFFERENCES

survive strong VIBRATIONS and ACCELERATIONS during rocket launches

over 15 years MAINTENANCE case FREE

RESISTANT against UV and gamma radiation in space

SATELLITE-LASER LINK

height: 36,000 km

GEOSTATIONARY SATELLITE

SATELLITE-LASER LINK

height: 700 km

NEAR-EARTH SATELLITE scans parts of the Earth’s surface

EARTH

RECEIVING STATION on Earth

DATA TRANSFER

20 LASER COMMUNICATION IN SPACE

Free space optical communication between near-Earth and geostationary satellites enables the fast transfer of data to a ground station. Vital data during natural catastrophes or in emergencies at sea can be received almost in real time in this way.
DATA TRANSFER

QR CODES

Cameras and optical sensors often work together with intelligent image or data processing. The QR code (Quick Response) shows this impressively.

USE OF QR CODES

QR codes are two-dimensional bar codes. A camera phone with the appropriate code reader software recognizes this information and decodes it.

QR code

scanning with a QR-code reader

decoding

access to website

SPECTARIS
QR-CODE STRUCTURE

Apart from the content, QR codes contain additional elements so that the software can recognize the data correctly.
This includes:

- positioning
- format information
- timing
- version information
- alignment

Up to 4,000 alphanumerical characters fit on a QR code.

ADVANTAGES OF QR CODES

In comparison to the classic barcode, QR codes can store more information on a smaller area and make fewer requirements of reading devices.

They also function even if they are partly damaged or corrupted:

- graphic/text in code
- distorted
- blurred
- twisted
IMAGE CAPTURE & DISPLAY
Today, brilliant images are possible with the smallest smartphone lenses. Why then is it still necessary to have large lenses in photography?

**SIZE COMPARISON**

(original sizes)

**SMARTPHONE LENS**

**SLR LENS**
Today, brilliant images are possible with the smallest smartphone lenses. Why then is it still necessary to have large lenses in photography?

**Size Comparison**

Despite their small size, smartphone lenses have sophisticated optics with complex lens arrangements.

**Lens Arrangement**

The most important consequence of the size difference is the different depths of field.

**Depth of Field**

- **Smartphone Lens**: Smartphones display all objects from near to far with the same sharpness.
- **SLR Lens**: The depth of field can be set selectively with large SLR lenses.
GESTURE CONTROL

Optical systems can capture and interpret hand movements contactlessly – this is ideal in sterile workplaces such as hospital operating rooms.

SURGICAL HAND-TRACKING SYSTEM
detailed view from below

Two infrared (IR) cameras capture the scene like two human eyes from slightly shifted perspectives.

A 3D camera, which is based on the propagation time of light, verifies the distance.

3D camera measures the distance
system captures finger positions
line laser marks interactive area
In contrast to early cathode ray tubes, flat screens save a great deal of energy per unit area. Impressive global production capacities meet the high demand for these displays.

**ELECTRICITY CONSUMPTION AT SAME DISPLAY SIZE**

<table>
<thead>
<tr>
<th>cathode ray tube</th>
<th>LCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>25%</td>
</tr>
</tbody>
</table>

**PRODUCTION OF FLAT SCREENS WITHIN ONE HOUR**

- 200,000 smartphone displays
- 2 football fields
LCD vs OLED

Today, LCD displays dominate the flatscreen market, but in smartphones, organic LEDs (OLEDs) are conquering an increasingly larger market share. OLED displays are thinner, more energy-efficient, and higher in contrast but more expensive to produce.

LCD DISPLAY STRUCTURE

Today’s most common type of display creates images by blocking off or letting through white light that LEDs create across the back of the display.
Today, LCD displays dominate the flatscreen market, but in smartphones, organic LEDs (OLEDs) are conquering an increasingly larger market share. OLED displays are thinner, more energy-efficient, and higher in contrast but more expensive to produce.

### OLED Display Structure
Organically luminous materials in OLED displays do not require a separate light source, which makes their construction depth much thinner.

**OLED – Organic Light Emitting Diode**

- **Cover glass**
- **Cathode**
- **Anode**
- **TFT** = thin-film transistors
- **Carrier material** (glass or plastic)
- **Organic layers**: Molecules are electrically excited to make them glow.

*These layers together are around 200 times thinner than a human hair.*
COUNTING BLOOD CELLS

Thousands of cells per second are counted and characterized in medical and biotechnical analytics with laser-based flow cytometry. This enables the fast and secure detection of blood anomalies.

