Ciências ULisboa

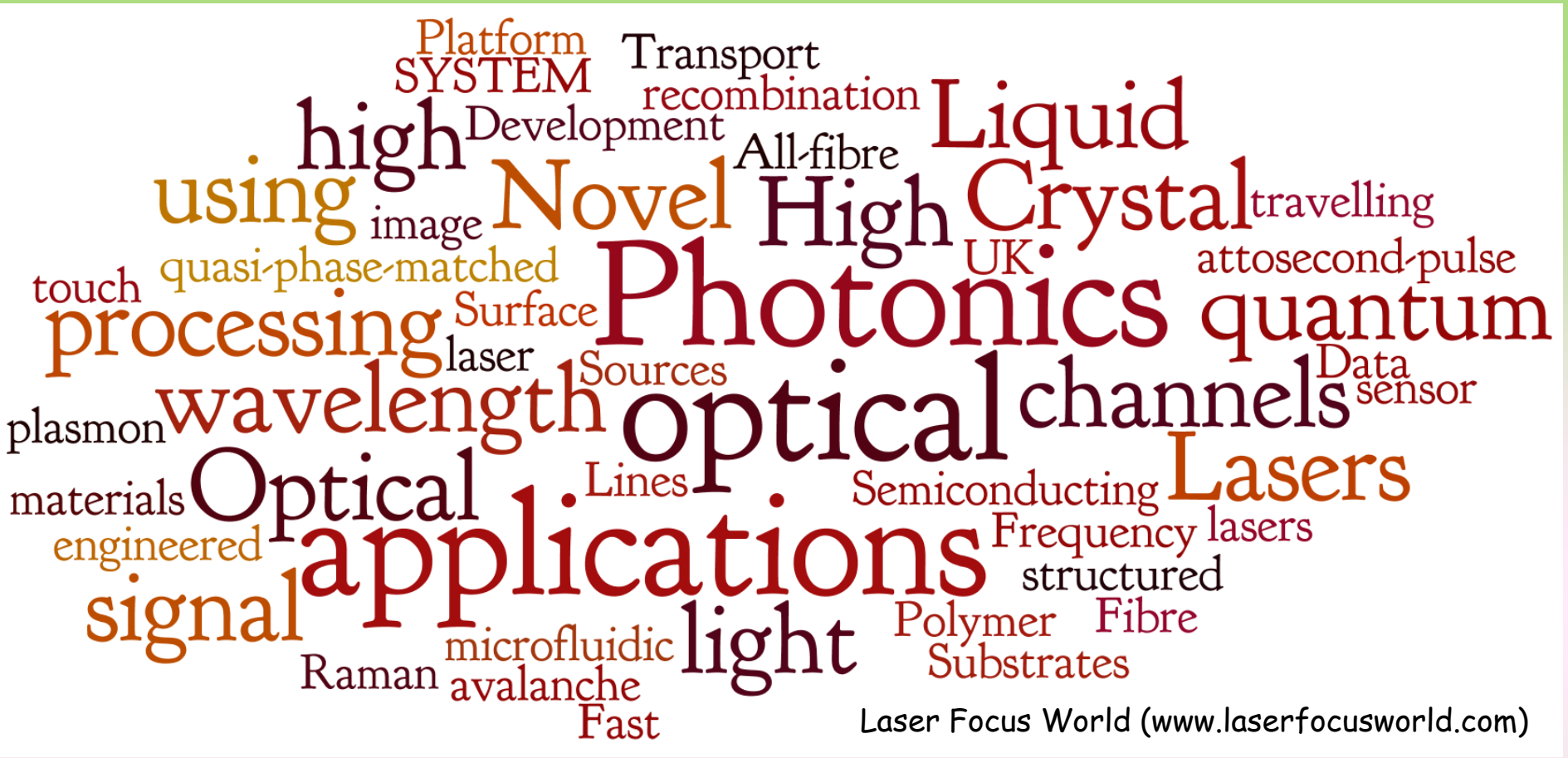
Photonics

Engineering Physics

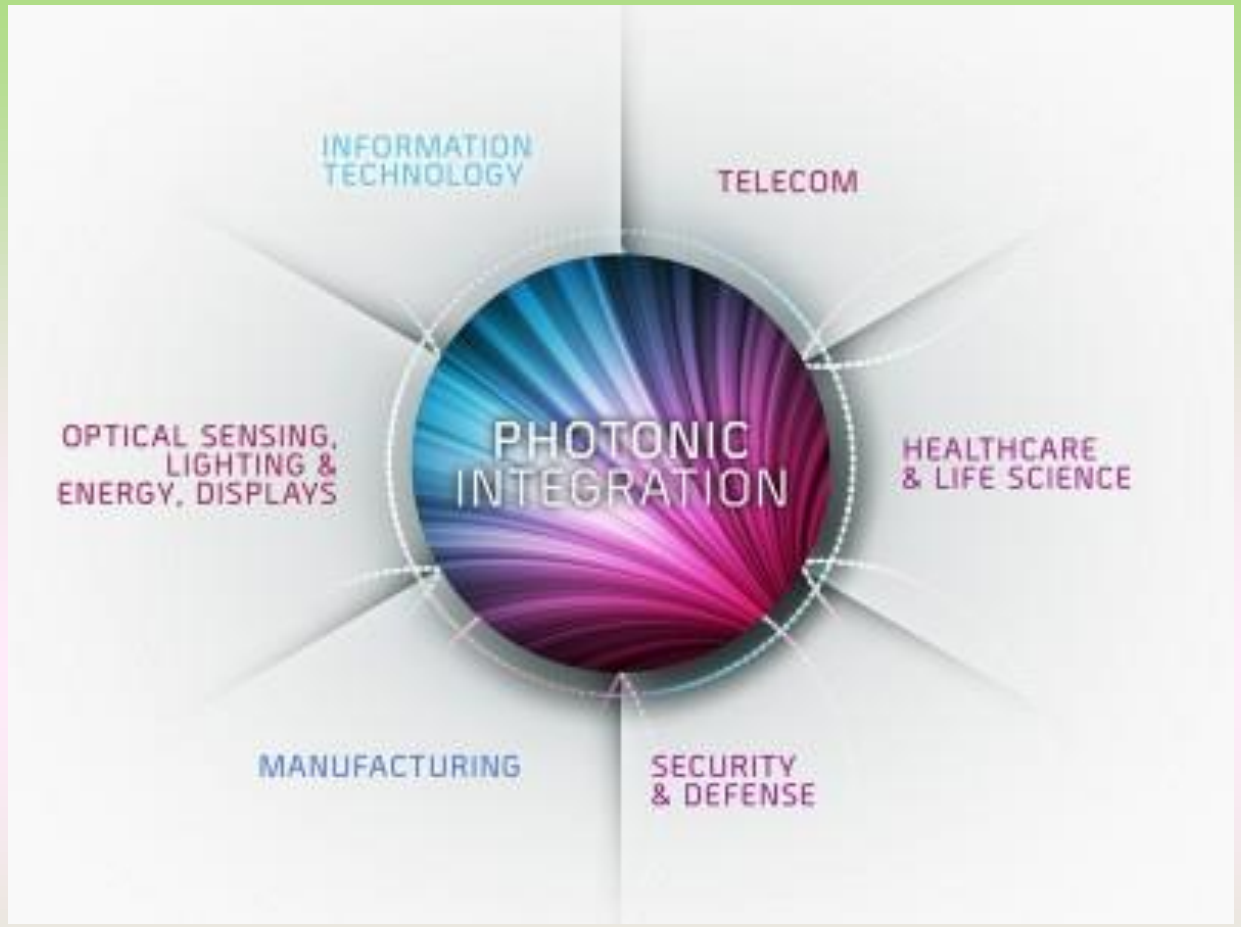
J. M. Rebordão
David Alves

Facebook: Fotónica – Ciências

2020/2021



Laser Focus World (www.laserfocusworld.com)

