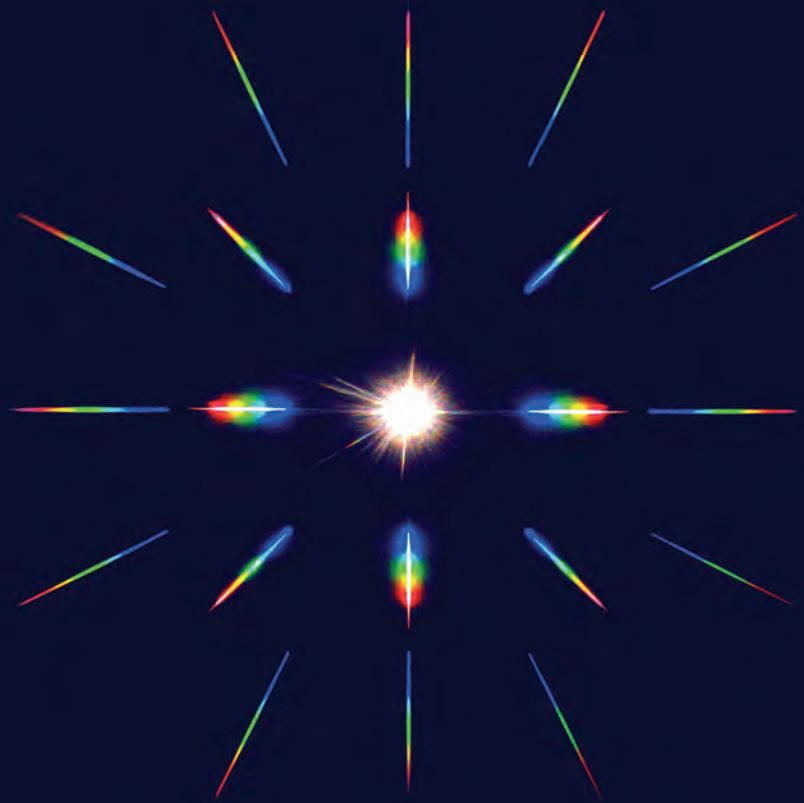
# PHOTONICS

Technical applications of light

**INFOGRAPHICS**



The field of photonics outlined in this book enables modern society and provides amazing opportunities for careers, which include options for technicians, engineers, scientists, and business people. **SPECTARIS** and **SPIE** hope this information will encourage the reader to pursue higher education and career opportunities working for the many thousands of companies and research organizations that we represent.

For more information about photonics and ideas about jobs in this field, please visit:

*www.spectaris.de | www.spie.org*

A very warm thank you to all the companies and institutes that made this publication possible:

## GOLD

ZEISS

TOPTICA

PHOTONICS NTN INNOVATION BOOSTER

SWISSMEM Photonics

LASER COMPONENTS®

## SILVER

JENOPTIK MORE LIGHT

LASER World of PHOTONICS

FH GR Fachhochschule Graubünden University of Applied Sciences

## BRONCE

Fraunhofer ILT

TRUMPF

NYNOMIC THE PHOTONICS GROUP

ASML

HAMAMATSU PHOTON IS OUR BUSINESS

# PHOTONICS

Technical applications of light

**INFOGRAPHICS**

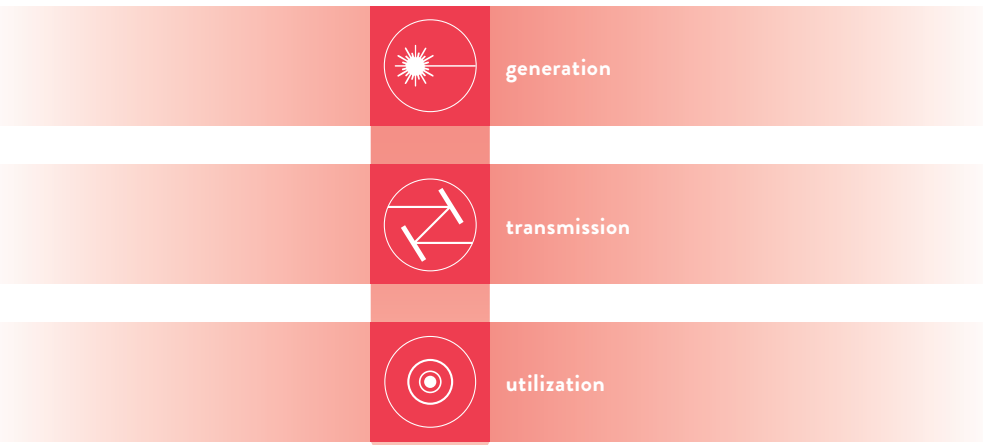
# CONTENTS

# BASICS

01

# WHAT IS PHOTONICS?

Photonics is the generation, transmission and utilization of light.
The smallest unit of light is the photon.
Photonics provides solutions to global challenges of our time.

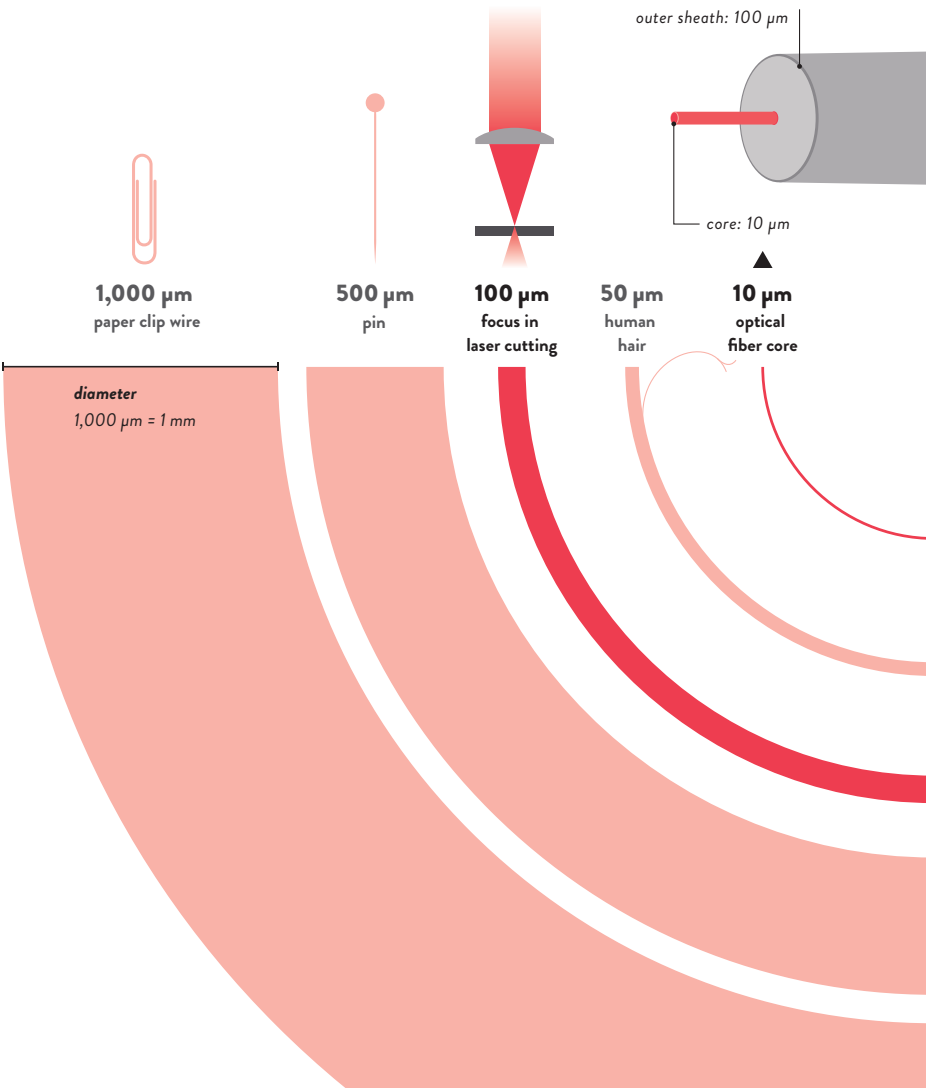



FUTURE POTENTIAL
HEALTH
COMMUNICATION
INFORMATION
MOBILITY
ENERGY
SECURITY
CLIMATE
SUSTAINABILITY

02

# SMALLEST POINTS

Light can be focused on extremely small diameters.



03

# HIGHEST VELOCITY

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

Moon

**1.5 m**
courier by foot

**20 m**
carrier pigeon

**250 m**
aircraft

**10 km**
Apollo moon rocket

**How far does a message travel in one second?**

*5 times around the Earth in an optical fiber cable*

**200,000 km**
optical fiber cable

*distance Earth – Moon 384,400 km*

Earth

**300,000 km**
light in space

04

# SHORTEST TIMES

Light makes even the fastest events measurable.

**second**
1 s

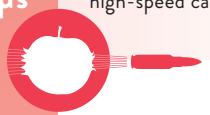
**1 s** blink

**millisecond**
= 0.001 s

**1 ms** athlete in action

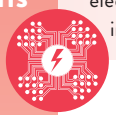
**microsecond**
= 0.000,001 s

**1 µs** high-speed camera



**nanosecond**
= 0.000,000,001 s

**1 ns** electric impulses in a computer



only measurable with light

**picosecond**
= 0.000,000,000,001 s

**1 ps** chemical processes such as the splitting of DNA

**femtosecond**
= 0.000,000,000,000,001 s

**1 fs** processes inside an atom

**attosecond**
= 0.000,000,000,000,000,001 s

**1 as** ← **5 as** fastest laser pulses

05

# HIGHEST POWER

With the pulsed operation of lasers, a power orders of magnitude greater than anything we have known before can be achieved. This is made possible through the concentration of laser power to very short femtosecond pulses.

## COMPARISON OF POWER

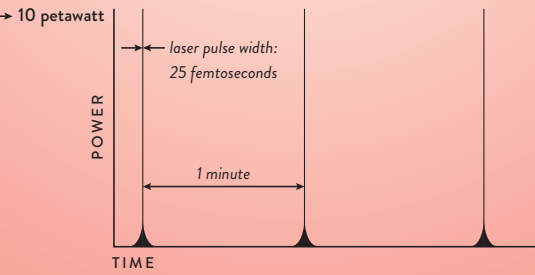
**Worldwide power generated by electric power plants**

3,3 terawatts = 3,300 gigawatts

around 3,000 times

**Generated Power at the ELI-NP Extreme Light Infrastructure – Nuclear Physics in Romania**

**10 petawatt**
**= 10,000,000 gigawatts**

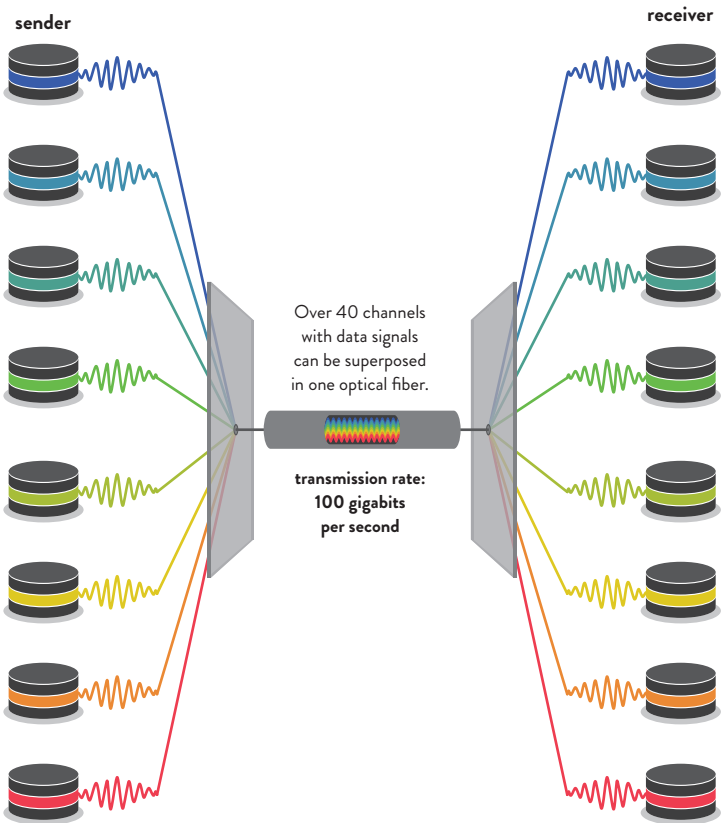



*Peak powers are reached periodically for very short time intervals.*

06

# UNDISTURBED SUPER-POSITION

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.

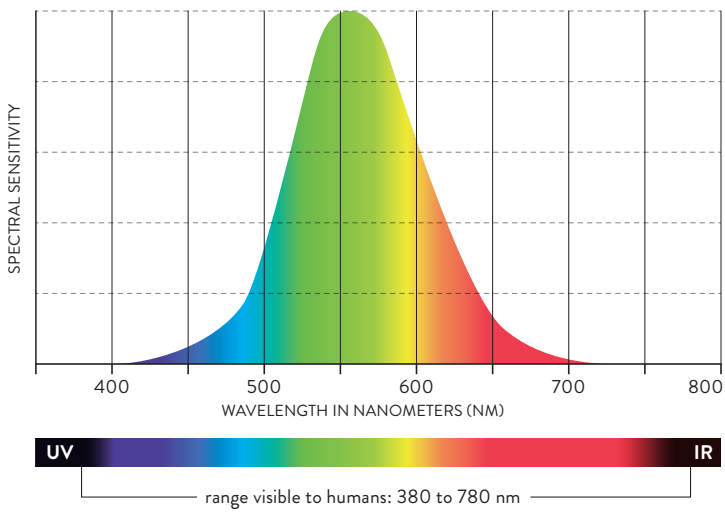


07

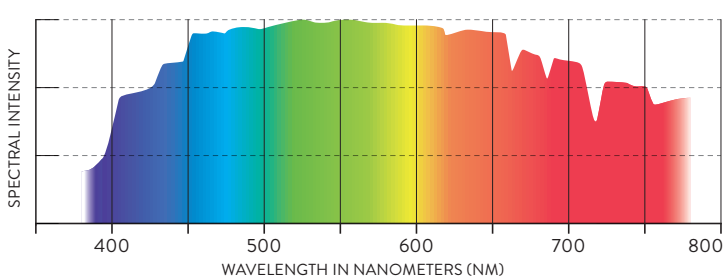
# LIGHT SPECTRUM

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



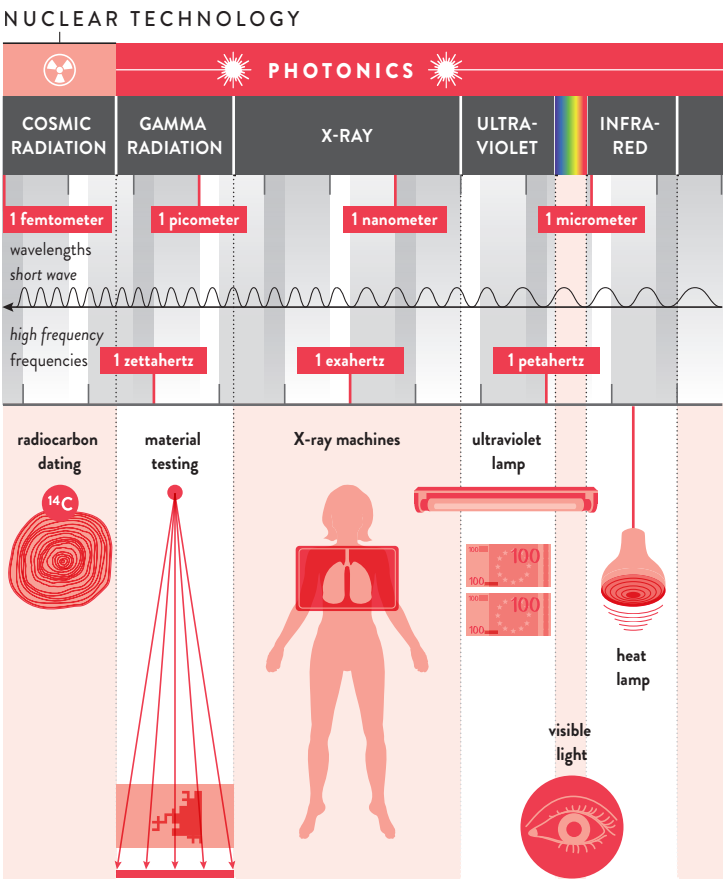

## SPECTRAL DISTRIBUTION OF SUNLIGHT ON EARTH

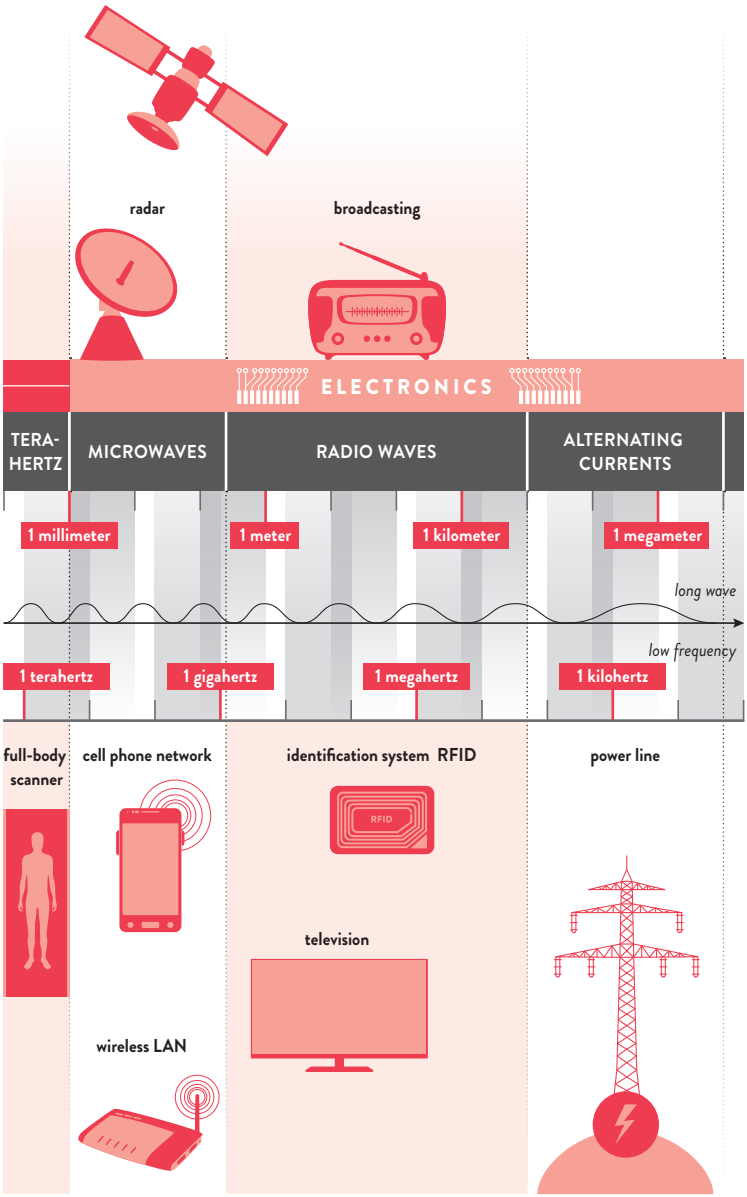


08

# HIDDEN REALM OF PHOTONICS

Photonic applications use a broad portion of the electromagnetic spectrum that is predominantly not visible to humans.