Cells are being excited to make them glow.

**fluorescent light:**
The color-separated light provides information about a variety of cell characteristics.

**side scatter:**
measurement of the cell's granularity

**forward scatter:**
measurement of the cell's volume
Endoscopes enable doctors to examine body cavities and hollow organs, detect illnesses, and treat them with minimal invasion at the same time, if required. The tubes, which are only a few millimeters thick, transfer illumination in one direction and high-resolution images in real time in the other direction.
Individually adjusted varifocals help older people have good vision for all distances. A variety of criteria is included in the calculation for personalized and individual lens design. CNC machines are used to translate the calculated design into individual lenses with micrometer precision.

**INDIVIDUAL CRITERIA**

- spectacle adjustment
- shape of spectacle frame
- wearer's characteristics
- intended use (sports, office, daily life)
- eye and head movement
- face form angle
- corneal vertex distance
- pupillary distance
- pantoscopic tilt
- fitting height
- pupillary distance
- fitting height
- eye correction
- spherical: myopia or hyperopia
- cylindrical: degree of astigmatism
- prismatic: associated heterophoria
- axial: direction of lens fitting
Individually adjusted varifocals help older people have good vision for all distances. A variety of criteria is included in the calculation for personalized and individual lens design. CNC machines are used to translate the calculated design into individual lenses with micrometer precision.

**Computer-Calculated Lens Design**

The different colors indicate the varying refractive power of the lens: from red (strong) to blue (weak).

**Model of Varifocals**

- **Distance vision**: > 2 m
- **Medium vision**: 0.5 – 2 m
- **Near vision**: < 0.5 m

The different colors indicate the varying refractive power of the lens: from red (strong) to blue (weak).
SEEING CLEARLY AGAIN

From the age of 60 onwards, most people get a slight cataract – known as the grey star. Treating cataracts is the most common operation around the world. The WHO estimates that by 2020, 32 million cataract operations will be performed. The use of the femtosecond laser with ultra-short pulses allows a precise and careful operation.

ANATOMY OF THE HUMAN EYE

cornea
iris
pupil
lens
sclera
vitreous cavity
choroid
optic disc (blind spot)
optic nerve
retina
fovea centralis
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**SEQUENCE OF A LASER OPERATION**

1. opening the lens

2. segmenting the lens

3. opening the cornea

4. suctioning the lens

5. inserting and centering the artificial lens
White light is a mix of red, blue and green.

LED chips make colorful light. White light is created by luminescence conversion:

- LED chip
- Yellow phosphor layer
- Lens
- Housing includes heat dissipation

The suppression of the blue peak results in a warmer light.

**SPECTRUM OF A WHITE LED LAMP**

WAVELENGTH IN NANOMETERS

<table>
<thead>
<tr>
<th>WAVELENGTH</th>
<th>SPECTRAL INTENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td></td>
</tr>
<tr>
<td>700</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td></td>
</tr>
</tbody>
</table>

The suppression of the blue peak results in a warmer light.
Since the light bulb, the light output of different types of lamps has been significantly increased. Today, white LEDs are the most efficient ones.
LAMP SPECIFICATIONS

Just a few years ago, you could find out almost everything you needed to know about the light of a domestic lamp just by looking at the number of watts. Nowadays, nearly a dozen criteria have to be considered.

- **Power (watts)**: electrical connected load
- **Brightness (lumens)**: how bright the lamp's light is
- **Color temperature (K)**: the higher the color temperature, the colder (more blue) the light
- **Warm-up time**: the time it takes for the lamp to fully light up
- **Dimmability**: lamp dimmable or not
- **Shelf life**: usage in hours
- **Color rendering index**: accuracy of color rendering
- **Energy savings**: in comparison to the conventional light bulb
- **Mercury content**: environmentally friendly without mercury
- **Illumination angle**: the scope and range of effective light
LED lights can be switched on and off so quickly that it is imperceptible to the human eye. In this way, hundreds of megabytes per second can be transmitted to a mobile optical receiver as an additional function apart from the lighting – completely without electrosmog or additional cables.
LASER SHOWS

Laser shows are an impressive way of demonstrating how fascinating photonics can be.

BRILLIANT COLORS

Only lasers can make colors that are completely saturated.

GREEN ENTERTAINMENT TECHNOLOGY

The relatively low energy consumption ensures environmentally-friendly entertainment for large crowds.