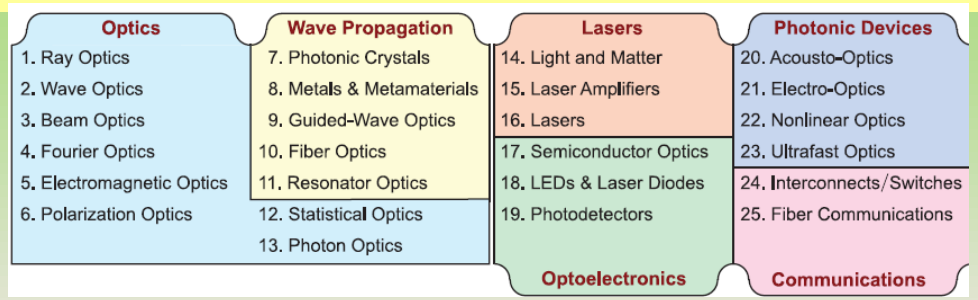


https://www.phiconference.com/photonics/why-europe-cares-about-the-exponential-success-of-photonics/

General Objectives

- Fornecer os conceitos fundamentais e o desenho (essencialmente) qualitativo das configurações que estão na base das principais aplicações da luz (fotónica) no século XXI.
- Identificar e descrever funções passíveis de implementação óptica no contexto das tecnologias da sociedade de informação (tais como, por exemplo, comunicações, comutação, processamento, interconexões, redes).
- Clarificar os domínios (sobreponíveis) associados à fotónica, optoelectrónica, óptica quântica e nano-óptica, tanto em termos científicos e tecnológicos, como industriais.

Saleh, *Photonics* (2019)



Optics

1. Ray Optics	8. Metals & Metamaterials	14. Light and Matter	20. Acousto-Optics
2. Wave Optics	9. Guided-Wave Optics	15. Laser Amplifiers	21. Electro-Optics
3. Beam Optics	10. Fiber Optics	16. Lasers	22. Nonlinear Optics
4. Fourier Optics	11. Resonator Optics	17. Semiconductor Optics	23. Ultrafast Optics
5. Electromagnetic Optics	12. Statistical Optics	18. LEDs & Laser Diodes	24. Interconnects/Switches
6. Polarization Optics	13. Photon Optics	19. Photodetectors	25. Fiber Communications
7. Photonic Crystals			

Photonic Devices

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Guided-Wave Optics

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Nonlinear & Ultrafast Optics

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Lasers

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Optical Information Processing

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Andrews, *Photonics - Scientific Foundations, Technology and Applications* (2015)

Contents – **theory**

- **EM Properties of Materials**
- **Wave guides**
  - Planar waveguides
  - Integrated optics
  - Optical fibers
    - Attenuation
    - Dispersion
- **Nonlinear optics**
  - Description
  - Parametric processes
    - 2nd harmoncs generations and *phase matching*
    - Effects of intensity on refraction index
    - Four Waves mixing
  - Non-Parametric processes
    - Dispersion: Rayleigh, Mie
    - Dispersion: Raman and stimulated Raman
    - Dispersion: Brillouin and stimulated Brillouin
- **Optics of anisotropic media**
  - Polarization modelling
  - Index ellipsoid
  - Electrooptics
  - Modulators
- **Sources**
  - Laser - fundamentals
  - Laser systems
  - Exemples
  - Semicondutor sources
    - LEDs
    - Semicondutor lasers
- **Laser pulses**
  - Pulses' mathematics
  - Filters
  - Metrology
  - CPA (Chirped Pulse Amplification)

Assessment

LABORATORY – 45%

- Acustoópticos: transmissão de som
- Fotodíodos: montagens e verificações de propriedades
- Lasers díodo: parâmetros de funcionamento, variações com temperatura, corrente ...
- Filtros/ atenuadores/ analisadores de espectro óptico

PROBLEMS – 0%

- Solving a number of problems per section of the program

MONOGRAPHY – 35%
(examples)

- Um dos capítulos do Andrews (inspiração)
- Óptica do grafeno
- Cristais fotónicos
- Sensores plasmónicos
- Metamateriais
- Lasers em fibra
- Lasers e sensores de poços quânticos (*quantum wells*)
- LED's de elevada radiância
- Fotónica das nanopartículas
- Fotónica do silício
- ….

ORAL PRESENTATIONS – 20% (examples)

- Fibras de alto débito binário
- Fibras para o IR médio
- Redes de fibra : componentes e funções
- Conjugação de fase
- 2ª harmónica e ajuste de fase
- Emissores super-luminescentes
- …

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fiber-modeling.pt

fibre_optics_presentation_(presentation).ppt

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Industry / Strategy

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Optics & Photonics: Essential Technologies for Our Nation

Innovation in Optics and Photonics: Enabling Technology for our future

Photonics

"Photonics is the science of the harnessing of light. *Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind."*

Photonics is an area of study that involves the use of radiant energy (such as light), whose fundamental element is the **photon** . Photonic applications use the photon in the same way that electronic applications use the electron . Among the large number of current or possible photonic applications are: photonic switching, photonic networks, the photonic computer.