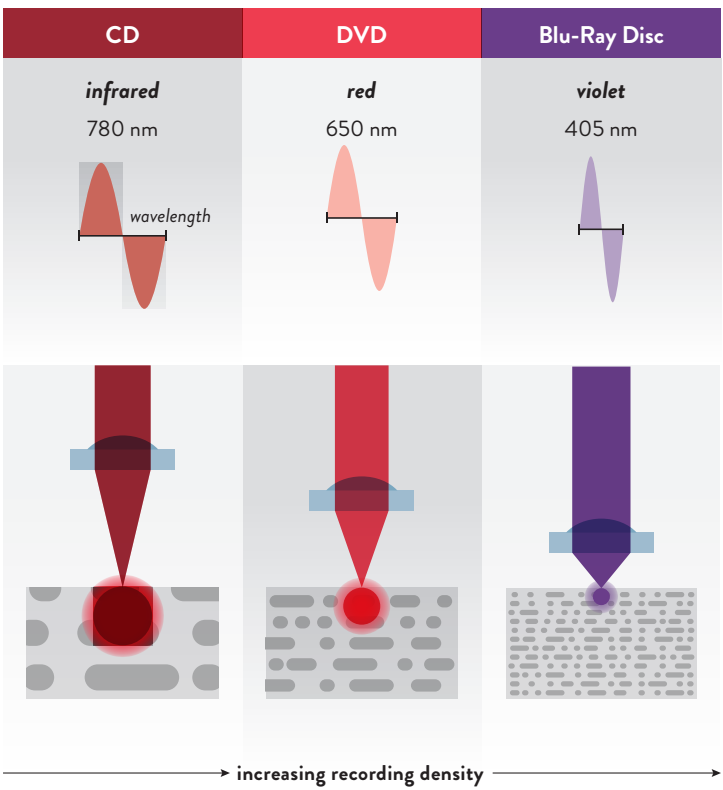

radar
broadcasting
ELECTRONICS
TERA-HERTZ
MICROWAVES
RADIO WAVES
ALTERNATING CURRENTS
1 millimeter
1 meter
1 kilometer
1 megameter
long wave
low frequency
1 terahertz
1 gigahertz
1 megahertz
1 kilohertz
full-body scanner
cell phone network
identification system RFID
RFID
power line
television
wireless LAN

09

# SHORTER WAVELENGTHS

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



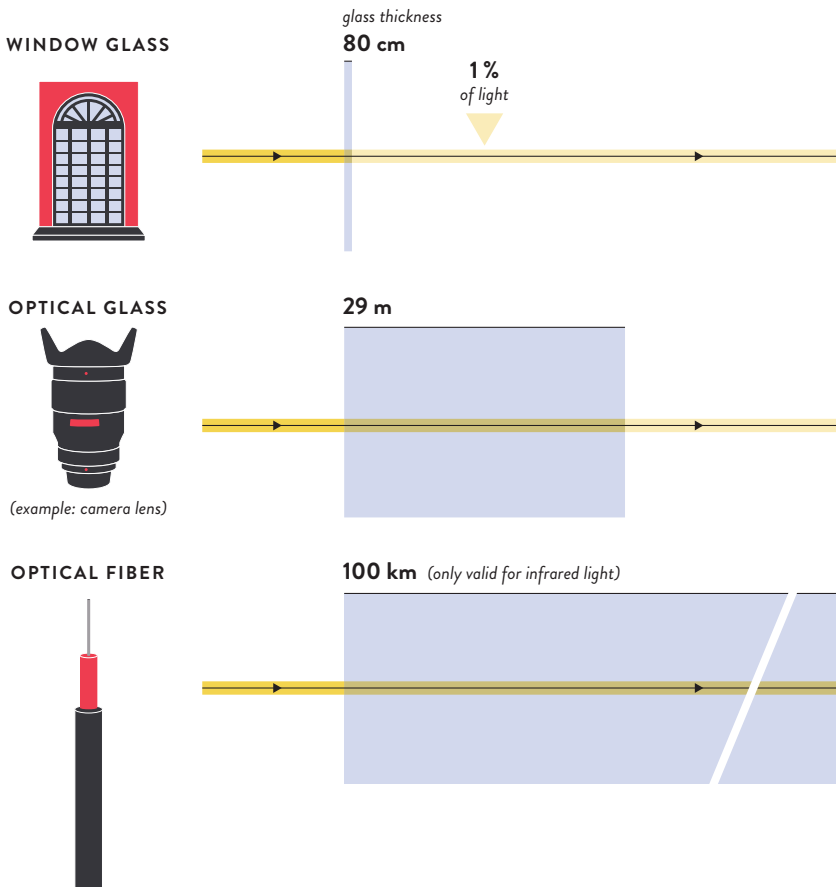
10

# 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?

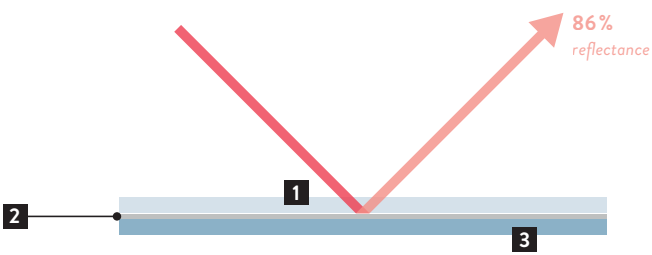


11

# 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

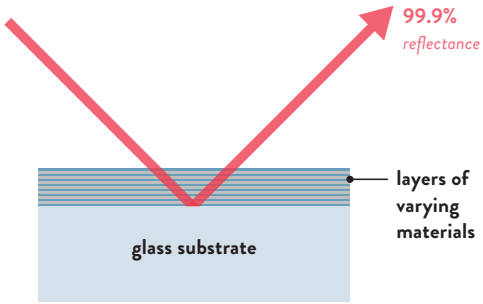



**1** glass plate

**2** back silver coating

**3** protective layer

## LASER MIRROR
CONSTRUCTION




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

12

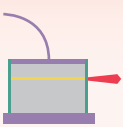
# LASER TYPES

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**

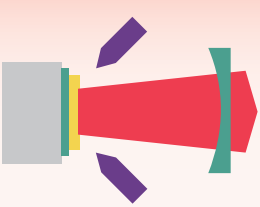
- active medium = excited atoms or molecules
- energy supply = pump — optical — electrical
- resonator (end mirror or output coupler)
- laser beam

## DIODE LASER



## FIBER LASER

## DISK LASER



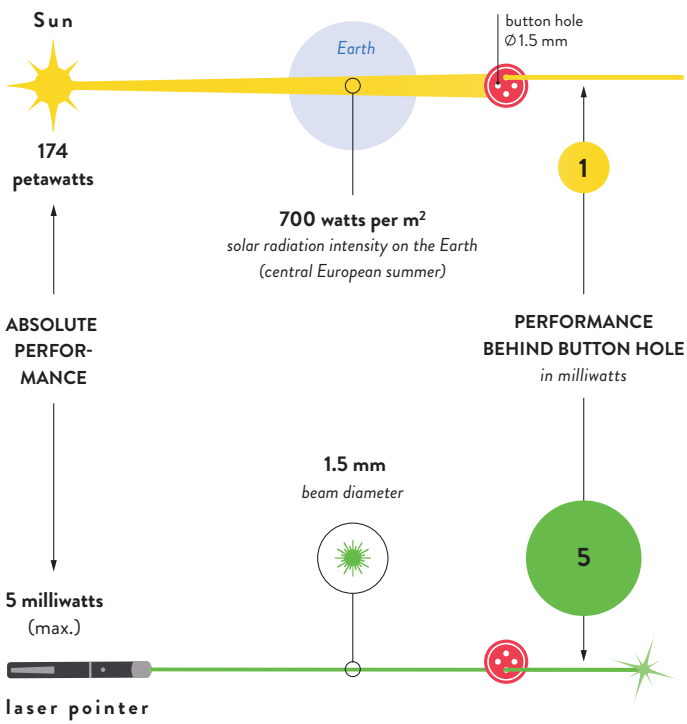
## GAS LASER

13

# 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



# PRODUCTION TECHNOLOGY

14

# IMAGE OF SMALLEST STRUCTURES

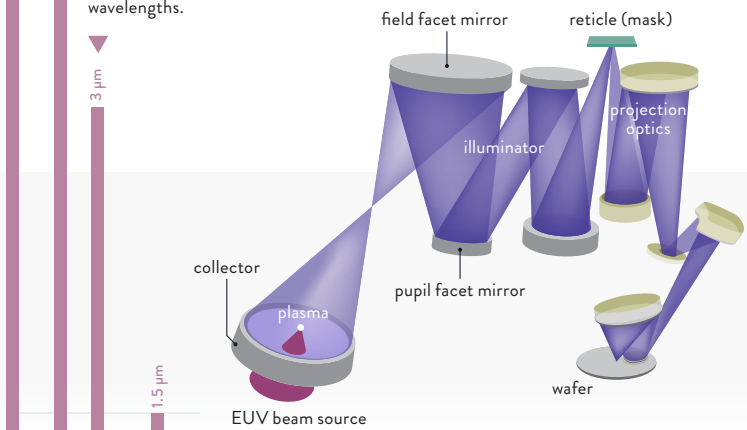
Modern technology requires efficient electronics in the smallest spaces. Thanks to optical technologies it is possible to organize increasingly smaller electronic components on semiconductor chips.

## DEVELOPMENT OF SEMICONDUCTOR PRODUCTION PROCESSES

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

## OPTICAL BEAM PATH

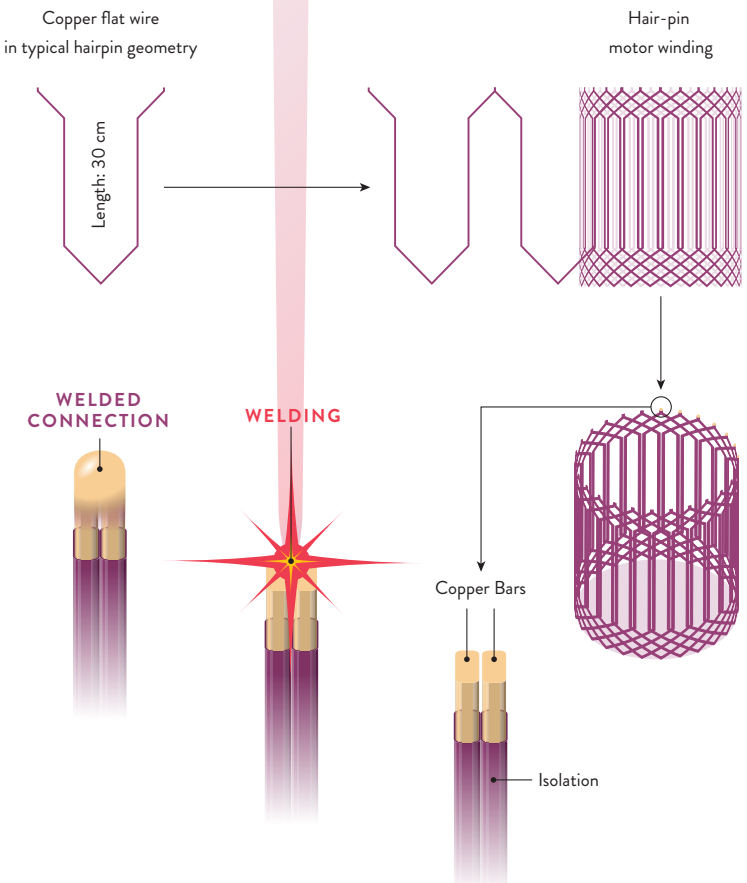
Extreme ultraviolet (EUV) light, which is already in use and which has a wavelength of only 13.5 nanometers, requires the application of purely reflective optics with extremely accurate geometry.



15

# HAIR-PIN LASER WELDING DRIVES ELECTROMOBILITY

In high-performance electric cars, the stationary part of the motor consists of many copper wires shaped like hairpins. Short-pulse laser technology has proven to be the perfect tool to connect the hairpins with high quality and reliability. The stripping of the wire coating and the geometry inspection are also performed with lasers.



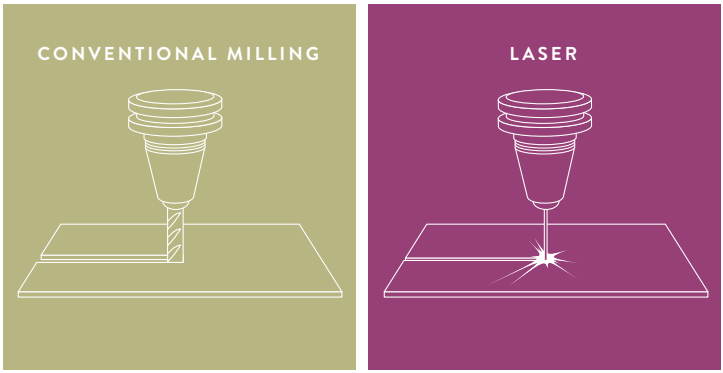
16

# LASER CUTTING

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

## EFFICIENCY AND PERFORMANCE COMPARISON OF CONVENTIONAL MILLING AND LASER CUTTING

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




### CUTTING WIDTH

*(millimeters)*

10

0.4

### TOOL PERFORMANCE

*(kilowatts)*

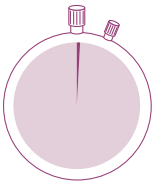
0.4

20

## DURATION PER METER

14 Minutes

12 Seconds



## ENERGY CONSUMPTION

*(kilowatt hours)*



## WASTE

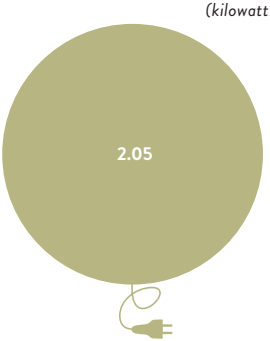
*(grams)*



## TOTAL ENERGY CONSUMPTION

*taking into account material savings*

*(kilowatt hours)*




# 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
- $CO_2$ laser
- ultrashort pulse laser
- UV excimer laser
- IR diode laser

**MACHINE PROCESS**

- edge
- area
- pattern
- holes

### Touchscreen

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

### Screen

- generation of polycrystalline layers
- encapsulation of laminated glasses

### Battery

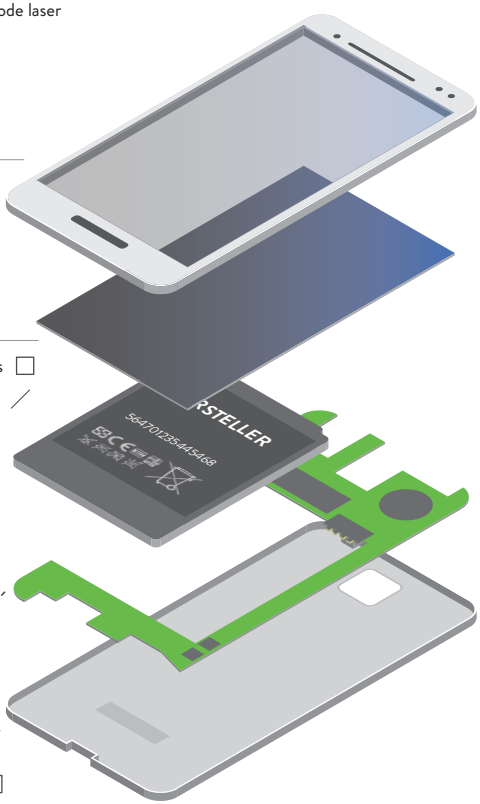
- welding of battery case
- marking logo, data-matrix-code, and serial number