ARTIFICIAL FOG

Fog makes the laser beam visible.
SINGLE BEAMS IN THE SKY
This is only possible with explicit authorization from the aviation safety authorities.

BRIGHT & HIGH CONTRAST
In comparison to a video, a laser image is focused at any distance.

LASER PROJECTOR
Two extremely fast-moving computer-controlled mirrors draw the laser image.

WATER CANVAS
Laser projections can be made on very large areas in any shape or form.

GREEN ENTERTAINMENT TECHNOLOGY
The relatively low energy consumption ensures environmentally-friendly entertainment for large crowds.

SINGLE BEAMS IN THE SKY
Lasers are used to project images onto objects or surfaces, creating stunning visuals that are both entertaining and informative. They are particularly well-suited for outdoor events, where they can be used to create large, engaging displays that can be seen from a distance.

BRIGHT & HIGH CONTRAST
In comparison to a video, a laser image is focused at any distance, making it easier to see from a distance. This is especially important for outdoor events, where the laser projections need to be visible to a large audience.

LASER PROJECTOR
Two extremely fast-moving computer-controlled mirrors draw the laser image. This allows for fast, smooth movements and creates a more dynamic and engaging display.

WATER CANVAS
Laser projections can be made on very large areas in any shape or form, allowing for creative and impressive displays. This is particularly useful for outdoor events, where the projections can be made on a variety of surfaces, such as water or large canvases.

GREEN ENTERTAINMENT TECHNOLOGY
Lasers are a low-energy alternative to other forms of entertainment, such as video displays. They are environmentally-friendly and can be used to create engaging displays for large crowds.
Measuring systems based on the roundtrip time of emitted and reflected infrared laser beams can calculate the speed of vehicles precisely. Cameras take pictures of the vehicle and driver if they have committed a traffic offence.

SPEED CAMERA COLUMN UNIT

- camera unit
- laser measuring unit

SPEED CAMERA COLUMN

- measuring area of laser
- area camera 1
- area camera 2
  - simultaneous measuring of cars in several lanes

maximum measuring distance: 75 m

infrared laser light:
- over 100 laser beams
- 100 times per second

laser measuring unit
Measuring systems based on the roundtrip time of emitted and reflected infrared laser beams can calculate the speed of vehicles precisely. Cameras take pictures of the vehicle and driver if they have committed a traffic offence.

Light impulses emitted from the speed camera column are reflected by the passing car and received again by the device.

infrared laser light:
over 100 laser beams
100 times per second

maximum measuring distance: 75 m
LIGHT ON AND IN THE CAR

Intelligent LED lights, camera-based assistance systems, and information displays ensure a greater security in all driving situations.

INTERIOR  EXTERIOR

- LED interior lighting (color temperature and brightness can be chosen)
- LED reading lights
- LED rear lights
- Dynamic LED indicator
- Rear-view mirror camera
- Interior light sensor
- Rear-view camera
- Adaptive LED headlights
- Dynamic LED indicator
- Front camera
- Driver information display
- Infotainment display
Intelligent LED lights, camera-based assistance systems, and information displays ensure a greater security in all driving situations.

- Rear-view mirror camera
- Camera for traffic sign recognition
- Rear-view camera
- LED rear lights
- Dynamic LED indicator
- Rain sensor
- Exterior light sensor
- LED indicator
- Head-up display
- Thermal imaging camera
- Front camera
- Adaptive LED headlights
- Dynamic LED indicator
- LED reading lights
- Interior light sensor
- LED interior lighting (color temperature and brightness can be chosen)
- Infotainment display
- Driver information display
- Head-up display
- Infotainment display
- Driver information display
- Front view
CAR HEADLIGHTS

Seeing further ahead: the combination of LED and laser light sources enables an optimum for roadway illumination in every traffic situation.

LIGHT CONE OF HEADLIGHTS

LED headlights
intelligent illumination to prevent glaring for oncoming traffic

LED high beams
large-scale illumination of the traffic situation

laser high beams
wide illumination for an optimal vision

LASER HIGH BEAMS

deflection mirror
beam combiner

color converter
3 blue laser diodes
parabolic mirror
The PAPI display signals the correct approach angle.

- too high (more than 3.5°)
- slightly too high (from 3.2°)
- correct approach angle (3°)
- slightly too low (from 2.8°)
- too low (more than 2.5°)

**PAPI** (Precision Approach Path Indicator)

**Airport Lighting**

Millions of new LED lamps lower the operation and maintenance costs of airports around the globe.