Photonics is one of the fastest growing **high-tech industries** in the world today. It includes:

- optical communications (e.g., fiber optics, lasers, and infrared links),
- optical imaging (e.g., spy and weather satellites, night vision, holography, flat screen display, and CCD video cameras),
  optical data storage and optical computing (e.g., CD's and DVD's),
- optical detectors (e.g., supermarket scanners, medical optics, and nondestructive evaluation of materials),
- lasers (e.g., welding lasers, laser surgery, laser shows, and laser rangefinders)
  spectroscopy (e.g., chemical and biological detection, anti-terror detection)
- quantum optics (e.g., quantum teleportation, quantum cryptography, and single-photon optics)

Photonics21

https://www.photonics21.org/

Photonics21 Downloads

PDF – 3.71 MB

Europe's age of light! How photonics will power growth and innovation

Download

PDF – 1.41 MB

Photonics21 Annual Activity Report 2018

Download

PDF – 5.14 MB

Photonics21 – Photonics cPPP Progress Monitoring Report 2018

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PDF – 5.73 MB

Photonics - A critical Key Enabling Technology for Europe

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Photonics PPP Services to European SMEs

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Photonics21 Vision Paper towards FP9

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Photonics Market Research Study 2017

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PDF – 2.3 MB

Key Data Photonics Research Study 2017

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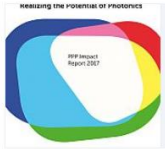


PDF – 6.09 MB

PPP Impact Report

Download

Photonics21 - Europe's age of light! How photonics will power growth and innovation (2017)

https://www.photonics21.org/ppp-services/photonics-downloads.php

Europe's age of light!

How photonics will powe growth and innovation

PHOTONICS21

Contents

Photonics for Health & Earth

As part of this month's special issue on photonics in Europe, here we look at some ways photonics could help solve major challenges facing Europe and the world by 2030—challenges such as keeping an aging population healthy and productive, making efficient use of resources, and providing safe and nutritious food for a growing population. These areas and several others are outlined in a vision document by the European technology platform Photonics21 (http://bit.ly/photonics21-vision-paper).

Worldwide, the number of people age 60 years or older will rise from **900 million** to **2 billion** by 2050.
World Health Organization

LIVING LONGER & HEALTHIER

Healthcare photonics

2030 MISSION: Instant diagnosis of major diseases

PLAN: Use next-generation photonics to make "theranostics" possible—precision medicine that combines diagnostics with therapy to treat diseases earlier and faster.

TREATING CANCER: Surgeons will use **multimodal imaging** (including fluorescence and molecular imaging) to identify cancerous tissues and individual cells, and **high-precision lasers** to immediately remove the identified pathological cells.

BEYOND CANCER: This "**smart laser scalpel**" could be deployed in future robotic surgery and applied to other medical conditions.

A CLEAN ENVIRONMENT

Green photonics

2030 MISSION: A truly circular economy with zero emission and less waste

PLAN: Design products with reuse in mind; use photonics technology for zero-defect, high-precision production, and to sort materials and parts for reuse.

MOVING TOWARD ZERO WASTE: **Multispectral** and **hyperspectral imaging** systems will help separate industrial and household waste. **Laser-induced plasma spectroscopy** will also help precisely identify materials. **Fluorescent tagging** of objects during production will allow sorters to identify them at the moment of disposal. **Laser-based** disassembly lines will be able to separate complex products into components for further use.

Every year, an estimated **12.6 million** people die as a result of living or working in an unhealthy environment.
World Health Organization

FEEDING THE WORLD

Agriphotonics

2030 MISSION: Safe, nutritious and affordable food for all

PLAN: Use precise sensors and measuring devices to monitor and certify the safety, quality, content and origin of food at any step in the process.

ON THE FARM: **Sensitive imaging** will detect earliest onset of pests and disease, reducing the need for chemicals. **Spectrometry** and **laser scanning** will detect produce ripeness and determine the best time to harvest and ship.

IN FOOD PROCESSING: **Hyperspectral imaging** will identify and remove defects and foreign matter. **Fluorescence spectroscopy** will monitor amino acids, vitamins and allergens.

AT RETAILER/CONSUMER LEVEL: **Spectrometers** connected via smartphones will be able to pinpoint the likely origin of produce based on information like sugars, phenols, amino acids and antioxidants.

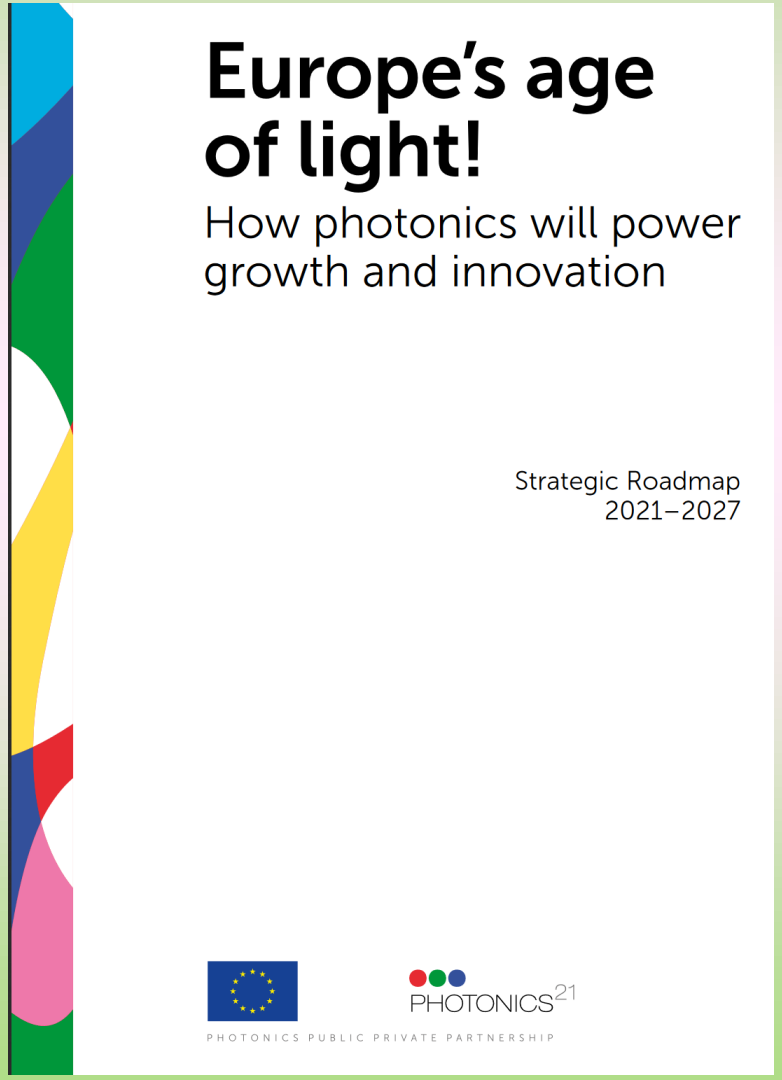
An estimated **600 million** people in the world fall ill after eating contaminated food every year.
World Health Organization