### Circuit board

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

### Housing

- cutting of housing
- marking logo and serial number



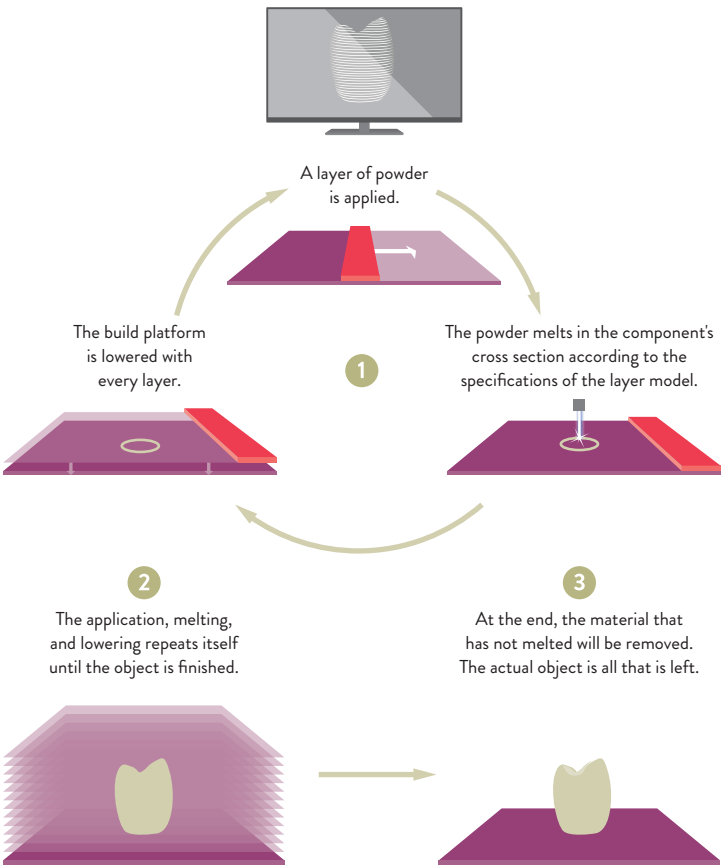
18

# 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.



# DATA TRANSFER

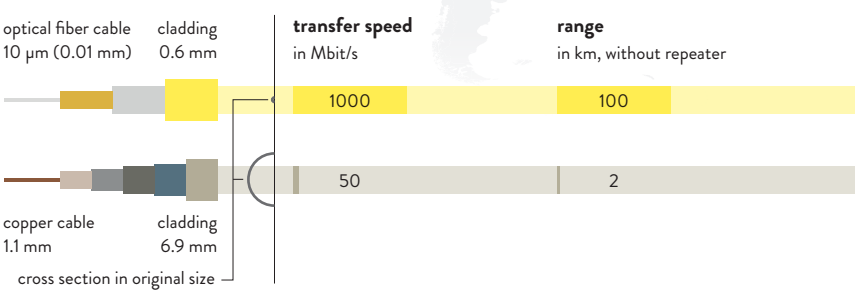
19

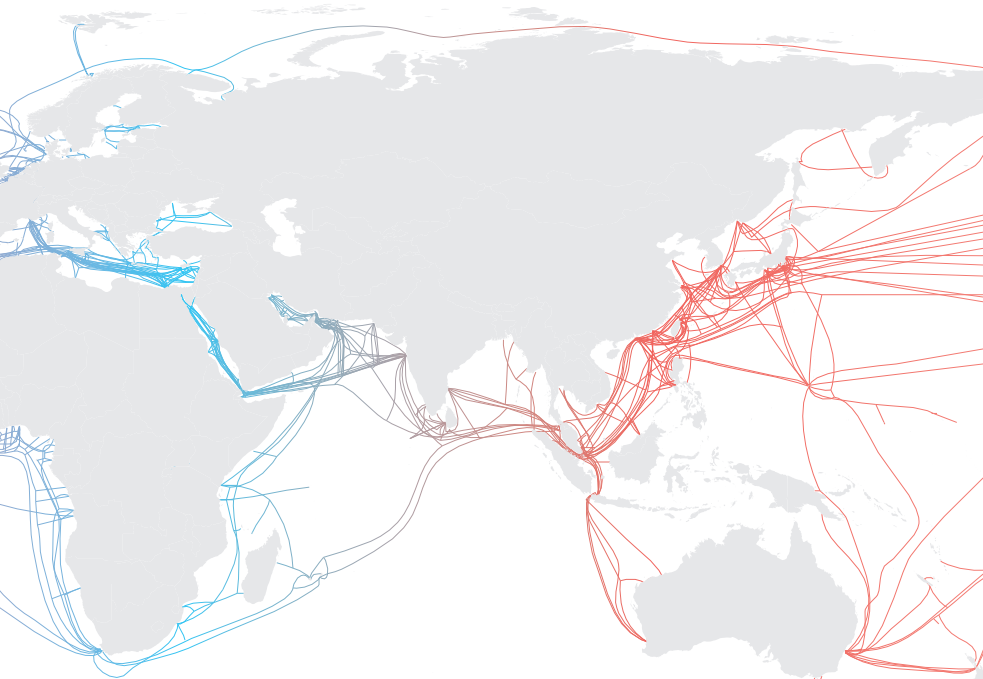
# OPTICAL FIBER NETWORKS

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 communication capacity. Today, submarine cables with capacities of up to several terabytes per second connect the whole Earth, so you can share video globally.

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





| **shelf life** in years | **weight** 100 m cable in kg | **energy consumption** in watts per user |
|---|---|---|
| 50 | 0.6 | 2 |
| 5 | 5.8 | 10 |

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.

## 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

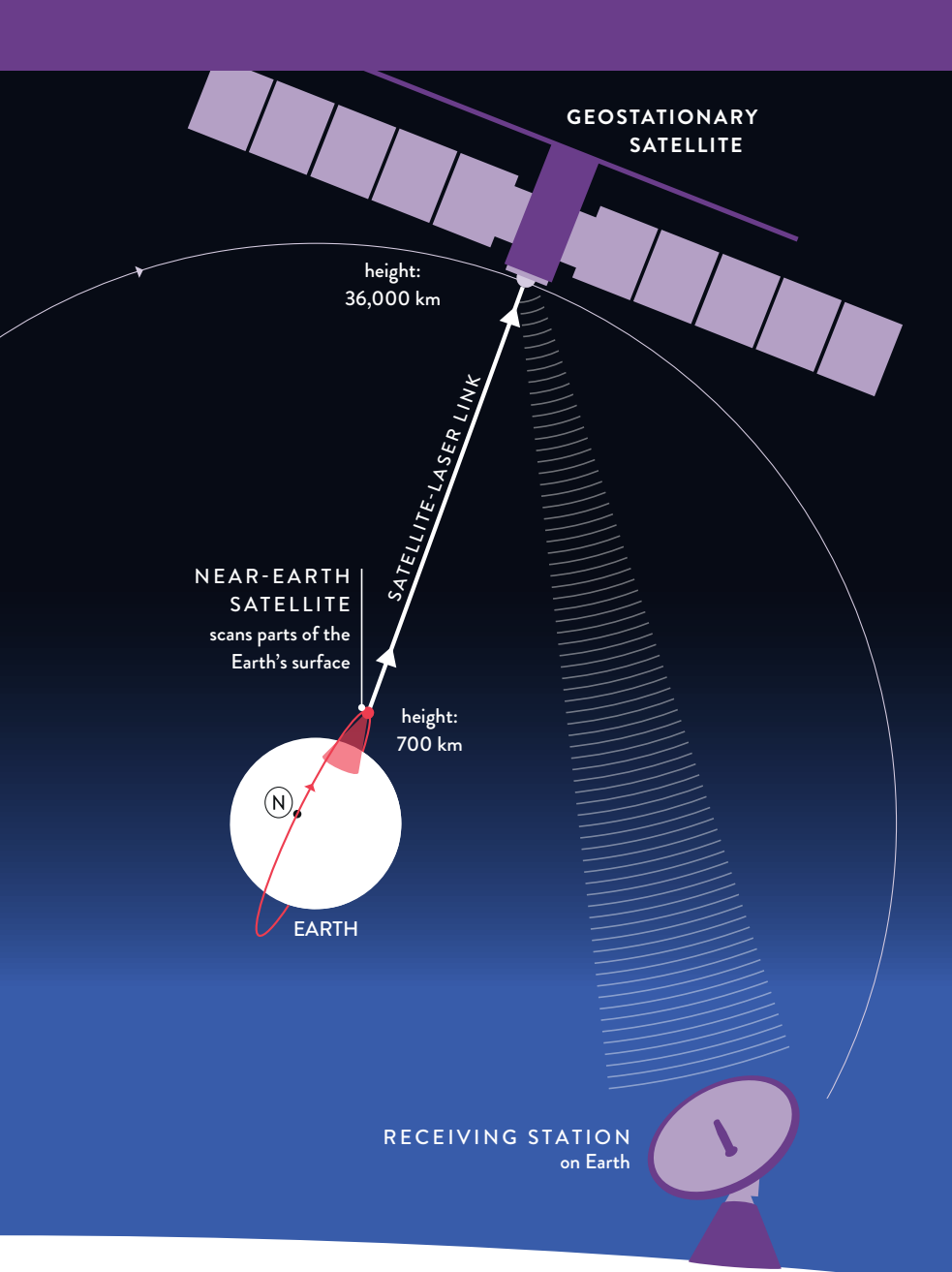
**SMALLEST TOLERANCE**
for generating a bundled laser beam across largest distances

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


GEOSTATIONARY SATELLITE
height: 36,000 km
SATELLITE-LASER LINK
NEAR-EARTH SATELLITE
scans parts of the Earth's surface
height: 700 km
N
EARTH
RECEIVING STATION
on Earth

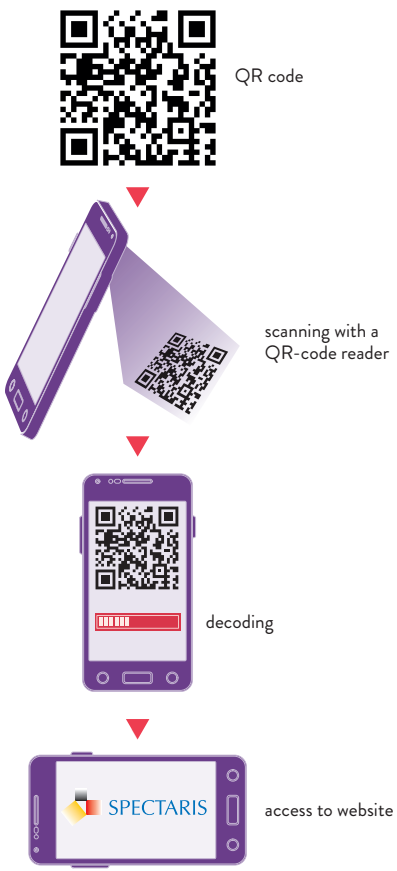
21

# 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 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

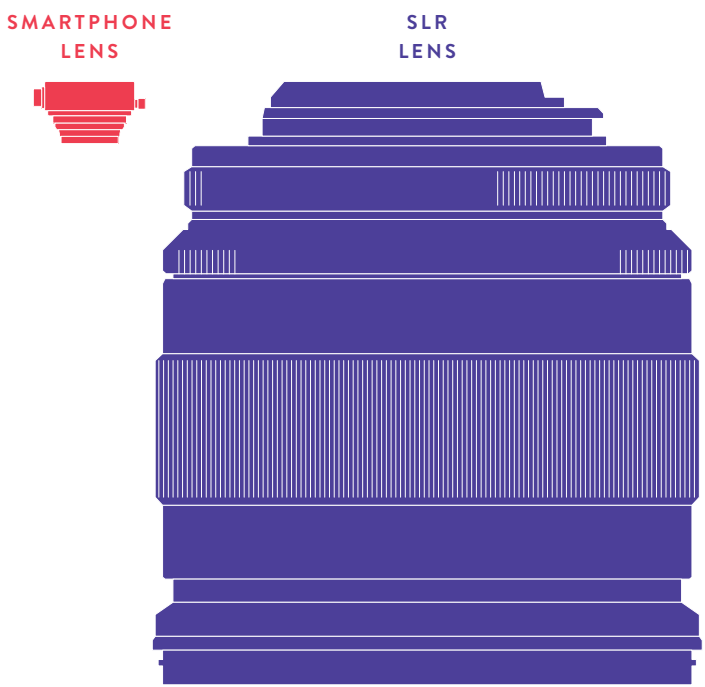
22

# CAMERA LENSES

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

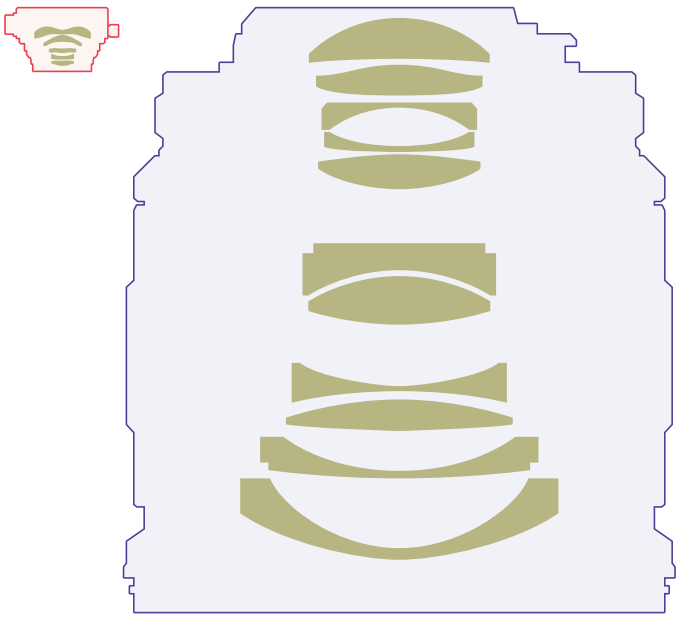
## SIZE COMPARISON

(original sizes)



## LENS ARRANGEMENT

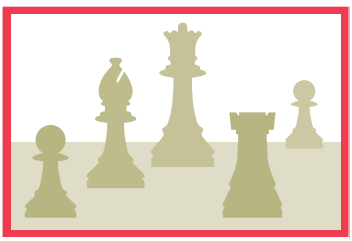
Despite their small size, smartphone lenses have sophisticated optics with complex lens arrangements, yet large lenses have advantages.



## DEPTH OF FIELD

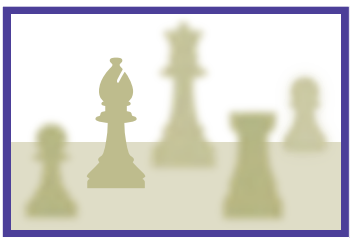
The most important consequence of the size difference is the different depths of field.

SMARTPHONE LENS



*Smartphones display all objects from near to far with the same sharpness.*

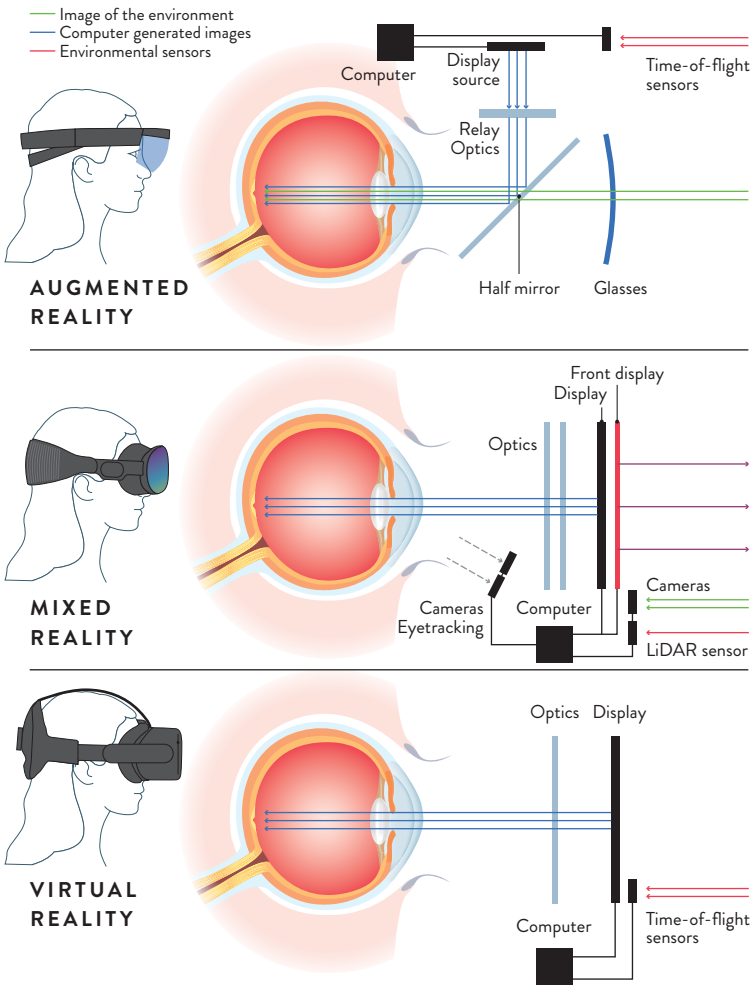
SLR LENS



*The depth of field can be set selectively with large SLR lenses.*

# GLASSES FOR AR & VR

**Stereoscopic display goggles immerse users of Virtual Reality (VR)** in a completely digital environment, while micro projectors and beam-combiners of **Augmented Reality (AR)** glasses overlay digital elements onto the real world. More opto-electronic components like cameras and LiDAR front-side displays enable interaction with the environment anywhere between AR and VR.

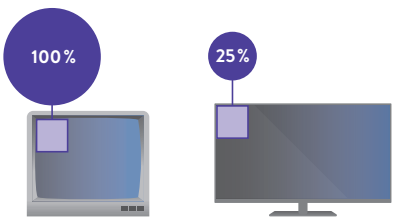


24

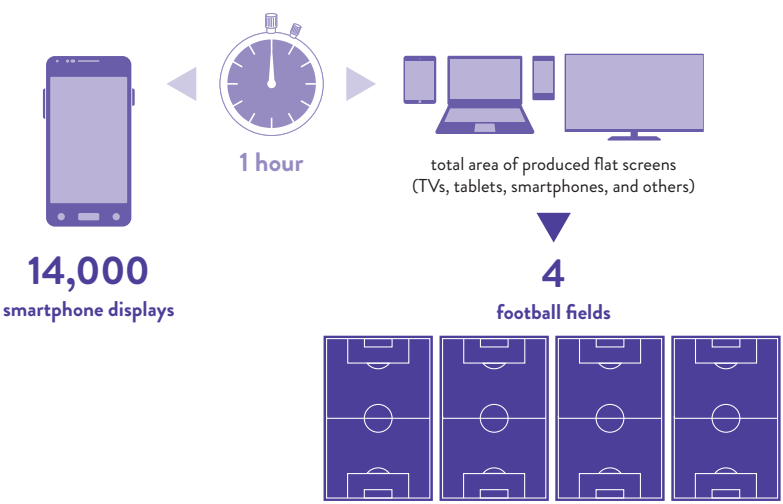
# FLAT SCREENS

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




## PRODUCTION OF FLATSCREENS WITHIN ONE HOUR



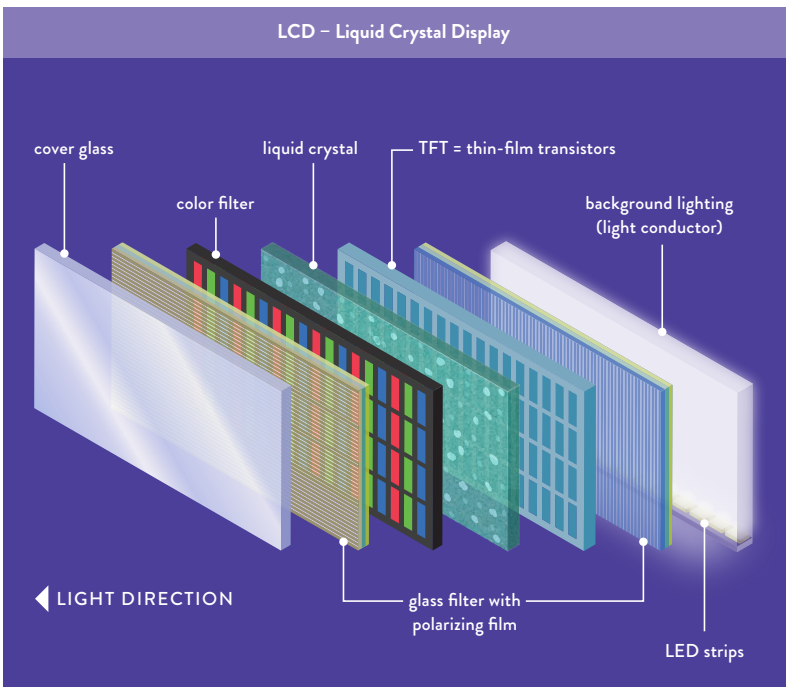
25

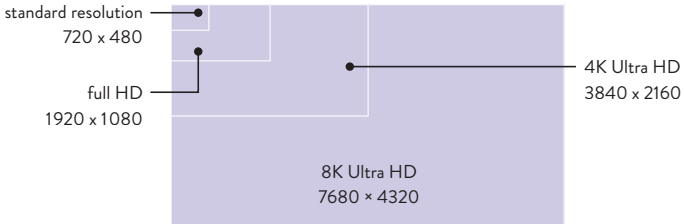
# LCD vs OLED

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.