**LED vs Halogen**

- hours shelf life: 60,000 vs 2,500
- typical connected load per lamp (W): 18 vs 65
Solar cells can transform sunlight directly into electricity. An efficiency of around 45% has already been achieved under laboratory conditions. In commercial use, efficiency has to be weighed against acquisition costs.

**BASIC COMMERCIAL TYPES**

**Monocrystalline silicon cells**
are cut out from a round silicon crystal. The missing corners of the squares are characteristic. This form is created because the round cross section of the raw material is exploited in the best possible way.

**Polycrystalline silicon cells**
feature a characteristic texture that comes from crystal borders that are very close together.

**Thin-film cells**
consist of amorphous silicone or other material compounds. They can be vapor deposited onto carrier materials, even onto flexible material.
Solar cells can transform sunlight directly into electricity. An efficiency of around 45% has already been achieved under laboratory conditions. In commercial use, efficiency has to be weighed against acquisition costs.

Monocrystalline silicon cells are cut out from a round silicon crystal. The missing corners of the squares are characteristic. This form is created because the round cross section of the raw material is exploited in the best possible way.

Polycrystalline silicon cells feature a characteristic texture that comes from crystal borders that are very close together.

Thin-film cells consist of amorphous silicone or other material compounds. They can be vapor deposited onto carrier materials, even onto flexible material.

### GLOBAL MARKET SHARE

- Monocrystalline: 54%
- Polycrystalline: 36%
- Thin layer: 10%

### CHARACTERISTICS

- **Monocrystalline**
  - Efficiency: 20%
  - Acquistion costs: 16%

- **Polycrystalline**
  - Efficiency: 16%
  - Acquistion costs: 20%

- **Thin layer**
  - Amorphous silicon: 8%
  - Copper indium diselenide: 13%
Solar energy has the potential to satisfy the world’s raising appetite for electricity without polluting the environment. What total size of solar power plants would be needed to run the United States on solar electricity?

US electricity consumption per year: 4093 TWh (2014)

Area of solar cells needed to supply this energy:

12,800 km²

This roughly equals the land area of the US state of Connecticut.

TOP PRODUCERS
installed power 2014 per capita in watts

Germany: 475
Italy: 303
Belgium: 275
Solar energy has the potential to satisfy the world's raising appetite for electricity without polluting the environment. What total size of solar power plants would be needed to run the United States on solar electricity?

**World photovoltaic energy per year**

180 Terawatt hours  
= 180,000,000,000 kilowatt hours

**Nuclear energy**

The photovoltaic energy produced corresponds to the electricity volume of 20 nuclear power stations.

**Crude oil**

With regard to petroleum, the equivalent is 42 million tons. This amount corresponds to 140 oil tankers with a capacity of 300,000 GRT* each.

* gross register tons
ENVIRONMENT
OPTICAL MEASUREMENTS IN CITIZEN PROJECTS

Smartphones with attachable mini-spectrometers make it possible to map current environmental data of entire countries with the help of thousands of citizens.
FINE DUST PARTICLES get into the air from different sources.

CENTRAL DATA EVALUATION: evaluation concerning the amount, particle size, and composition.

MAPPED DATA THAT IS ACCURATE IN TIME AND LOCATION: example: the Netherlands Pollution.

Very strong — Very low.
FOREST FIRE SURVEILLANCE

Automated optical sensor systems monitor large forest areas day and night for fires.

EXAMPLE
surveillance of the Teltow-Fläming county, near Berlin, Germany

Coverage of an area of 310,000 ha
with 10 SYSTEMS
on fire watchtowers
Automated optical sensor systems monitor large forest areas day and night for fires. For example, the surveillance of the Teltow-Fläming county, near Berlin, Germany receives data and images if a fire is detected.

The optical sensor system registers smoke development automatically in the visible and infrared spectral range. The camera turns itself in stages on its own axis over 6 minutes. Coverage of an area with 310,000 ha is achieved by 10 systems on fire watchtowers of optics for nighttime operation and optics for daytime operation.

Camera angle of vision: 60° per minute.

15 km
92 km
55 km
Efficient sorting facilities are used to recover many materials in their raw form from heaps of domestic waste. Together with fast image processing software, multispectral cameras capture within a split second what should be placed in which raw material container.