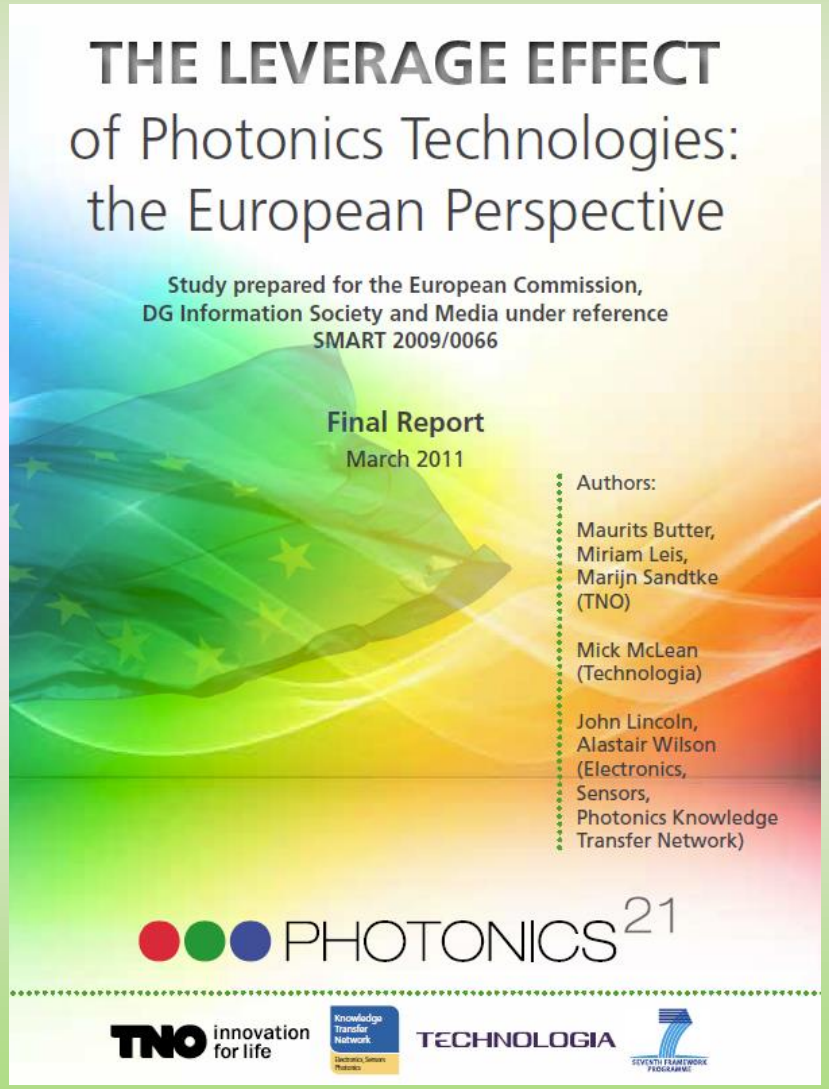
In 2015, **8.8 million** people died from cancer—nearly 1 in 6 global deaths.
World Health Organization

Source: Photonics21, "Europe's Age of Light" (November 2017)
Photos: Getty Images / Infographic by Alessia Kirkland

Photonics21 - http://www.photonics21.org (2019)

"Photonics is the science of the harnessing of light. *Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind."*





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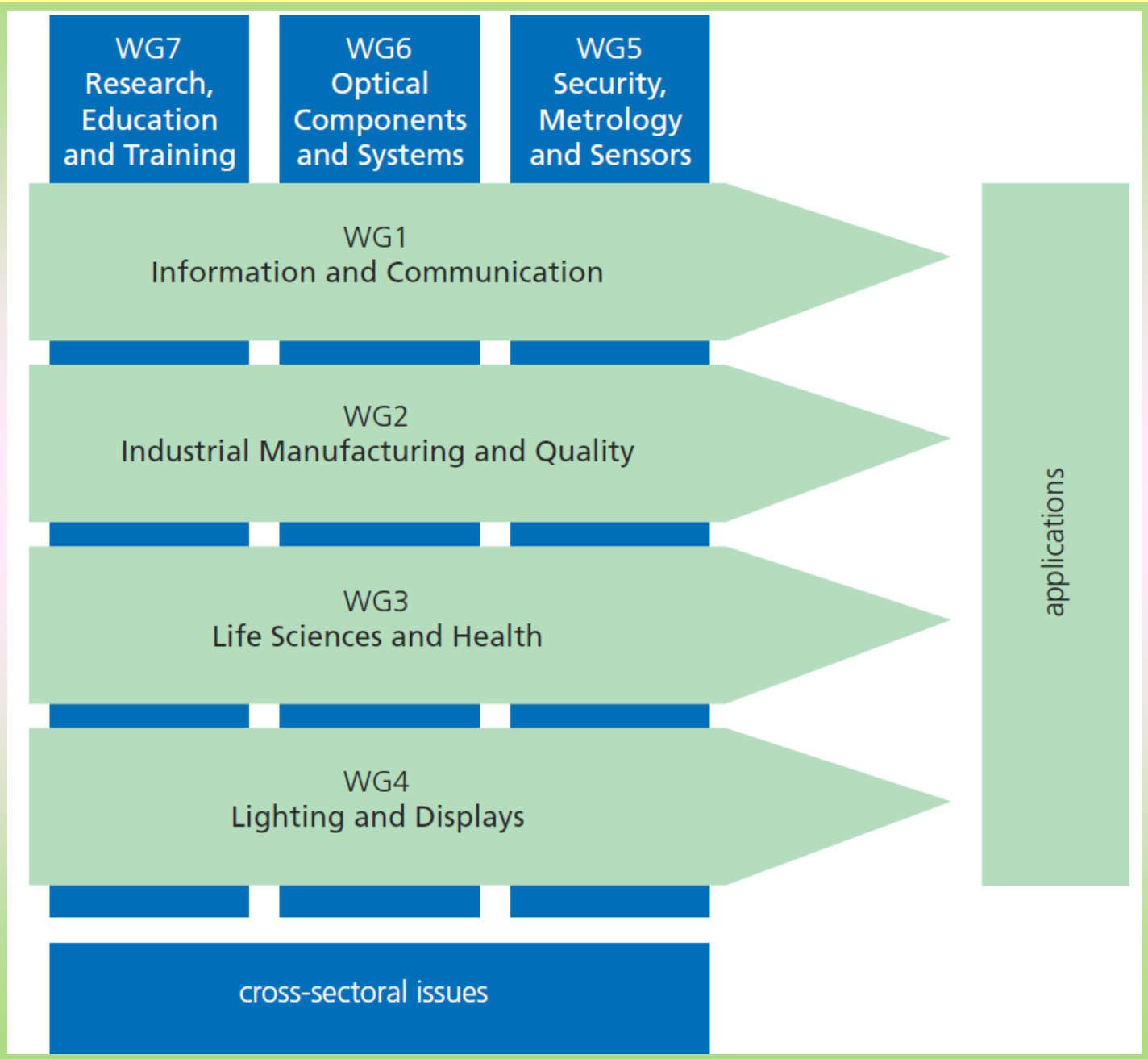
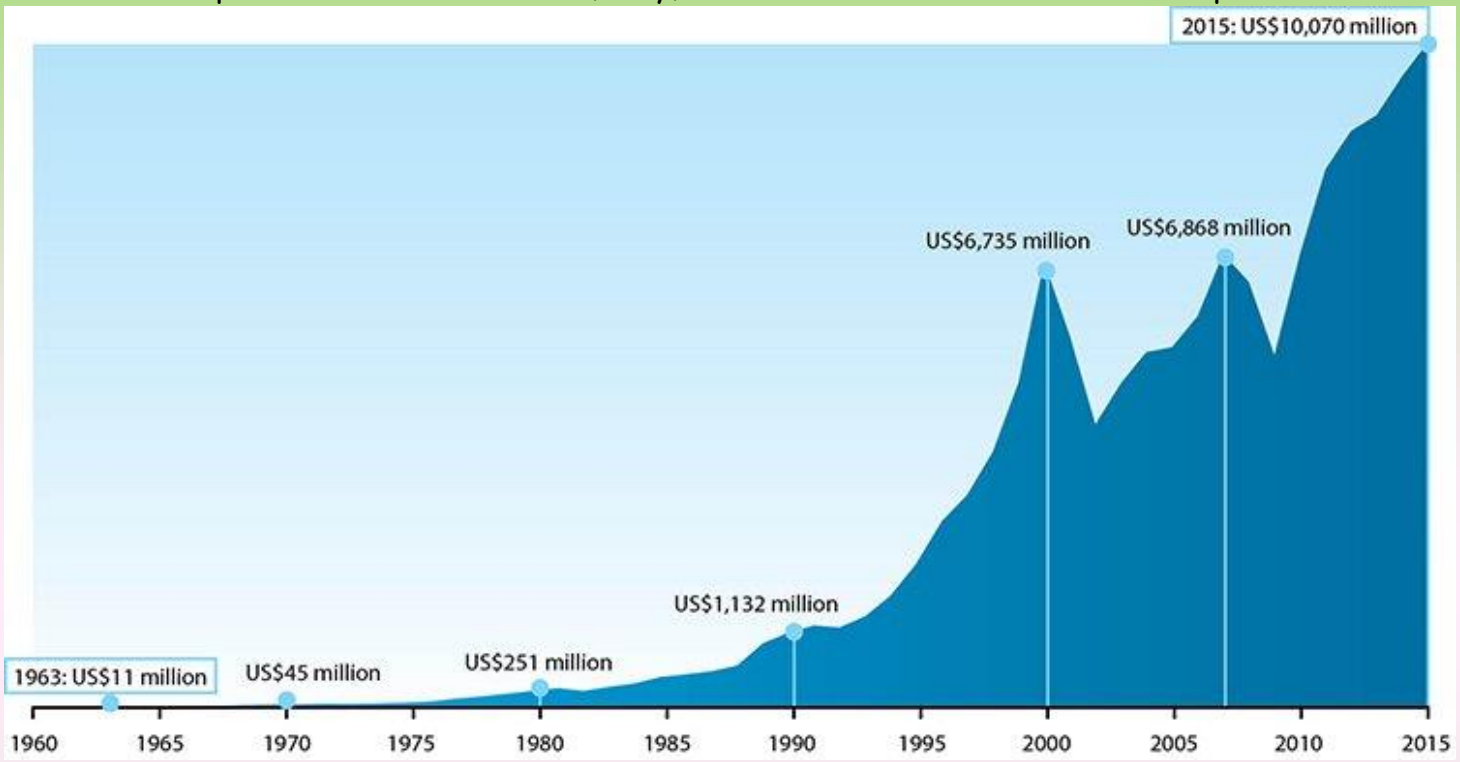