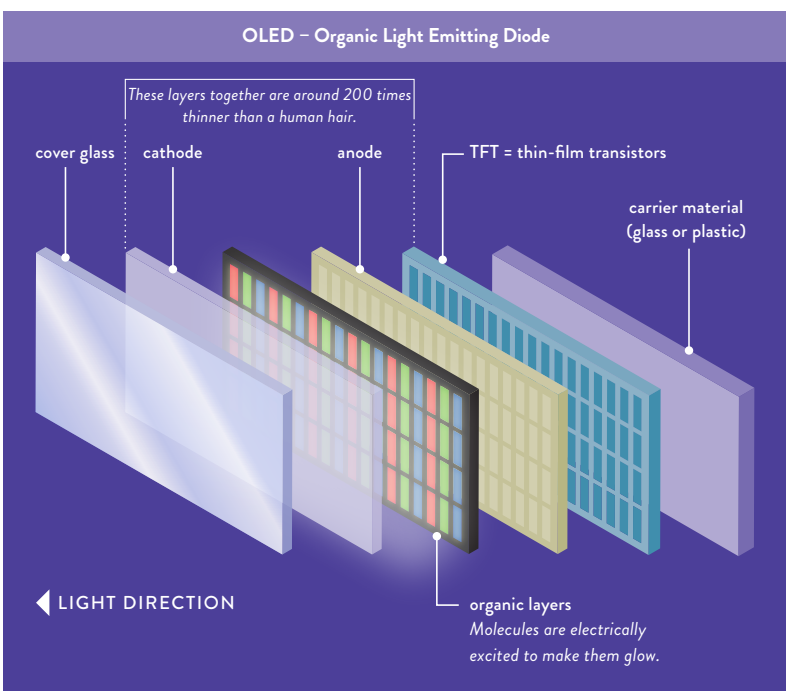





**display resolutions**
in pixels

## OLED DISPLAY STRUCTURE

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

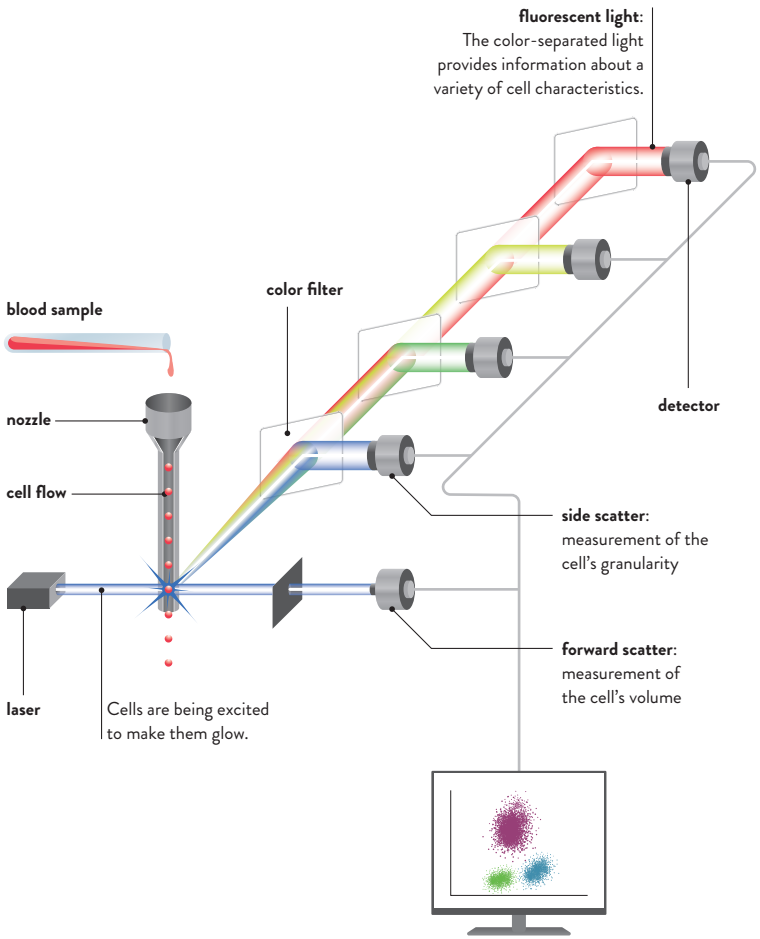


# MEDICAL TECHNOLOGY

26

# COUNTING BLOOD CELLS

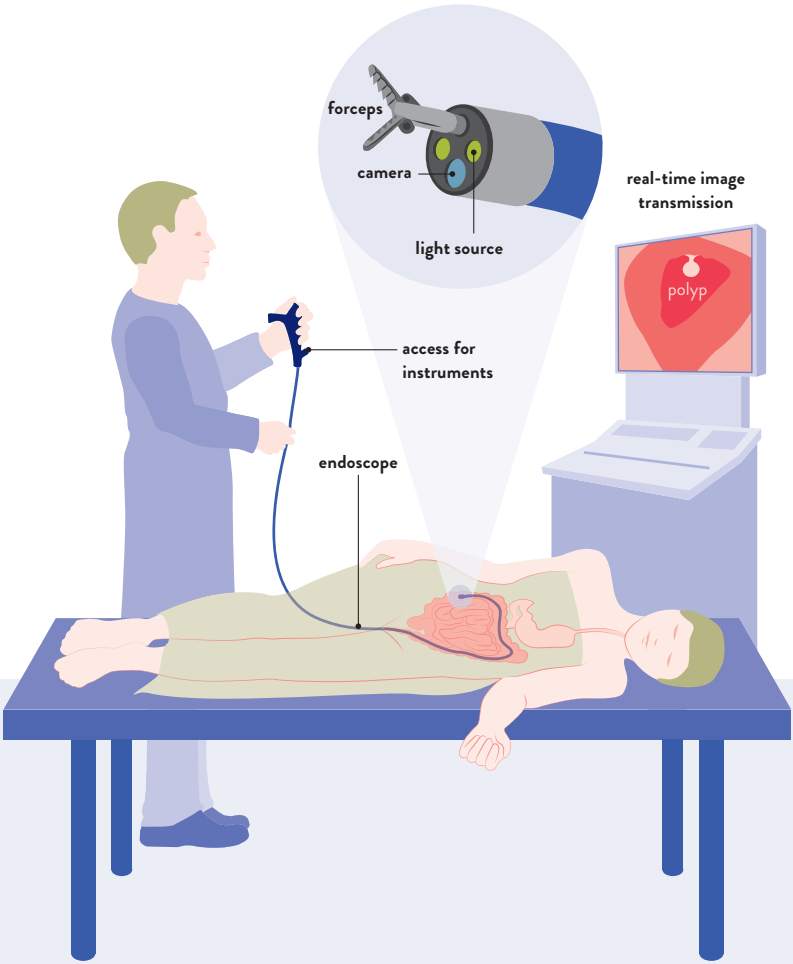
Thousands of cells per second are counted and characterized in medical and biotechnical analytics with laser-based flow cytometry. This enables the fast and secure detection of blood anomalies.



27

# ENDOSCOPY

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.

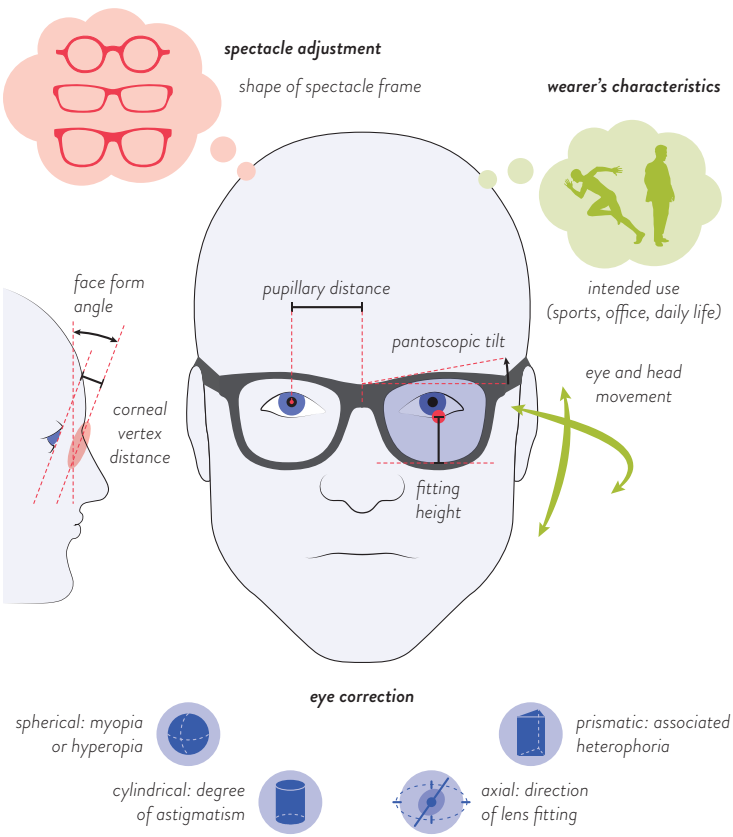


28

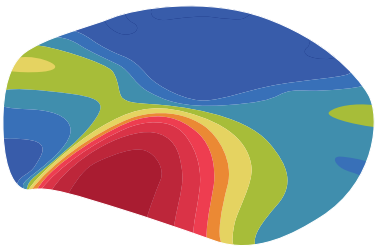
# SEEING NEAR AND FAR

Individually adjusted varifocals help older people have good vision for all distances. A variety of criteria are 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

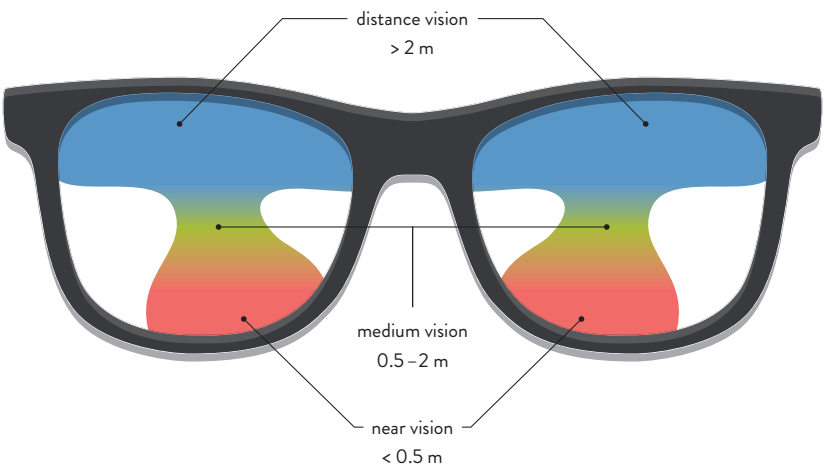


## COMPUTER-CALCULATED LENS DESIGN



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

## MODEL OF VARIFOCALS

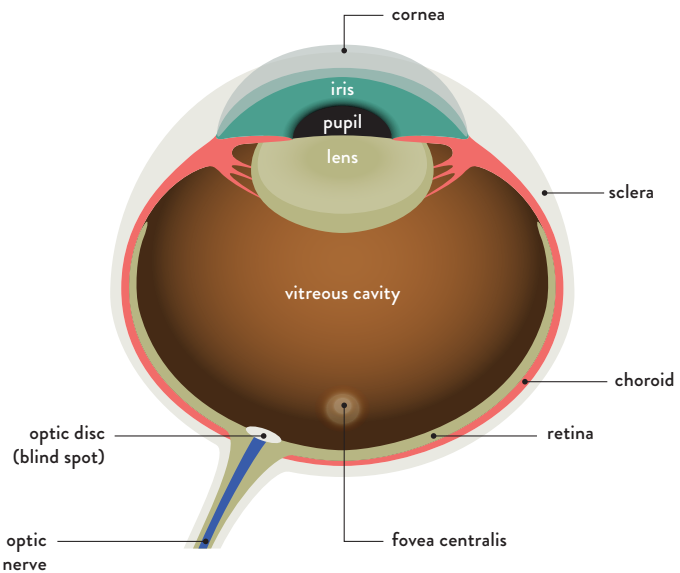


29

# SEEING CLEARLY AGAIN

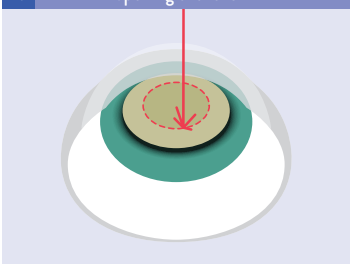
From the age of 60 onwards, most people get a slight cataract – known as the grey star. Treating cataracts is the most common operation around the world. For 2022, the WHO reported more than 29 million cataract operations. The use of the femtosecond laser with ultra-short pulses allows a precise and careful operation.

## ANATOMY OF THE HUMAN EYE

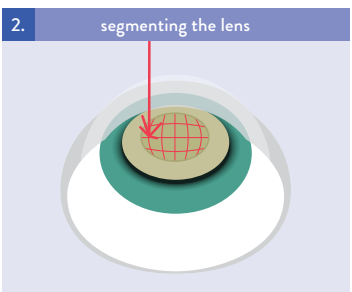


## SEQUENCE OF A LASER OPERATION

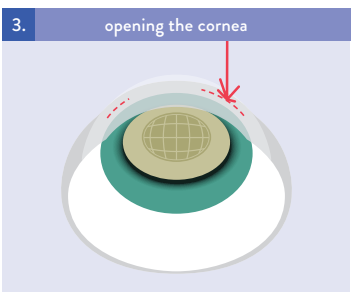
1. opening the lens



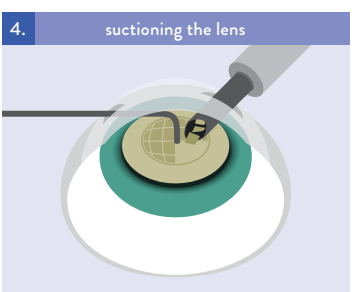
2. segmenting the lens



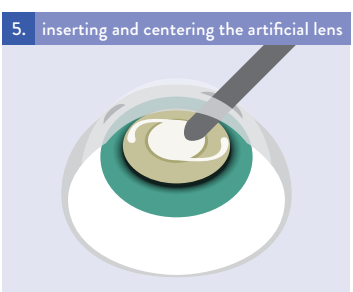
3. opening the cornea



4. suctioning the lens



5. inserting and centering the artificial lens

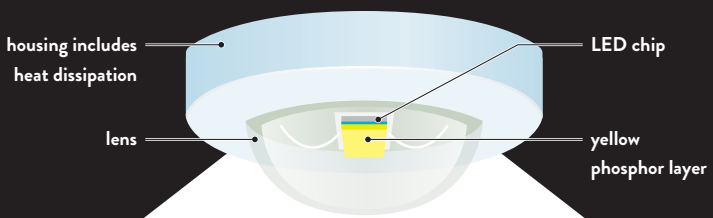


# LIGHTING

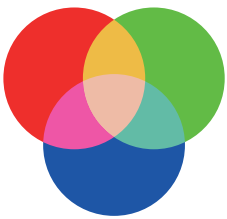
30

# WHITE LED LIGHT

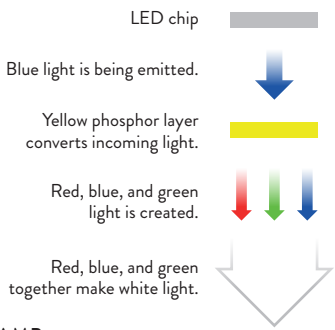
LED chips make colorful light.
White light is created by luminescence conversion.



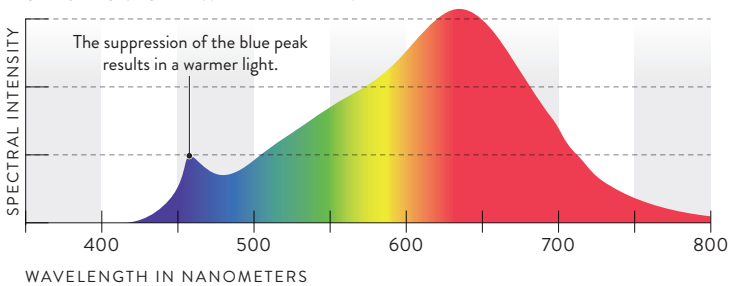

**White light is a mix of red, blue and green.**



**Creation of white LED light through luminescence conversion:**



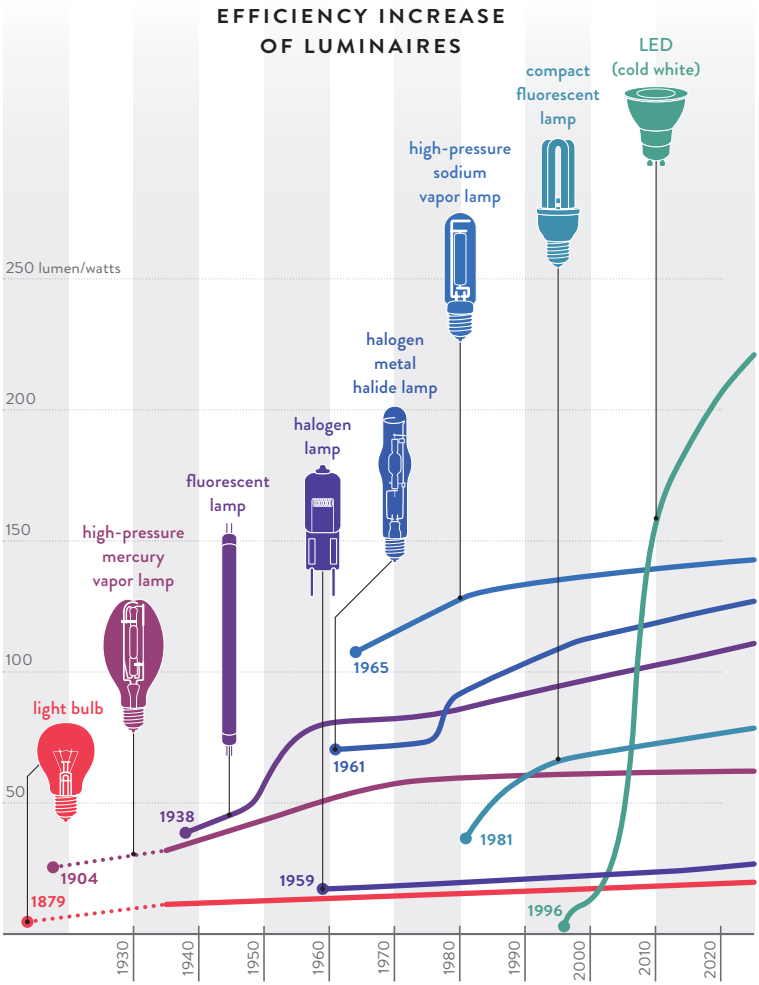

## SPECTRUM OF A WHITE LED LAMP



31

# BRIGHTER WITH LEDs

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.