SORTING POSSIBLE ACCORDING TO

- MATERIAL
- SHAPE
- COLOR

SCHEMATIC REPRESENTATION OF A WASTE-SORTING FACILITY

- multispectral camera
- conveyor belt width: 2 meters
- line lighting
- conveyor belt speed: 3 meters per second
Efficient sorting facilities are used to recover many materials in their raw form from heaps of domestic waste. Together with fast image processing software, multispectral cameras capture within a split second what should be placed in which raw material container.
Within a few decades, the term photonics has developed from a technical term, used in research, to an industry term that encompasses all technical applications of light.

From the 1960s:
- Photons are researched as an alternative to electrons for circuitry tasks. The term Photronics is coined in connection with this.
- Invention of the laser

Leading US industry magazine changes its name from Optical Spectra to Photonics Spectra
PHOTONICS AS AN INDUSTRY SECTOR

Within a few decades, the term photonics has developed from a technical term, used in research, to an industry term that encompasses all technical applications of light.

- In the context of the high-tech strategy for Germany, photonics replaces the term of “optical technologies” which had been used so far.
- European Commission defines photonics as key technology.
- Foundation of the European photonics community - Photonics21.
- Foundation of the American National Photonics Initiative to promote photonics in the US.
- Leading German industry magazine changes its name from LaserOpto to Photonik.
- Photonics21 Roadmap as strategy for European photonics in the years 2014-2020.
- Public Private Partnership between European Commission and European photonics industry.
Photonics is a global industry today. This graphic shows the strongest market segments in each region.

Global market share in the market segment (information in %)
To emphasize regional strengths, only market shares of more than 10% are shown.

Market segments:
- Production technology
- Image processing & metrology
- Security & defense technology
Photonics is a global industry today. This graphic shows the strongest market segments in each region.
Nobel laureates with a connection to photonics since the invention of the laser in 1960

NUMBER OF LAUREATES
by country at the time of the award ceremony

17

USA

Nobel laureates with a connection to photonics since the invention of the laser in 1960

RESEARCH & ECONOMY

Ernst Ruska (DE)
electron microscope

Nicolaas Bloembergen (US)
Arthur L. Schawlow (US)
laser spectroscopy

Charles H. Townes (US)
Nicolay G. Basov (SU)
Aleksandr M. Prokhorov (SU)
quantum electronics for the construction of the maser and laser

Alfred Kastler (FR)
optical pumping

Dennis Gabor (GB)
holography

1970
1975
1980
1985
1965
Charles H. Townes (US)
Nicolay G. Basov (SU)
Aleksandr M. Prokhorov (SU)
quantum electronics for the construction of the maser and laser

Alfred Kastler (FR)
optical pumping

Dennis Gabor (GB)
holography

Nicolaas Bloembergen (US)
Arthur L. Schawlow (US)
laser spectroscopy

Ernst Ruska (DE)
electron microscope

Charles Kuen Kao (GB)
communication via glass fibers

Steven Chu (US)
Claude Cohen-Tannoudji (FR)
William D. Phillips (US)
cooling and capturing of atoms with laser beams

Eric Betzig (US)
William E. Moerner (US)
Stefan W. Hell (DE)
super-resolved fluorescence microscopy

Isamu Akasaki (JP)
Hiroshi Amano (JP)
Shuji Nakamura (US)
blue LEDs

Serge Haroche (FR)
David J. Wineland (US)
quantum optics, laser cooling and frequency standards

Willard Boyle (US)
George Elwood Smith (US)
CCD Sensors

John Lewis Hall (US)
Theodor Hänsch (DE)
high-precision laser spectroscopy

Wolfgang Ketterle (US)
Carl E. Wieman (US)
Eric A. Cornell (US)
creation of a Bose-Einstein condensate with laser cooling

Zhores I. Alferov (RU)
Herbert Kroemer (US)
fundamental developments in laser diodes

Roy Jay Glauber (US)
quantum optics

Charles Kuen Kao (GB)
communication via glass fibers

Eric Betzig (US)
William E. Moerner (US)
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Roy Jay Glauber (US)
quantum optics
PHOTONICS COUNTRIES

The highest density of photonics professionals are found in Europe and East Asia.

Number of photonics professionals in relation to the total workforce of the country (a.u. USA = 100)

- > 500
- 401–500
- 301–400
- 201–300
- 101–200
- 51–100
- 10–50
- < 10 or insufficient data
Business-oriented social media reveal where photonics-savvy professionals got their education.
ECONOMIC IMPACT OF PHOTONICS

Data suggests that there were approximately 2.32 million jobs in photonics in 2015.