Photonics (2015)

Optics and Photonics News, May, 2016 – The 100-Year of Photonics: part 1

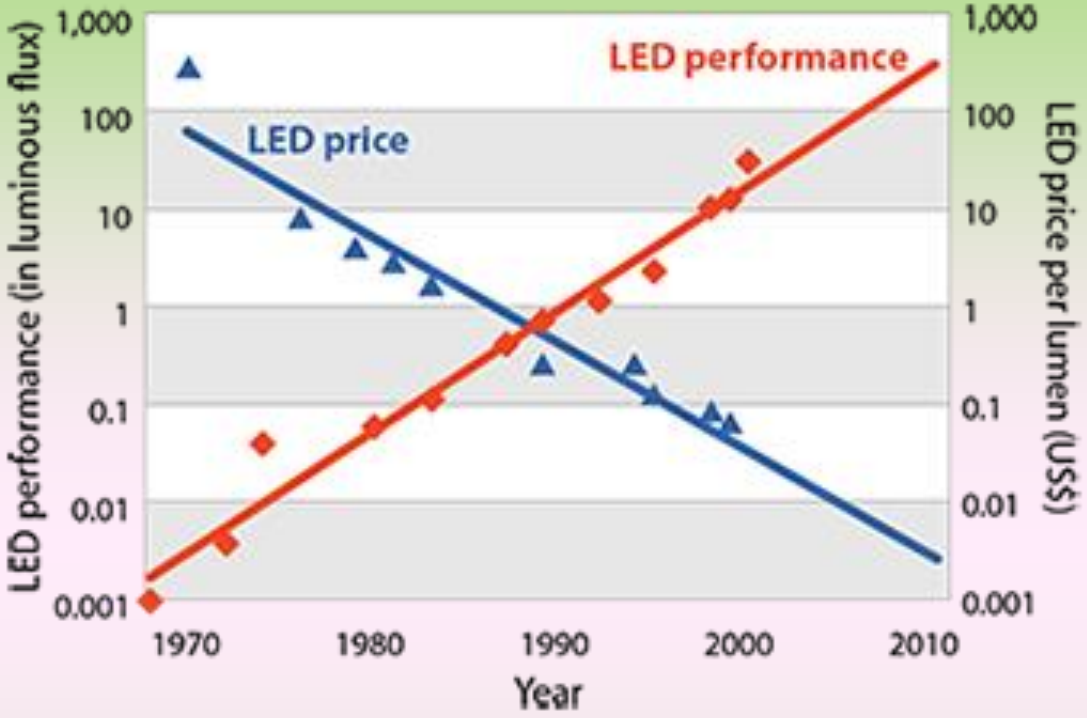


Seven major developments drove Photonics:

- Electric lighting
- Displays
- Fiber Optics communnications
- Cameras and Imaging
- Microlithography optics
- Deep science
- Vision correction

A “Moore’s Law” for LEDs?

http://www.osa-opn.org/home/articles/volume_27/november_2016/features/osa_centennial_snapshots_illuminating_the_new_cen/



Computer scientists are familiar with an observation made by Intel Corp. co-founder Gordon Moore that notes that the number of transistors on an integrated circuit doubles every two years. Does a similar rule hold for a different kind of semiconductor chip—the light-emitting diode?