**W** **power** (watts)
electrical connected load

**lm** **brightness** (lumens)
how bright the lamp's light is

**T** **color temperature** (Kelvin)
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

**h** **shelf life**
usage in hours

**$R_a$** **color rendering index**
accuracy of color rendering

**10 w** **60 w** **energy savings**
in comparison to the conventional light bulb

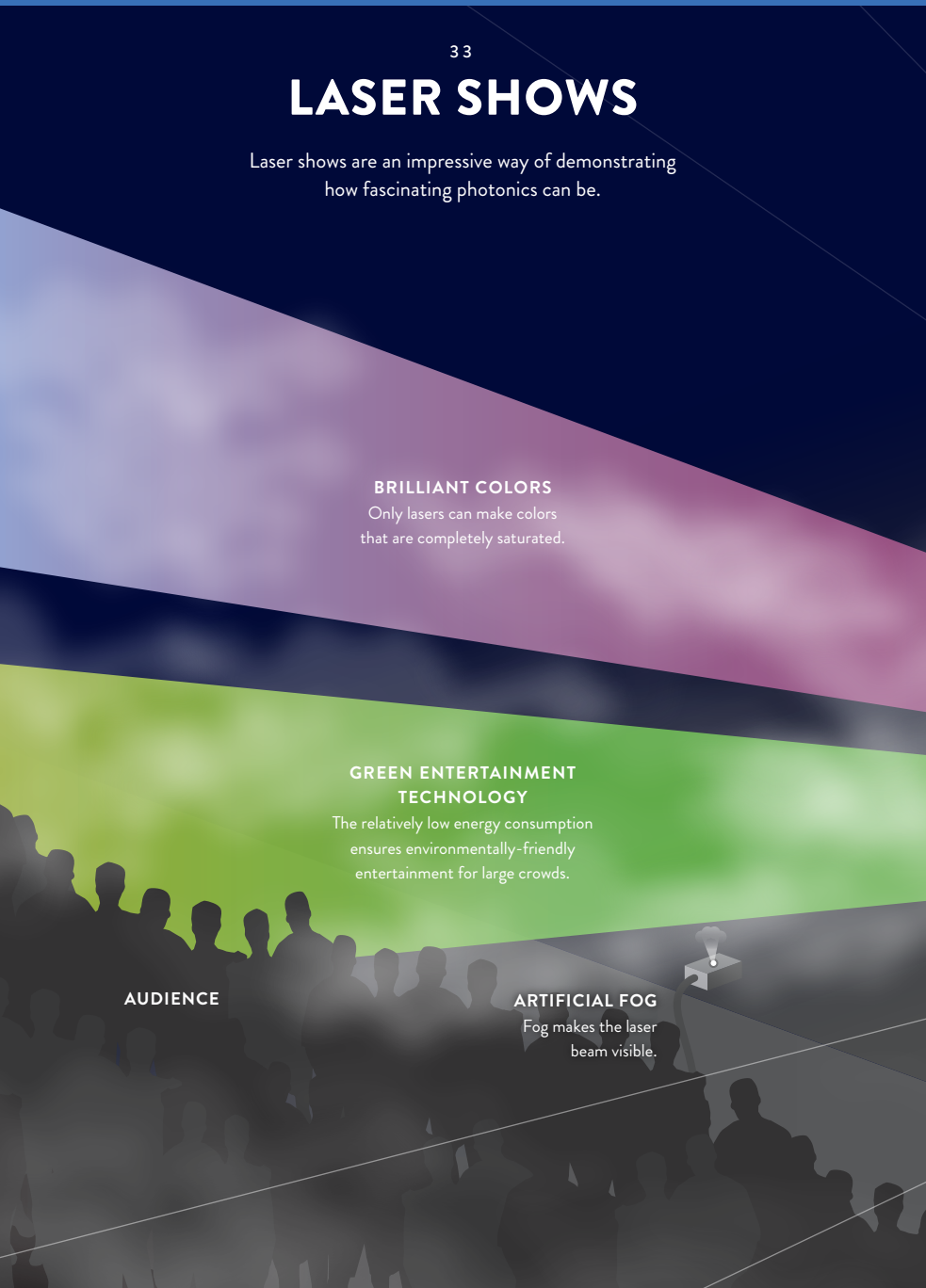
**Hg** **mercury content**
environmentally friendly without mercury

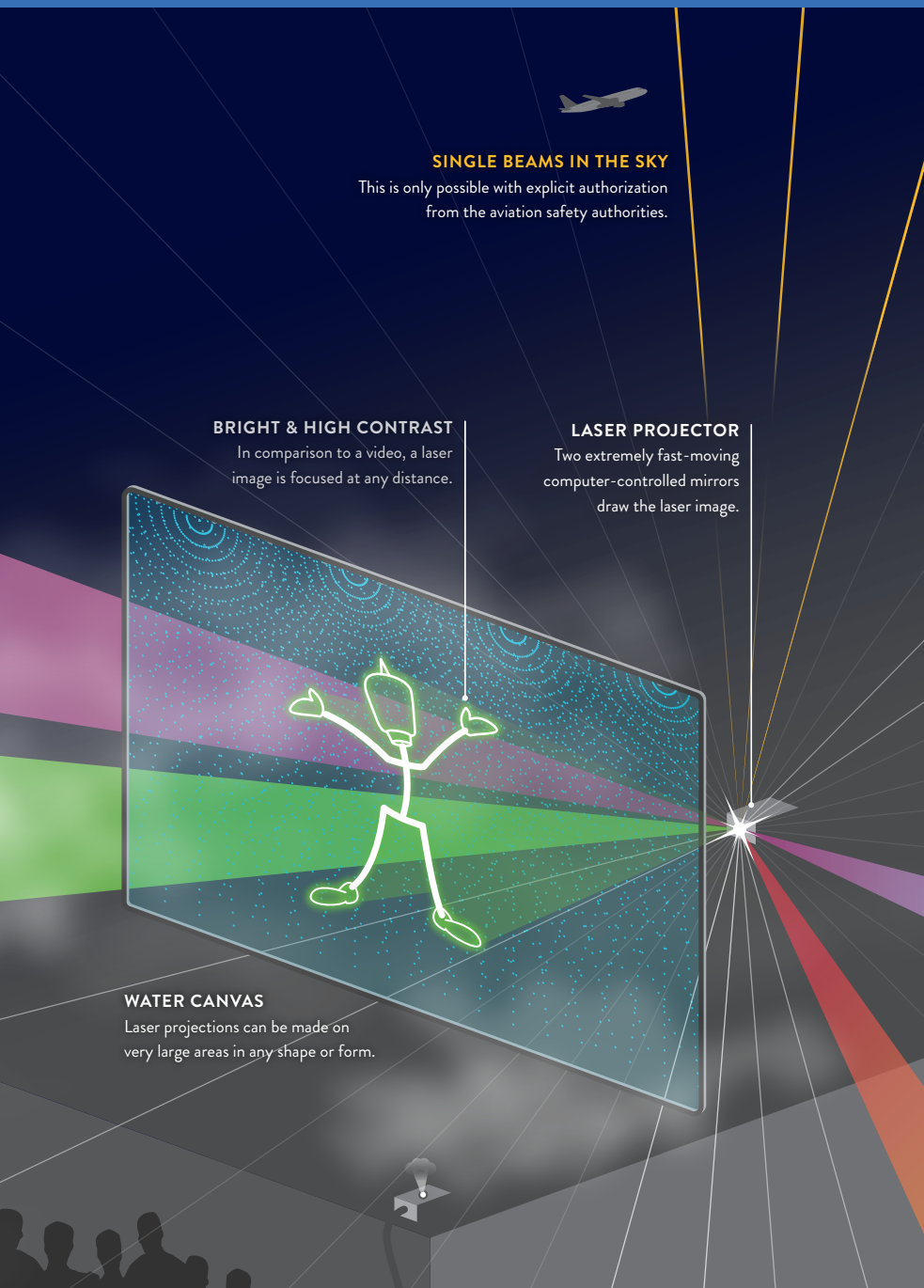
**36°** **illumination angle**
the scope and range of effective light

33

# LASER SHOWS

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



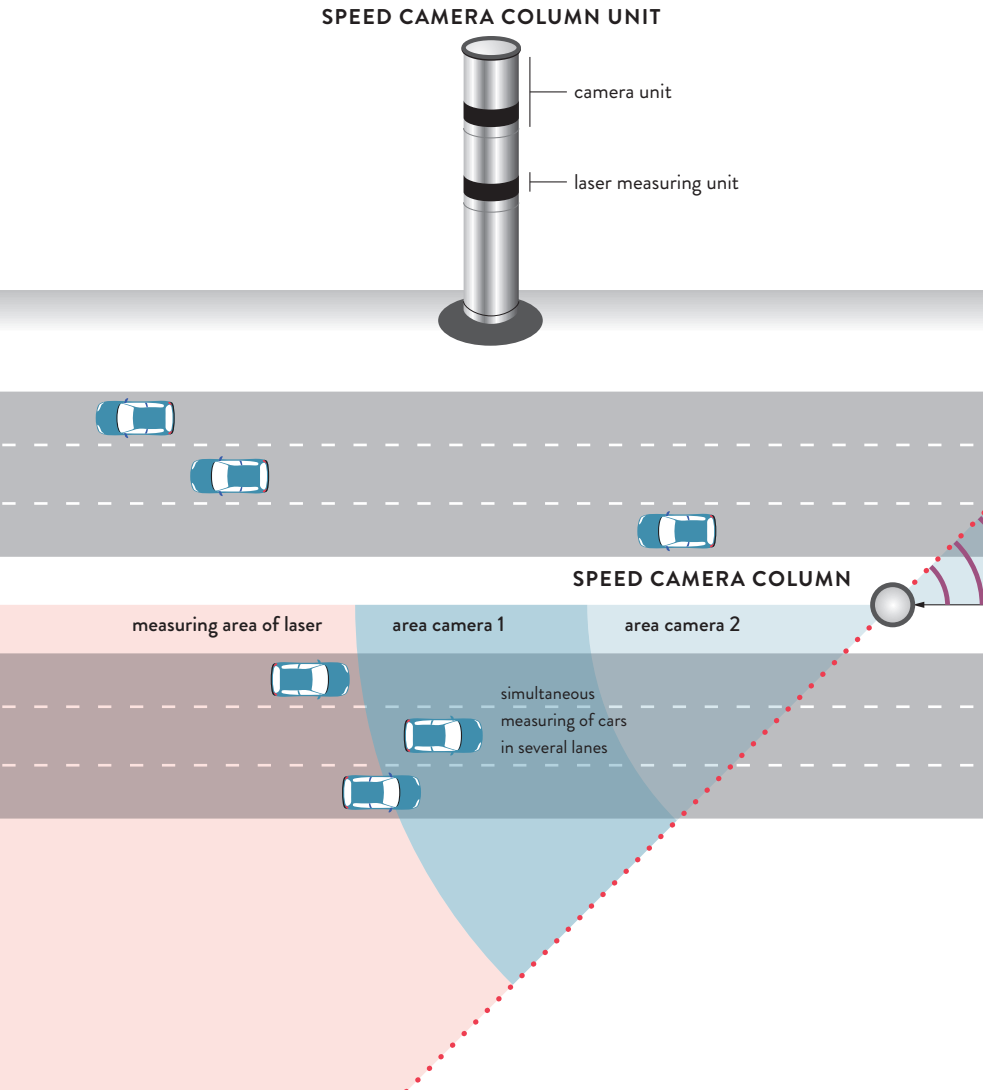

SINGLE BEAMS IN THE SKY
This is only possible with explicit authorization from the aviation safety authorities.
BRIGHT & HIGH CONTRAST
In comparison to a video, a laser image is focused at any distance.
LASER PROJECTOR
Two extremely fast-moving computer-controlled mirrors draw the laser image.
WATER CANVAS
Laser projections can be made on very large areas in any shape or form.

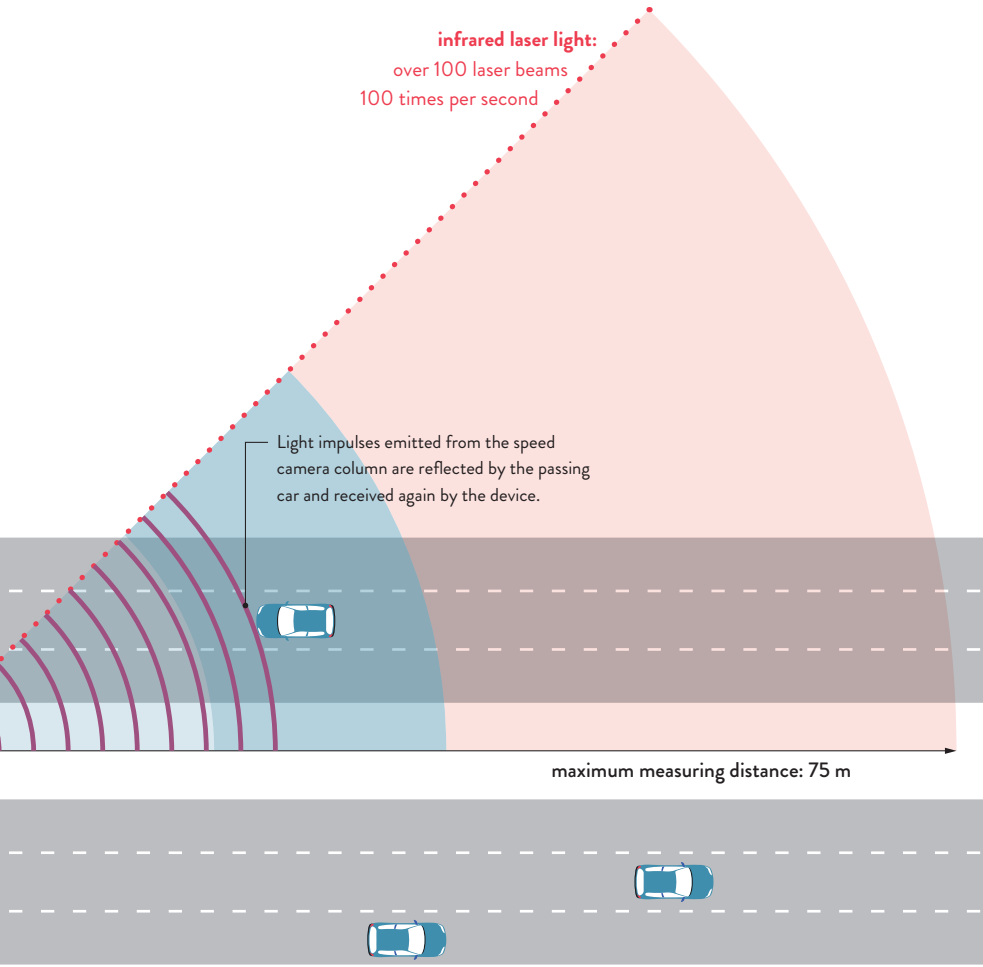
# TRANSPORTATION

34

# TRAFFIC ENFORCEMENT

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 offense.