Photonics marketplace from components to enabled services

Market by country share of market in %

18 Japan
18 Korea
17 USA
16 Taiwan
15 Europe
12 China
4 other
PHOTONICS ENTHUSIAST

An enthusiasm for photonics can also be implemented in the leisure sector.
**SOURCES**

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<tr>
<td>01</td>
<td>spectaris.de</td>
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<td>02</td>
<td>Wikipedia</td>
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<td>03</td>
<td>Wikipedia</td>
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<tr>
<td>04</td>
<td>Wikipedia</td>
</tr>
<tr>
<td>05</td>
<td>lbl.gov • bp.com/statisticalreview (2014)</td>
</tr>
<tr>
<td>06</td>
<td>Wikipedia</td>
</tr>
<tr>
<td>07</td>
<td>Wikipedia</td>
</tr>
<tr>
<td>08</td>
<td>photonics.com • spectaris.de</td>
</tr>
<tr>
<td>09</td>
<td>blu-raydisc.com</td>
</tr>
<tr>
<td>10</td>
<td>schott.com</td>
</tr>
<tr>
<td>11</td>
<td>edmundoptics.com</td>
</tr>
<tr>
<td>12</td>
<td>trumpf-laser.com</td>
</tr>
<tr>
<td>13</td>
<td>spectaris.de</td>
</tr>
<tr>
<td>14</td>
<td>zeiss.de</td>
</tr>
<tr>
<td>15</td>
<td>bosch.de</td>
</tr>
<tr>
<td>16</td>
<td>trumpf-laser.com</td>
</tr>
<tr>
<td>17</td>
<td>trumpf.de • rofin.de • coherent.com</td>
</tr>
<tr>
<td>18</td>
<td>ilt.fraunhofer.de</td>
</tr>
<tr>
<td>19</td>
<td>glasfaser.net • itwissen.info • telos.com</td>
</tr>
<tr>
<td>20</td>
<td>esa.eu</td>
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<tr>
<td>21</td>
<td>explanthatstuff.com</td>
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<td>22</td>
<td>zeiss.de</td>
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<td>23</td>
<td>hhi.fraunhofer.de</td>
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<td>24</td>
<td>statista.com • Wikipedia</td>
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<td>25</td>
<td>howstuffworks.com</td>
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<td>URL</td>
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<td>26</td>
<td>flowcytometry.med.ualberta.ca/</td>
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<td>27</td>
<td>karlstorz.com</td>
</tr>
<tr>
<td>28</td>
<td>spectaris.de • zeiss.de • optikum.at</td>
</tr>
<tr>
<td>29</td>
<td>northtorontoeycare.com • techfak.uni-bielefeld.de</td>
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<td>30</td>
<td>osram.com</td>
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<td>osram.com</td>
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<td>osram.com</td>
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<td>33</td>
<td>hhi.fraunhofer.de</td>
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<td>34</td>
<td>lobo.de</td>
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<td>35</td>
<td>vitronic.com</td>
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<td>audi.com</td>
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<td>37</td>
<td>audi.com • bmw.com</td>
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<tr>
<td>38</td>
<td>frankfurt-airport.de • caeoxfordinteractive.com</td>
</tr>
<tr>
<td>39</td>
<td>solarbuzz.com</td>
</tr>
<tr>
<td>40</td>
<td>eia.gov • bp.com • spectaris.de</td>
</tr>
<tr>
<td>41</td>
<td>ispex.nl</td>
</tr>
<tr>
<td>42</td>
<td>fire-watch.de</td>
</tr>
<tr>
<td>43</td>
<td>lla.de</td>
</tr>
<tr>
<td>44</td>
<td>photonics21.org • spectaris.de</td>
</tr>
<tr>
<td>45</td>
<td>Spectaris, VDMA, ZVEI, BMBF: Photonics Industry Report 2013 • ieapvps.org</td>
</tr>
<tr>
<td>46</td>
<td>nobelprize.org</td>
</tr>
<tr>
<td>47</td>
<td>linkedin.com • spectaris.de</td>
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<td>48</td>
<td>linkedin.com • spectaris.de</td>
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<td>49</td>
<td>spie.org</td>
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<td>amazon.com • ebay.com</td>
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