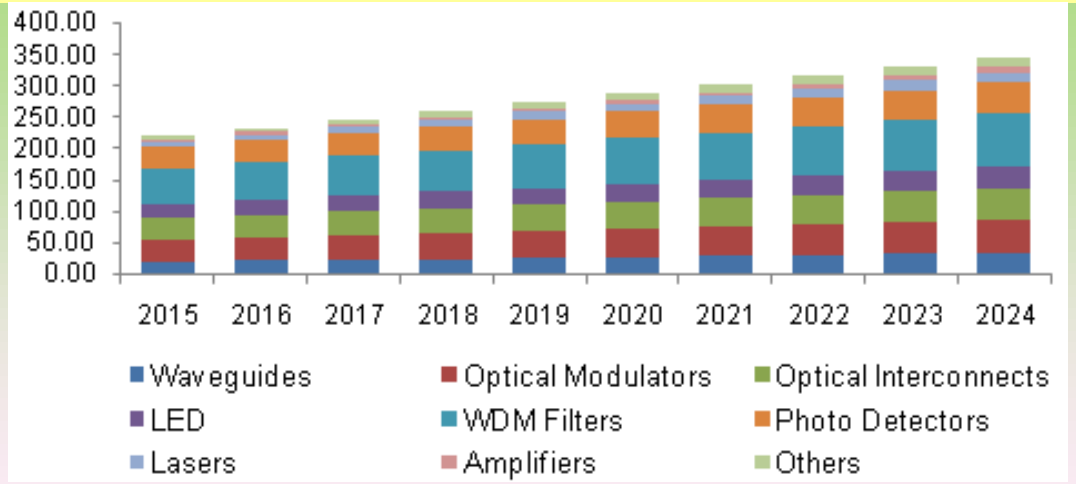
Roland Haitz (1935-2015) thought so. A longtime researcher at Hewlett-Packard and Agilent Technologies, he was co-author of a 1999 Optoelectronics Industry Development Association report that, at a conference in 2000, projected that the amount of light generated from LEDs would increase by a factor of 20 per decade—accompanied by a factor-of-10 decrease in cost per lumen over the same period. Haitz also predicted that the industry would reach the efficiency benchmark of 200 lumens per watt by 2020. As it had done for Moore’s Law, the optimization of the semiconductor-manufacturing process would drive these changes.

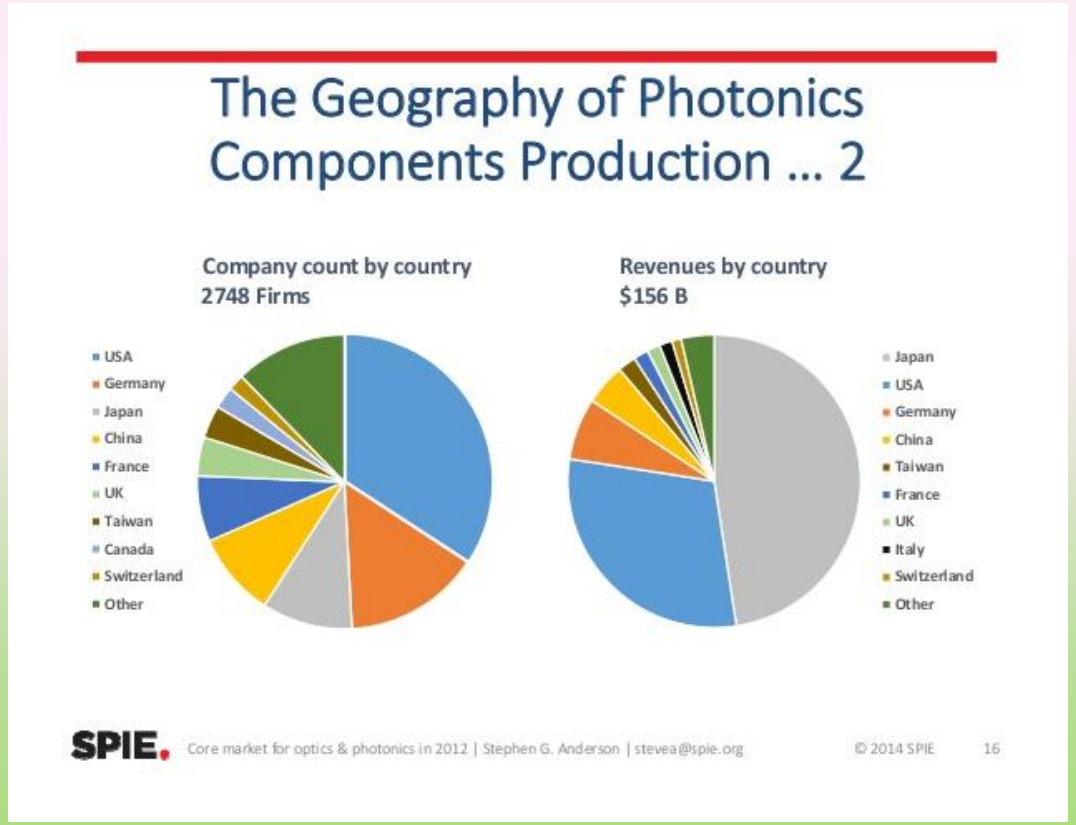
Accumulated data over the past decade and a half have generally borne out “Haitz’s law.” The L Prize-winning bulb emitted 94 lumens per watt, and manufacturer Cree Inc. claimed that it had broken 100 lm/W in 2010. Today, a quick online search for 60- and 100-W equivalent LED bulbs finds many in the approximate 100 lm/W range.

Photonics

North America photonics market by product, 2015 - 2024 (USD Billion)