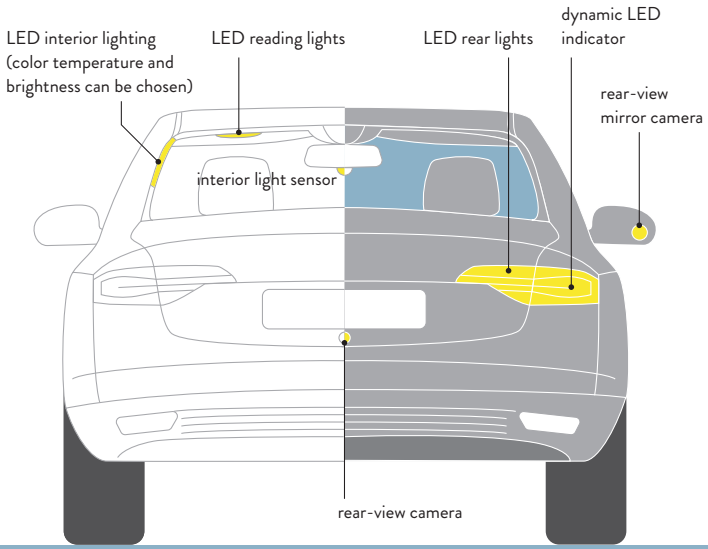

infrared laser light:
over 100 laser beams
100 times per second
Light impulses emitted from the speed camera column are reflected by the passing car and received again by the device.
maximum measuring distance: 75 m

35

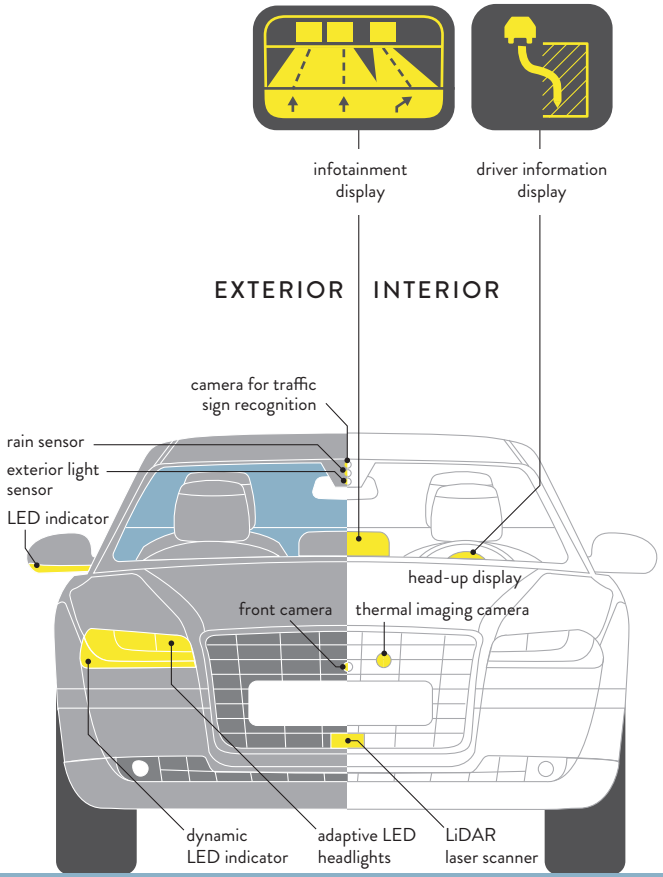
# LIGHT ON AND IN THE CAR

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

INTERIOR EXTERIOR




REAR VIEW


infotainment display
driver information display
EXTERIOR
INTERIOR
camera for traffic sign recognition
rain sensor
exterior light sensor
LED indicator
head-up display
front camera
thermal imaging camera
dynamic LED indicator
adaptive LED headlights
LiDAR laser scanner

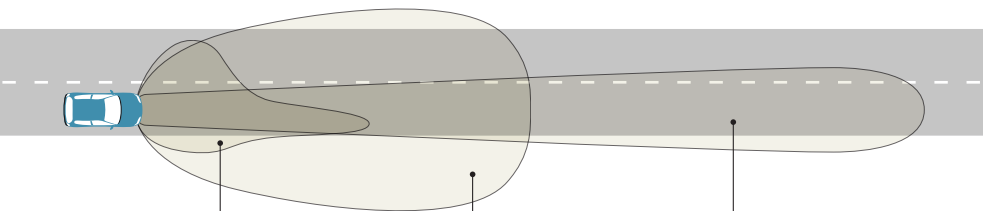
## FRONT VIEW

36

# 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

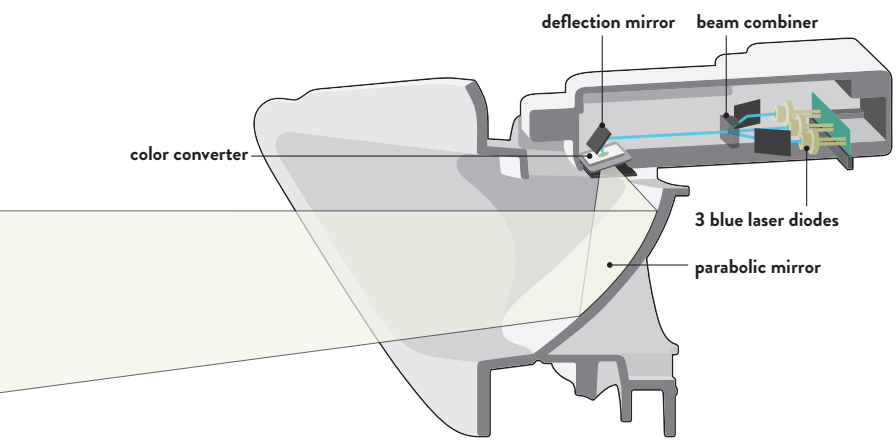


**LED headlights**
intelligent illumination to prevent glaring for oncoming traffic

**LED high beams**
large-scale illumination of the traffic situation

**laser high beams**
focused illumination for an optimal vision

## LASER HIGH BEAMS



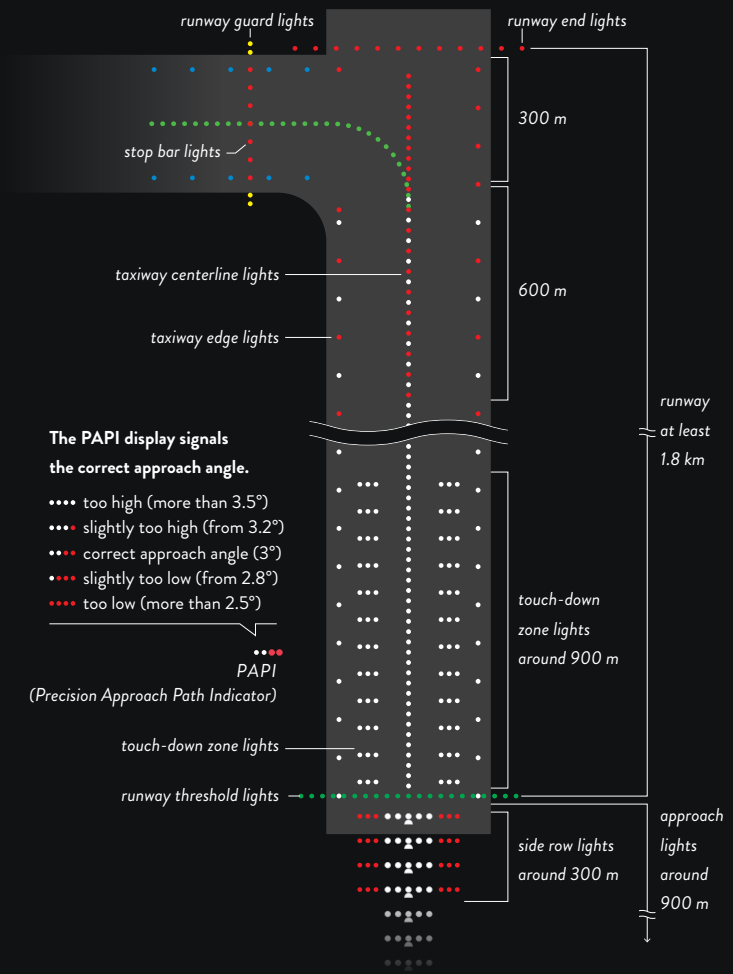
37

# AIRPORT LIGHTING

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

**LED vs Halogen**

| | LED | Halogen |
|---|---|---|
| hours shelf life | 60,000 | 2,500 |
| typical connected load per lamp (W) | 18 | 65 |



# SUSTAINABLE ENERGY

38

# SOLAR CELLS

Solar cells can transform sunlight directly into electricity. An efficiency of around 48 % 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.

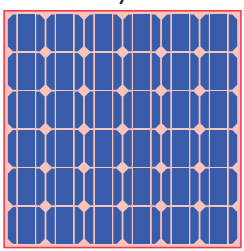
**Polycrystalline silicon cells** feature a characteristic texture that comes from crystal borders that are very close together.

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

## GLOBAL MARKET SHARE


## CHARACTERISTICS

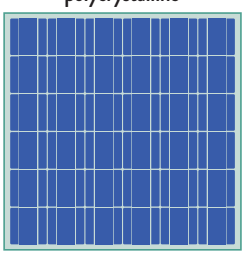
**monocrystalline**



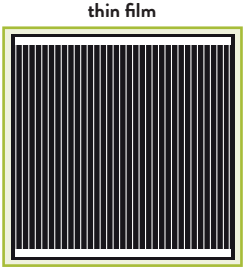
efficiency


acquisition costs

**polycrystalline**

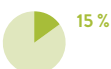



**thin film**



**amorphous silicon**


**copper indium diselenide**




39

# SOLAR ENERGY

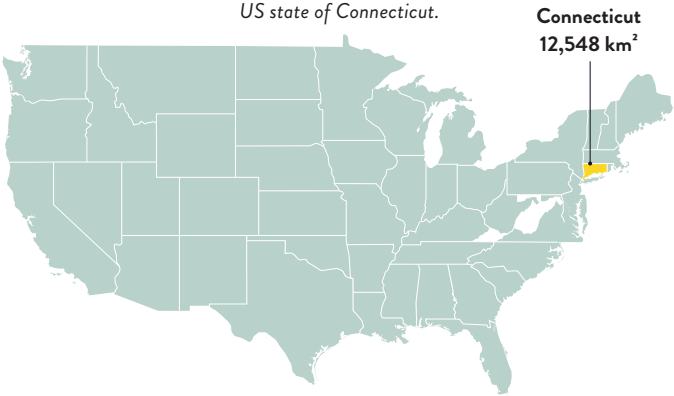
Solar energy has the potential to satisfy the world's raising appetite for electricity without polluting the environment. What total size of solar power plants would be needed to run the United States on solar electricity?

US electricity consumption per year: 4050 TWh (2022)

**Area of solar cells needed to supply this energy:**

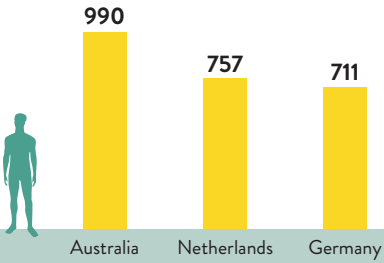
**12,700 km²**

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




## TOP PRODUCERS

installed power 2022 per capita in watts



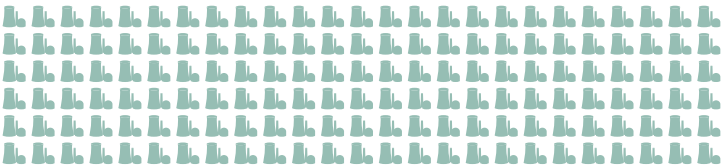
## PRODUCTION COMPARISON 2022

### World photovoltaic energy per year

**1.32 petawatt hours**
= 1.320,000,000,000 kilowatt hours

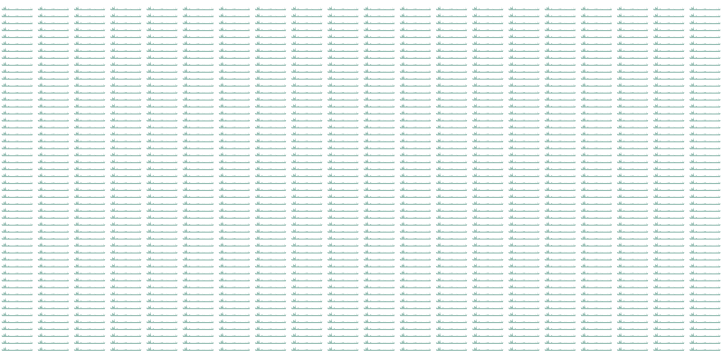
### Nuclear energy

*The photovoltaic energy produced corresponds to the electricity volume of 150 nuclear power stations.*



### Crude oil

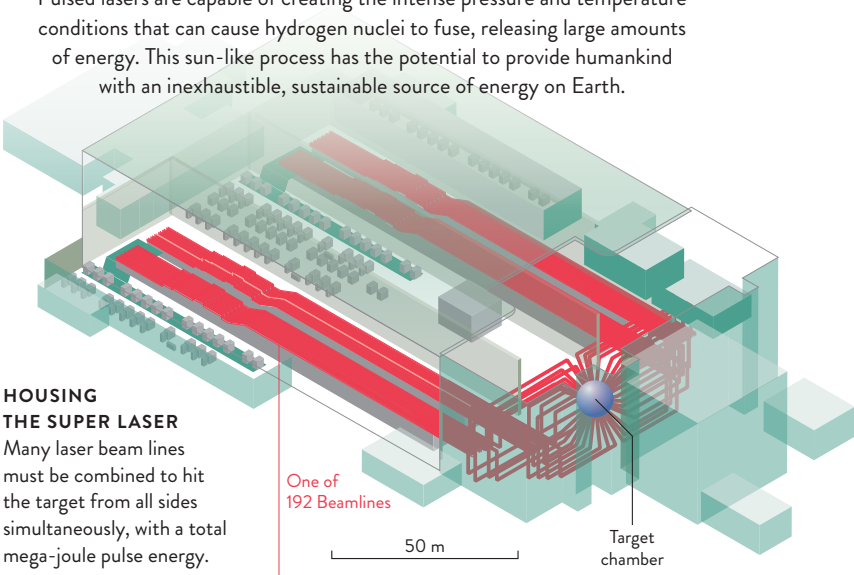
*With regard to petroleum, the equivalent is 310 million tons. This amount corresponds to 1000 oil tankers with a capacity of 300,000 GRT* each.*



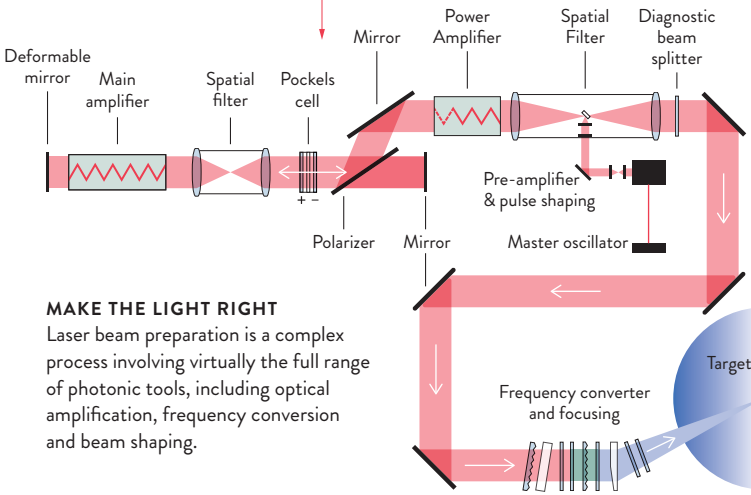
* *gross register tons*

# LASER FUSION

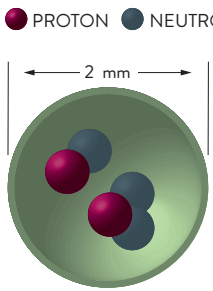
Pulsed lasers are capable of creating the intense pressure and temperature conditions that can cause hydrogen nuclei to fuse, releasing large amounts of energy. This sun-like process has the potential to provide humankind with an inexhaustible, sustainable source of energy on Earth.



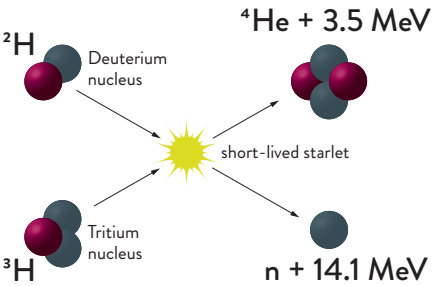

**HOUSING THE SUPER LASER**
Many laser beam lines must be combined to hit the target from all sides simultaneously, with a total mega-joule pulse energy.



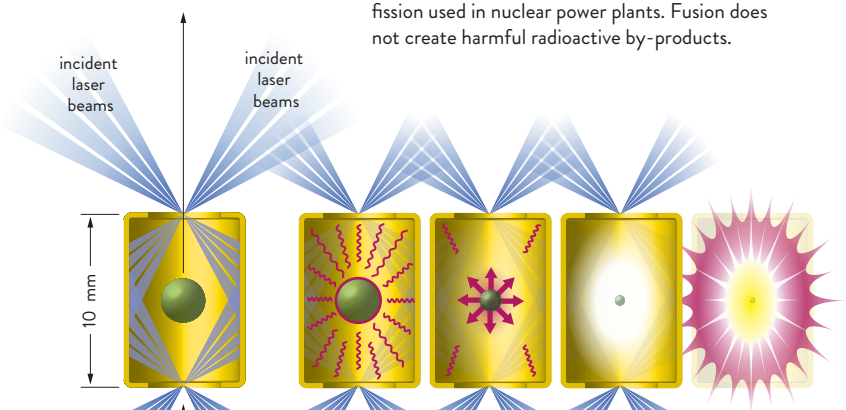

**MAKE THE LIGHT RIGHT**
Laser beam preparation is a complex process involving virtually the full range of photonic tools, including optical amplification, frequency conversion and beam shaping.




In the middle of the cylinder is a fuel capsule filled with a mixture of deuterium and tritium

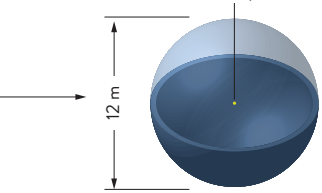



**WHAT MAKES FUSION SPECIAL?**
Fusion is the joining of atomic nuclei and produces far more energy than that created by fission used in nuclear power plants. Fusion does not create harmful radioactive by-products.




1. Lasers deposit energy into the golden hohlraum, generating X-rays
2. X-rays are absorbed by the fuel capsule, forming a plasma surface
3. The plasma surface explodes, compressing the fuel core
4. The capsule accelerates inwards and ignites the fusion process
5. Fusion energy released as heat is converted into electrical energy

In the middle of the target chamber is a small cylinder




Target chamber

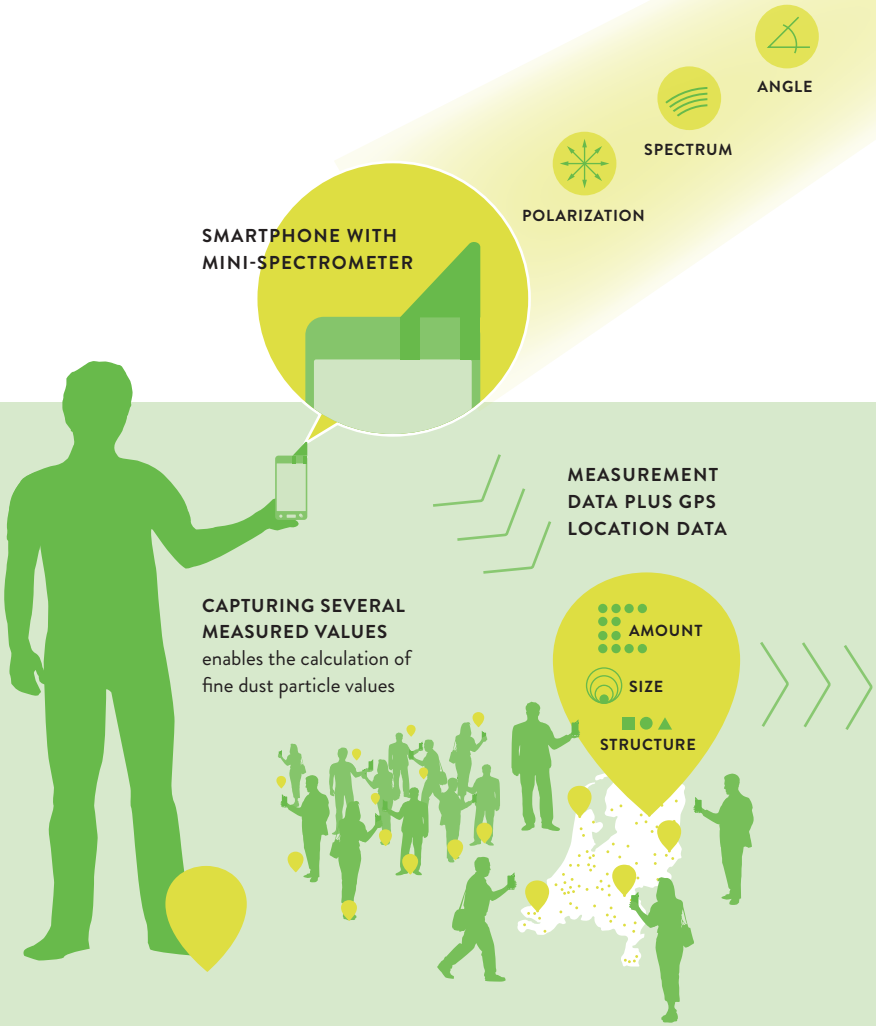
**ONE, TWO, THREE, FOUR, - BANG!!!**
Lasers contribute the starting energy to the fusion process, which seems simple but actually has many physical and technical pitfalls that scientists and engineers are working hard to overcome.

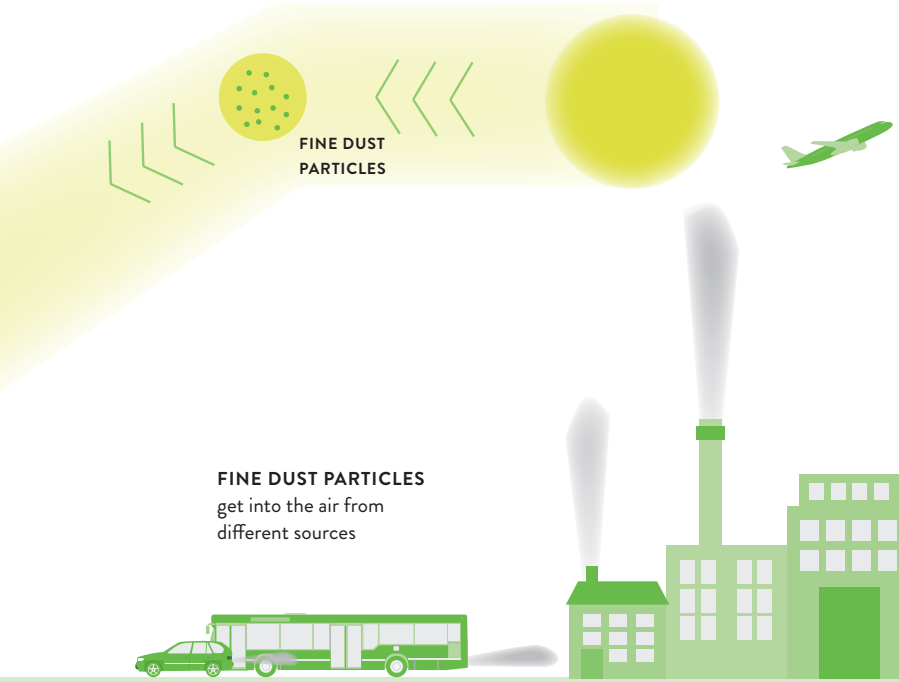
# ENVIRONMENT

41

# 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

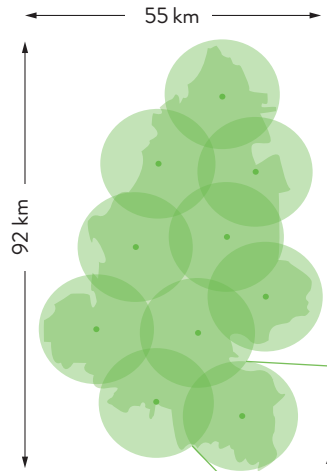
**POLLUTION**

very strong — very low

42

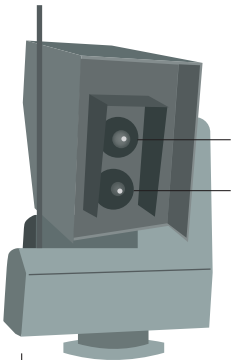
# FOREST FIRE SURVEILLANCE

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




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

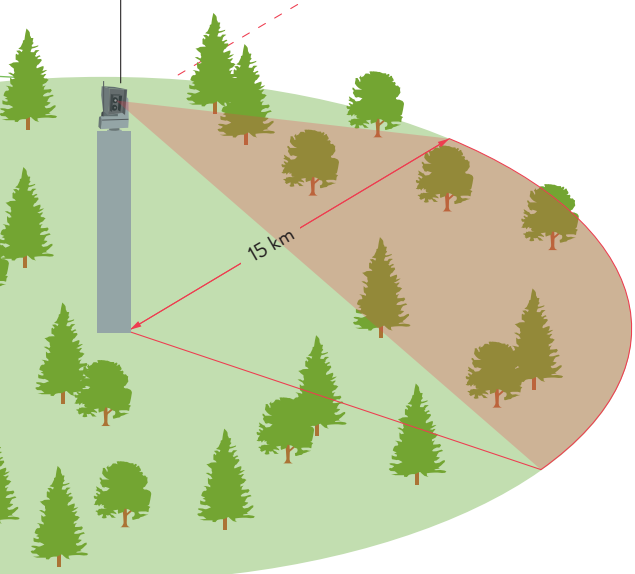

Coverage of an area
of **3100 km²**
with **10 SYSTEMS**
on fire watchtowers




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.

**OPTICAL SENSOR SYSTEM**

**FOREST FIRE ALARM CONTROL CENTER**
receives data and images if a fire is detected

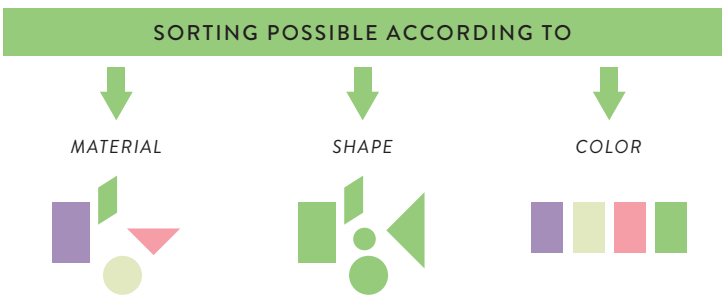


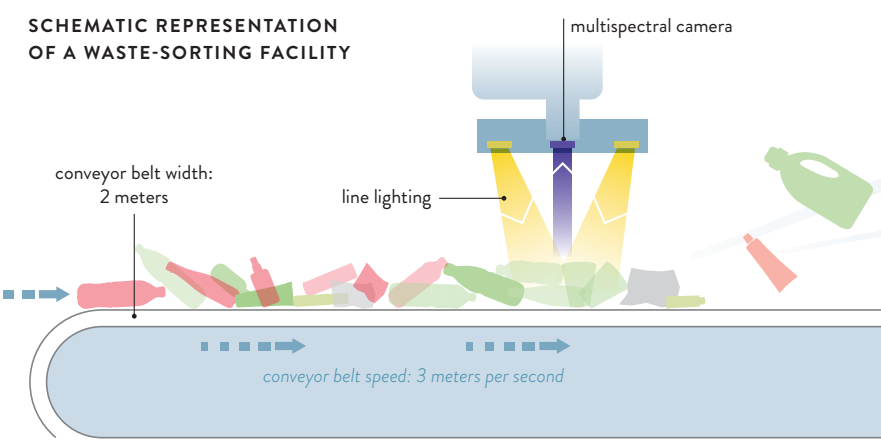

**CAMERA ANGLE OF VISION**
60° per minute

43

# OPTICAL SORTING

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 for recycling.



## IDENTIFICATION OF MATERIALS

*PAPER & CARDBOARD*



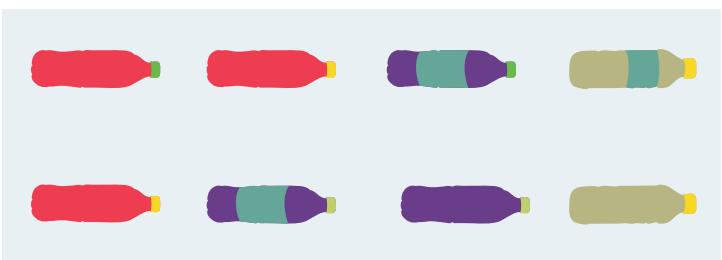
*PLASTIC CONTAINERS*

*IMPURITIES*



## OBJECT RECOGNITION AND VISUALIZATION OF BOTTLES

PET PE PP PET+PVC PET+PP PET+PS



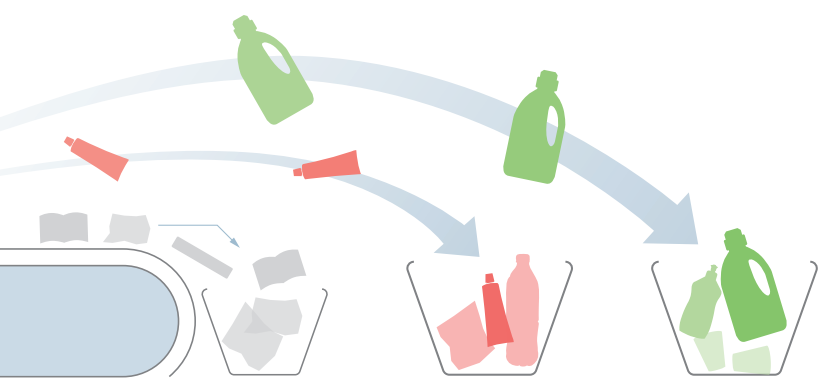
**PE** polyethylene

**PET** polyethylene terephthalate

**PP** polypropylene

**PS** polystyrene

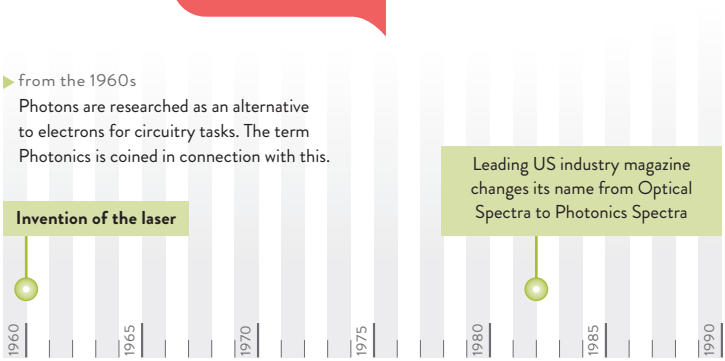
**PVC** polyvinyl chloride

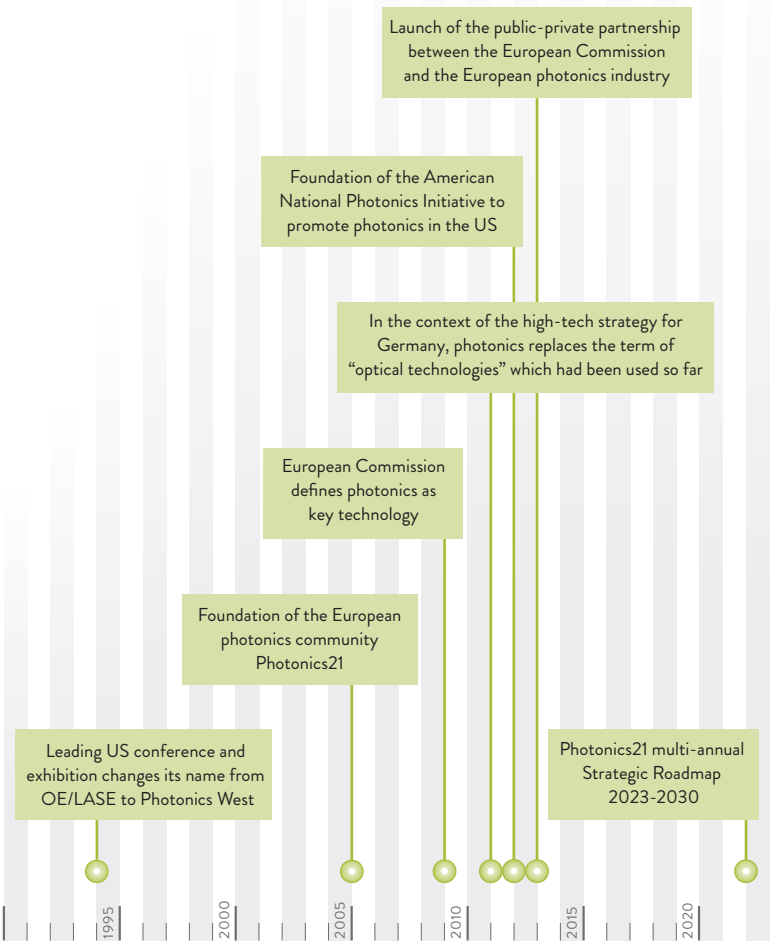


# RESEARCH & ECONOMY

# 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.

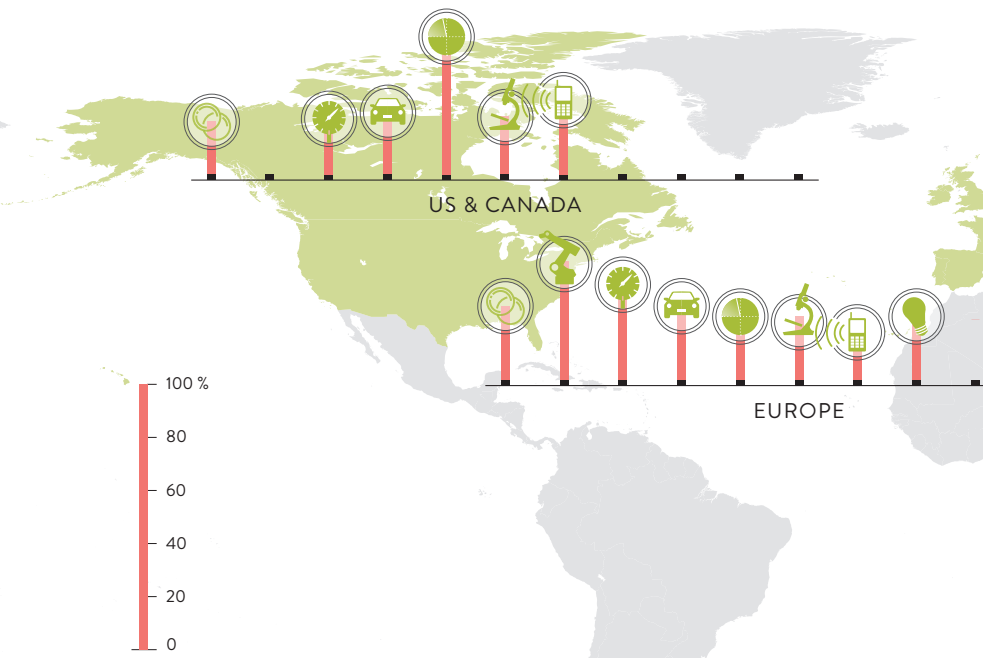




Launch of the public-private partnership between the European Commission and the European photonics industry
Foundation of the American National Photonics Initiative to promote photonics in the US
In the context of the high-tech strategy for Germany, photonics replaces the term of "optical technologies" which had been used so far
European Commission defines photonics as key technology
Foundation of the European photonics community Photonics21
Leading US conference and exhibition changes its name from OE/LASE to Photonics West
Photonics21 multi-annual Strategic Roadmap 2023-2030
1995
2000
2005
2010
2015
2020

45

# PHOTONICS AROUND THE GLOBE

Photonics is a global industry today. This graphic shows the strongest market segments in each region. These translate into tremendous economic impact and great career opportunities.

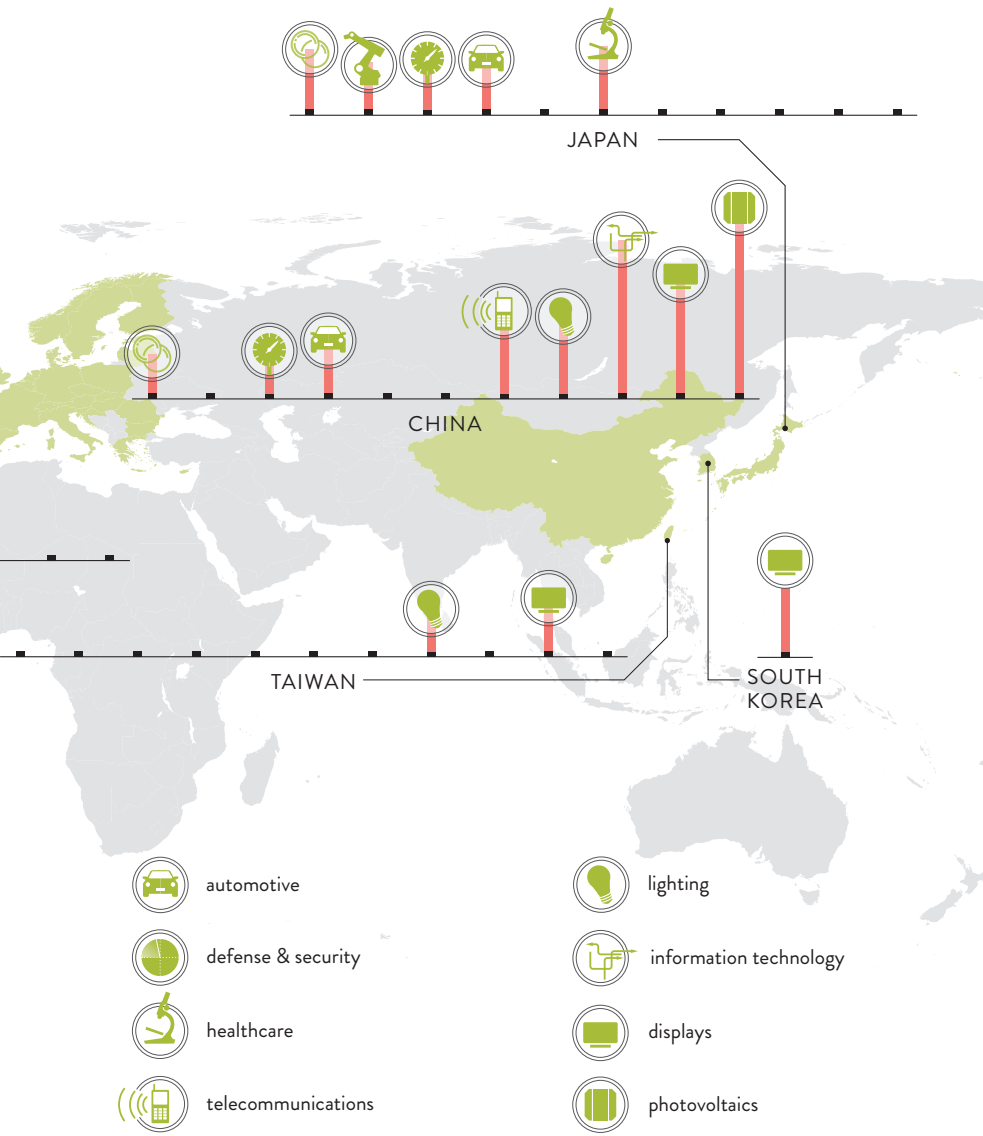



**Global market share in the market segment**

To emphasize regional strengths, only market shares of more than 10% are shown.