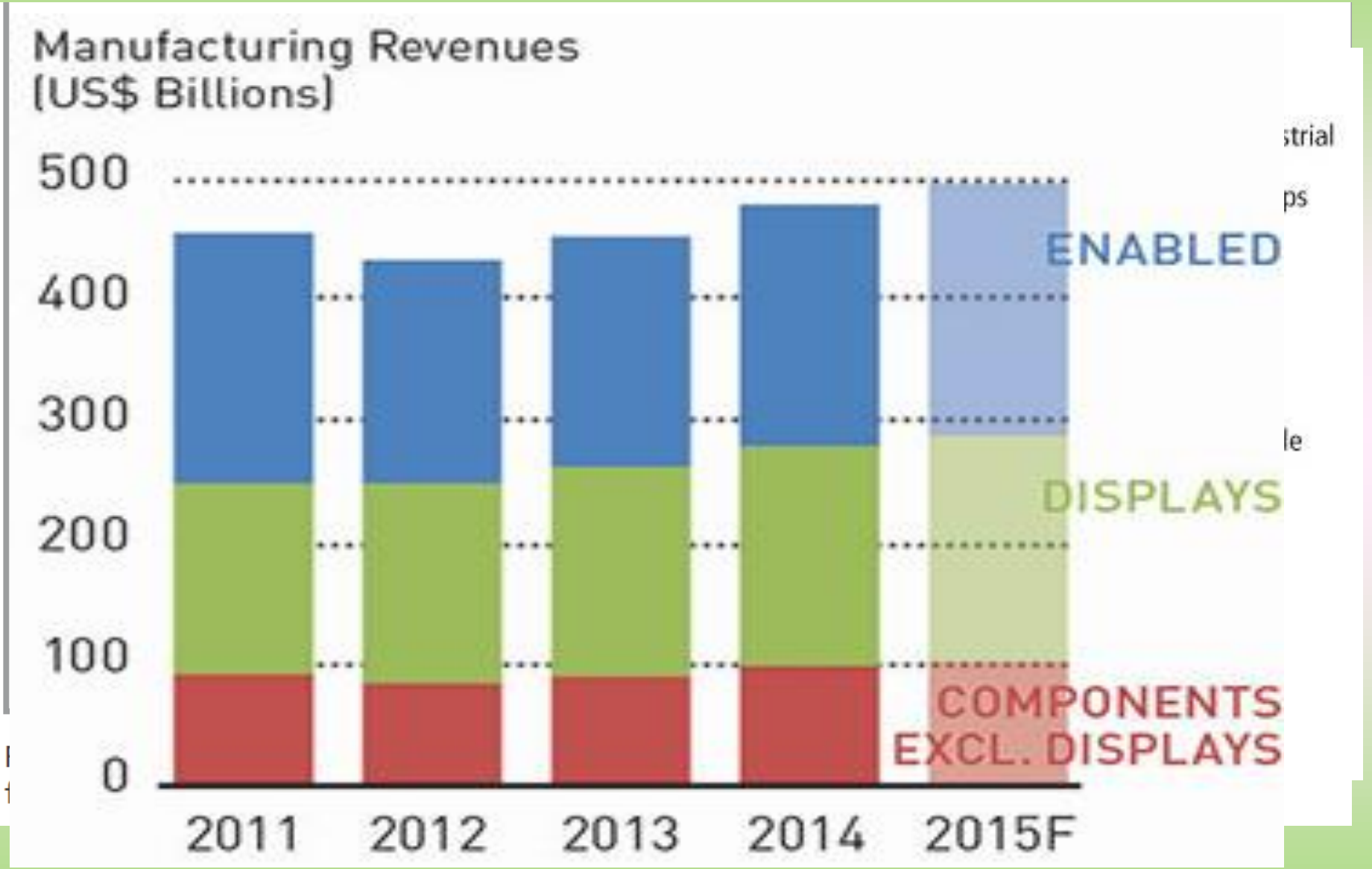
https://www.grandviewresearch.com/industry-analysis/photonics-market

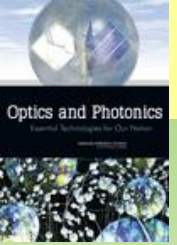




https://www.slideshare.net/stephenga/optics-and-photonics-core-market (data in 2012)

Photonics[21]





Photonics – Optical Society of America (OSA)

Optics & Photonics: Essential Technologies for Our Nation

Innovation in Optics and Photonics: Enabling Technology for our future

Optics and Photonics are Specialized Fields of Physics and Engineering

From fiber optics and telecommunications to medical imaging and cancer research, optics and photonics are advancing today's critical technologies. Based on the science of light, optics and photonics are specialized fields of physics and engineering. These technologies are prevalent in almost every aspect of day-to-day life. From your computer screen to your cell phone and car headlights, optics and photonics are critical technologies that will continue to grow and enhance people's lives.

Optics and Photonics Technologies Enhance the Quality of Life in Many Areas

Medicine and Health

Optics and photonics are utilized in numerous medical devices that help to save lives. Imaging equipment used for CAT, MRI and PET scans, as well as mammography, aid in the diagnosis of disease.

Defense and Homeland Security

Science and engineering research is the basis for many of the technologies currently being deployed to prevent and detect chemical, biological, radiological, nuclear and conventional terrorist attacks, as well as treat victims.

Telecommunications

Fiber optics connect the world through high-speed communications. In fact, the World Wide Web was developed by optics researchers. Today's optics research is bringing higher-speed communications to our homes via fiber technology – enabling advanced data transmissions, like video streaming, and other broadband applications.

Consumer Technologies

Many of today's "must-have" technologies such as digital cameras, high definition TVs and PDAs, were developed through optics and photonics research. Further research is expected to yield even more consumer products designed to enhance quality of life.

Photonics – Europe

EPIC – European Photonics Industry Consortium

MONA project (Merging Optics and Nanotechnologies

A European roadmap for photonics and nanotechnologies (MONA, March, 2008)

Holland Photonics Roadmap (2-12-2011)

Applications "Markets"	Components + Systems "Functions"	Technologies "Capabilities"	Processes "Supply chain"
HTSM, ICT, Agro Food, Water, Energy, Chemicals, Aerospace, Logistics, Healthcare, Life sciences, Security, Lighting, Manufacturing, Automotive	Detection, Emission, Propagation, Light processing, Interconnection	Photonic integration, Photonic – Electronic integration, Core- & disruptive technologies, Free space- micro-optics, New materials	Equipment, Manufacturing, Prototyping, Simulation, Design
Requirements	**Performance**	**Integration level**	**Realisation**

nature Photonics (https://www.nature.com/nphoton/)

Photonics — the scientific study and application of light — has evolved to become a key technology behind many devices found in the modern home, factory and research lab.

Today, the field is both a Nobel-prize-winning science and a billion-dollar industry, underpinning applications such as fibre-optic communication, data storage, flat-panel displays and materials processing.

Coverage extends from research into the fundamental properties of light and how it interacts with matter through to the latest designs of optoelectronic device and emerging applications that exploit photons.

The journal covers **topics including** (2018):

- **Lasers, LEDs and other light sources**
- **Imaging, detectors and sensors**
- **Optoelectronic devices and components**
- **Novel materials and engineered structures**
- **Physics of light propagation, interaction & behaviour**
- **Quantum optics and cryptography**
- **Ultrafast photonics**
- **Biophotonics**
- **Optical data storage**
- **Spectroscopy**
- **Fibre optics and optical communications**
- **Solar energy and photovoltaics**
- **Displays**
- **Terahertz technology**
- **Nonlinear optics**
- **Plasmonics**
- **Nanophotonics**
- **X-rays**

Photonics – RP Photonics Encyclopedia

Photonics is the science and technology of light, with an emphasis on applications. Alternative: ***lightwave technology*.**

At the heart of photonics are technologies for generating light (e.g. with lasers or with light-emitting diodes), transmitting, amplifying, modulating and detecting light, and particularly using light for practical purposes. It thus builds heavily on optical technology, supplemented with modern developments such as lasers and amplifiers.