**Market segments**

- optical components
- production systems
- machine vision




automotive

defense & security

healthcare

telecommunications

lighting

information technology

displays

photovoltaics

46

# NOBEL LAUREATES

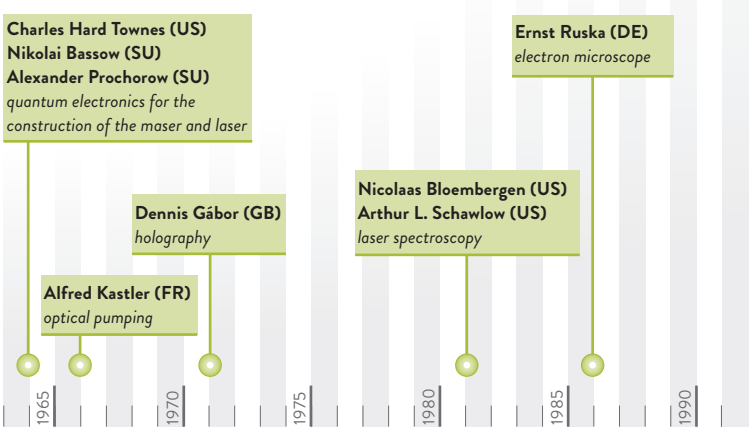
Nobel laureates with a connection to photonics
since the invention of the laser in 1960

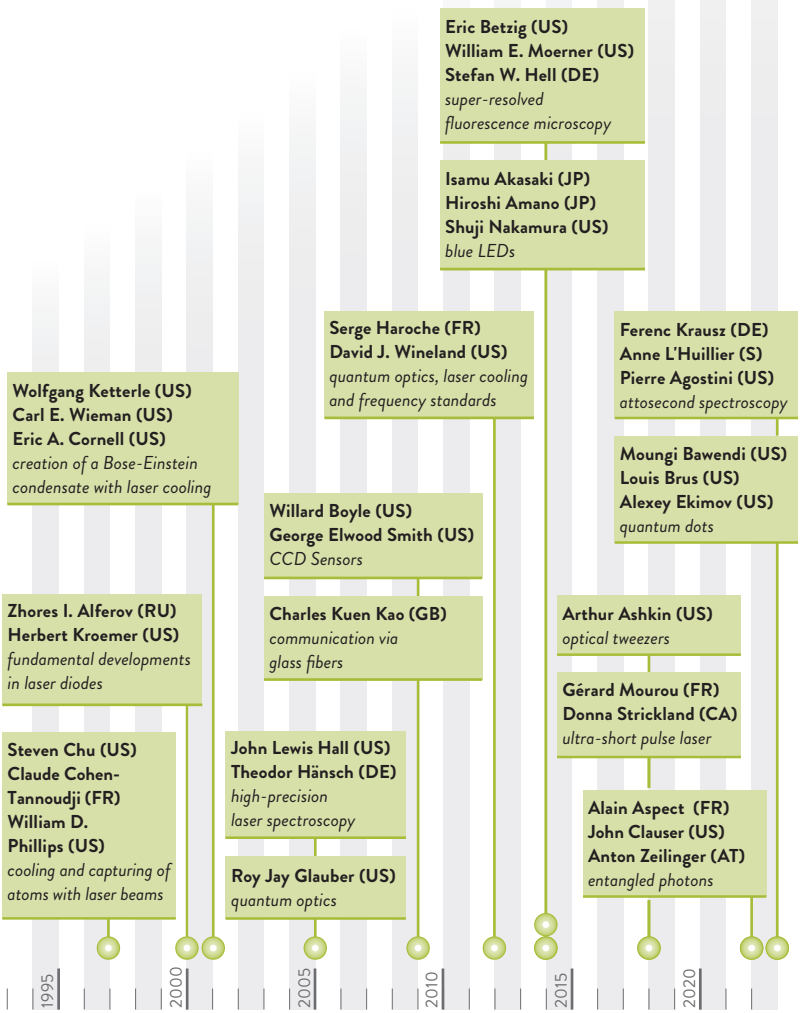
## NUMBER OF LAUREATES

by country at the time of the award ceremony


## NOBEL LAUREATES

with award-winning research projects

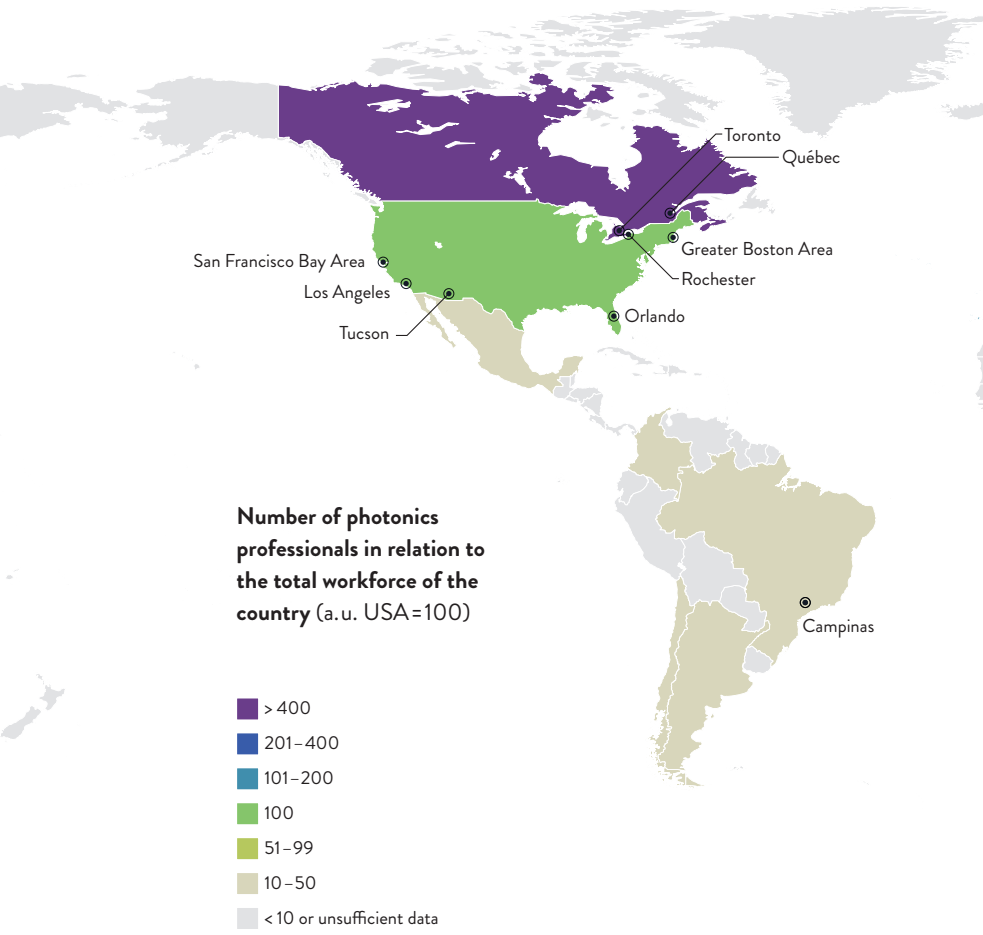



Eric Betzig (US)
William E. Moerner (US)
Stefan W. Hell (DE)
super-resolved fluorescence microscopy
Isamu Akasaki (JP)
Hiroshi Amano (JP)
Shuji Nakamura (US)
blue LEDs
Serge Haroche (FR)
David J. Wineland (US)
quantum optics, laser cooling and frequency standards
Ferenc Krausz (DE)
Anne L'Huillier (S)
Pierre Agostini (US)
attosecond spectroscopy
Wolfgang Ketterle (US)
Carl E. Wieman (US)
Eric A. Cornell (US)
creation of a Bose-Einstein condensate with laser cooling
Mounqi Bawendi (US)
Louis Brus (US)
Alexey Ekimov (US)
quantum dots
Willard Boyle (US)
George Elwood Smith (US)
CCD Sensors
Zhores I. Alferov (RU)
Herbert Kroemer (US)
fundamental developments in laser diodes
Charles Kuen Kao (GB)
communication via glass fibers
Arthur Ashkin (US)
optical tweezers
Gérard Mourou (FR)
Donna Strickland (CA)
ultra-short pulse laser
Steven Chu (US)
Claude Cohen-Tannoudji (FR)
William D. Phillips (US)
cooling and capturing of atoms with laser beams
John Lewis Hall (US)
Theodor Hänsch (DE)
high-precision laser spectroscopy
Roy Jay Glauber (US)
quantum optics
Alain Aspect (FR)
John Clauser (US)
Anton Zeilinger (AT)
entangled photons
1995
2000
2005
2010
2015
2020

47

# PHOTONICS COUNTRIES

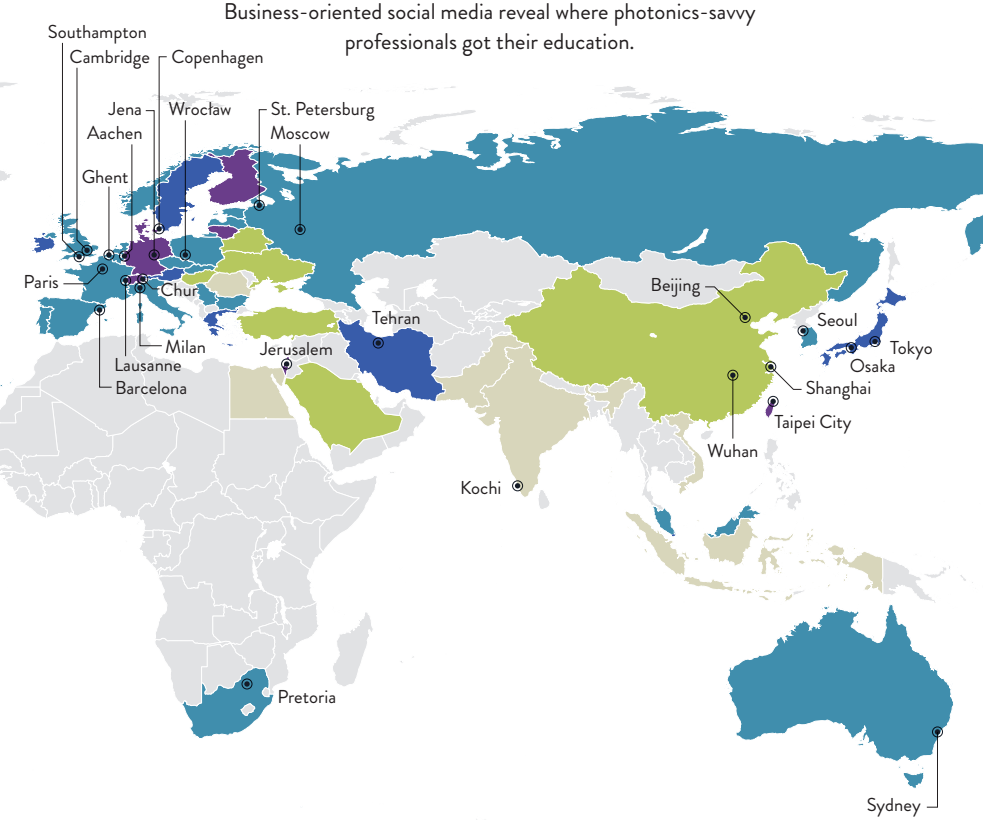
The highest density of photonics professionals are found in Europe and East Asia.



48

# PHOTONICS SCHOOLS

Business-oriented social media reveal where photonics-savvy professionals got their education.




**A selection of great places to study photonics**

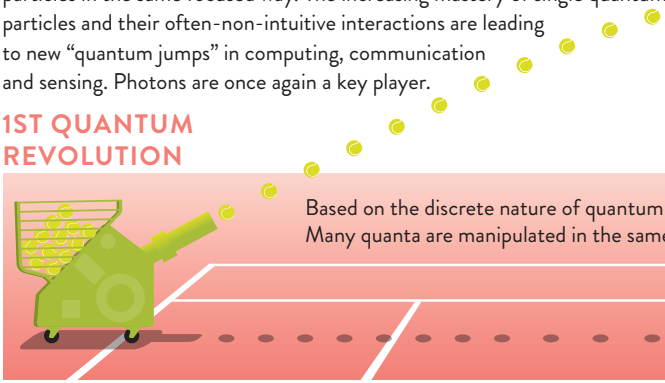
◉ University town

49

# QUANTUM TECHNOLOGIES

Lasers and electronics use quantum theory to manipulate myriad quantum particles in the same focused way. The increasing mastery of single quantum particles and their often-non-intuitive interactions are leading to new "quantum jumps" in computing, communication and sensing. Photons are once again a key player.

## 1ST QUANTUM REVOLUTION



Based on the discrete nature of quantum particles. Many quanta are manipulated in the same way.

## THEORY

### QUANTUM MECHANICS

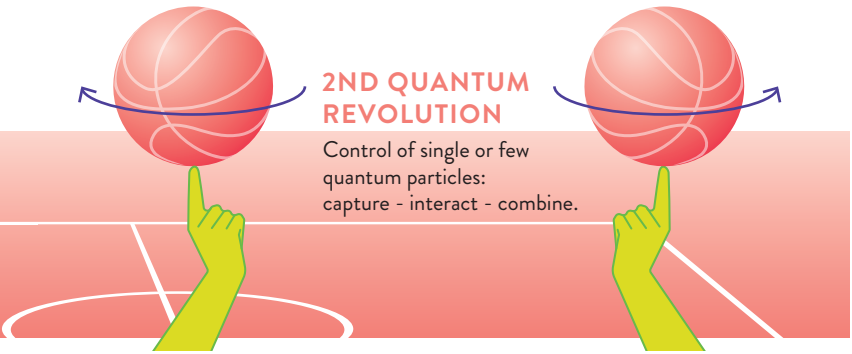
**DISCIPLINES**

- ATOMIC PHYSICS AND CHEMISTRY
- SOLID STATE PHYSICS
- NUCLEAR PHYSICS

**TECHNOLOGIES**

- **NUCLEAR FISSION** — Nuclear power plants
- **TRANSISTOR** — Microelectronics
- **ATOMIC CLOCKS** — Global timekeeping
- **LASER** — Photonics
- **NUCLEAR MAGNETIC RESONANCE** — Magnetic resonance imaging

## 20TH CENTURY



## 2ND QUANTUM REVOLUTION

Control of single or few quantum particles:
capture - interact - combine.

### QUANTUM INFORMATION SCIENCE

- QUANTUM COMPUTING
- QUANTUM COMMUNICATION
- QUANTUM SENSING

- QUANTUM KEY DISTRIBUTION
- INTER- & INTRA-CITY COMMS
- GRAVIMETER
- FAULT-TOLERANT QUANTUM COMPUTER
- INTERMEDIATE SCALE QUANTUM COMPUTER
- QUANTUM INTERNET
- QUANTUM COMPASS
- MEDICAL QUANTUM IMAGING

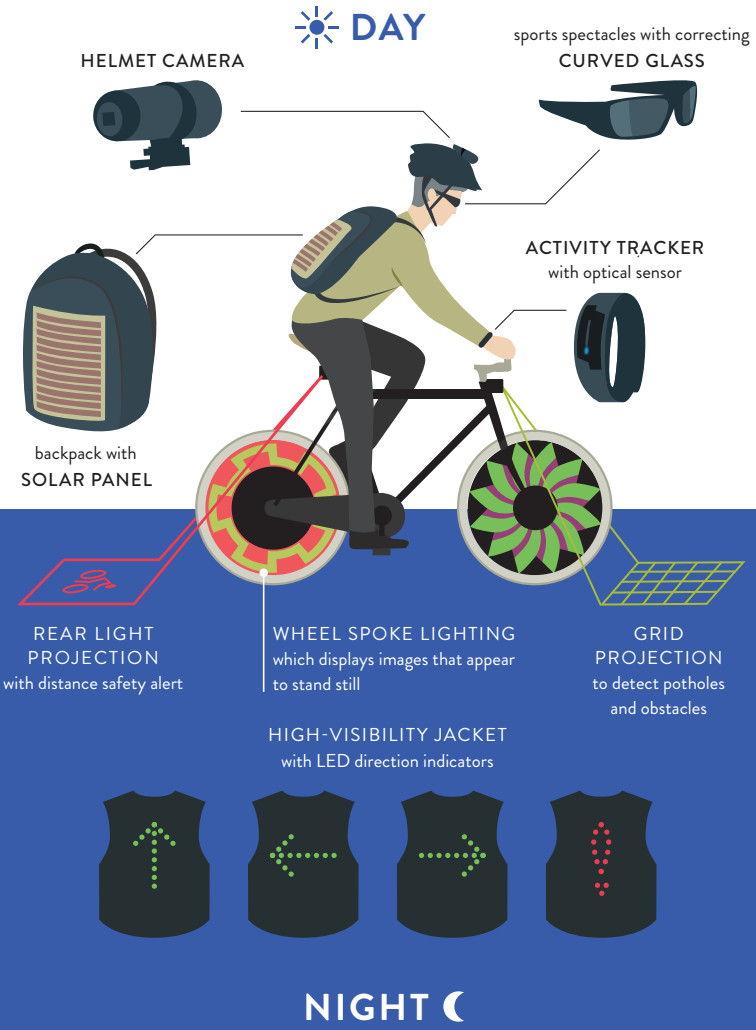
**21TH CENTURY**

# ONE MORE THING...

50

# PHOTONICS ENTHUSIAST

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



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