Typical application areas:

- information technology: e.g. optical fiber communications, free-space optical communications, and optical data storage, in the future probably also optical computing
- health care and life sciences: e.g. medical diagnostics and therapy in ophthalmology and cancer research; biology, biotechnology, DNA analysis
- optical metrology in various areas: e.g. frequency metrology for time keeping or distance measurements with lasers
- sensing: e.g. fiber-optic sensors, high-speed cameras, infrared motion detectors or industrial process control
- manufacturing: e.g. laser material processing, semiconductor chip manufacturing, printing
- lighting: e.g. energy-efficient LED illumination
- defense and space technology: e.g. satellite surveillance systems, navigation, night vision, imagers, missile guidance, anti-missile systems, high-power directed-energy weapons

Photonic key technologies of particular importance: lasers and amplifiers, light-emitting diodes (LEDs), optical fibers and other waveguides, optical modulators, photo-detectors (including cameras), and displays.

Analogy with electronics: just as electronics is the utilization of electrons, photonics works on the basis of photons. The quantum (photon) nature of light is often, but by far not always, of interest in photonics.

Photonics is considered as one of the **key technologies of the 21st century**:

It supplements electronics in the form of optoelectronics (optronics) and exhibits a strong market growth, which is expected to continue for the foreseeable future. So far, photonics has achieved a deep penetration of mass markets in only a few areas, e.g. laser diodes in CD/DVD players and related data storage equipment. Huge growth opportunities could arise from the development of silicon photonics and other technologies for photonic integrated circuits, from LEDs with improved output power and efficiency, or from laser types (e.g. VECSELs) which are suitable for cost-effective mass production.

Opto-electronics

IOA – International Optoelectronics Association

Optoelectronics: study & application of e^- **devices** to **source, detect and control light**. A sub-field of photonics.

Light includes all forms of radiation: gamma rays, X-rays, ultraviolet and infrared, in addition to visible light.

Optoelectronic devices are electrical-to-optical or optical-to-electrical **transducers**, or instruments that use such devices in their operation.

Electro-optics is erroneously used as a synonym: wider branch of physics that deals with **interactions** *between* light and electric fields inside materials

Optoelectronics is based on the quantum mechanical **effects of light** on electronic materials, especially semiconductors, sometimes in the presence of electric fields:

Photoelectric or photovoltaic effect:

- photodiodes (including solar cells)
- phototransistors
- photomultipliers
- integrated optical circuit (IOC) elements

Photoconductivity:

- photoresistors
- photoconductive camera tubes
- charge-coupled imaging devices

Stimulated emission:

- injection laser diodes
- quantum cascade lasers

Radiative / electroluminescence recombination

- light-emitting diodes or LED

Photoemissivity:

- photoemissive camera tube

Photonics integration

http://www.photonics.com/Article.aspx?PID=2&VID=111&IID=713&Tag=Features&AID=54836

Standardized Process Could Revolutionize Photonic Integration (EuroPhotonics, September, 2013)

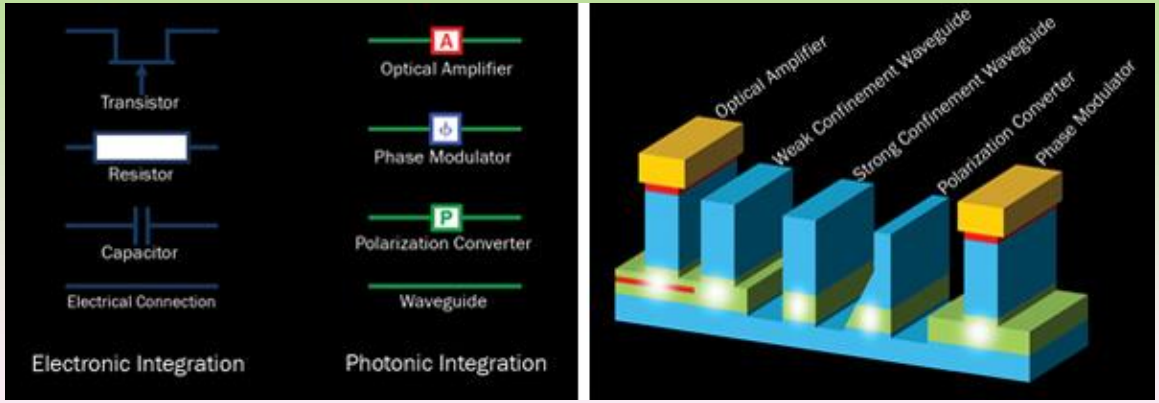


Figure 1. *A generic foundry process could open up photonic integrated circuits (PICs) to much wider availability. The generic photonic integration philosophy (a), and a schematic drawing of building blocks in an integration platform (b). Courtesy of COBRA Research Institute,*

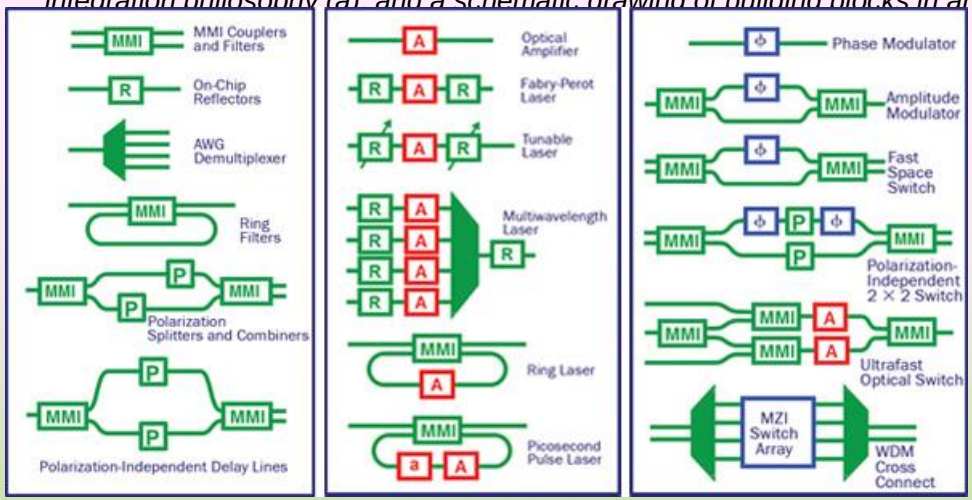


Figure 2. *Examples of composite building blocks using the generic integration technology. MMI = multimode interference; MZI = Mach-Zehnder Interferometer; AWG = arrayed-waveguide grating; WDM = wavelength division multiplexing. Courtesy of COBRA Research Institute, Eindhoven.*

Photonics integration

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Building Block	Performance		
	InP	Si	TriPlex
Passive Components	●	●●	●●●
Lasers	●●●	o	o
Modulators	●●●	●●	●
Switches	●●●	●●●	●
Optical Amplifiers	●●●	o	o
Detectors	●●●	●●●	o
Footprint	●●	●●●	●
Chip Cost	●	●●	●●
CMOS Compatibility	oo	●●	●
Low-Cost Packaging	o	o[1]/●●[2]	●●

Performance	
●●●	Very Good
●●	Good
●	Modest
o	Challenging

Figure 3. *Comparison of three different technology platforms. Courtesy of COBRA Research Institute, Eindhoven. 1 = end-fire coupling (low reflection); 2 = vertical coupling (medium reflection)..*

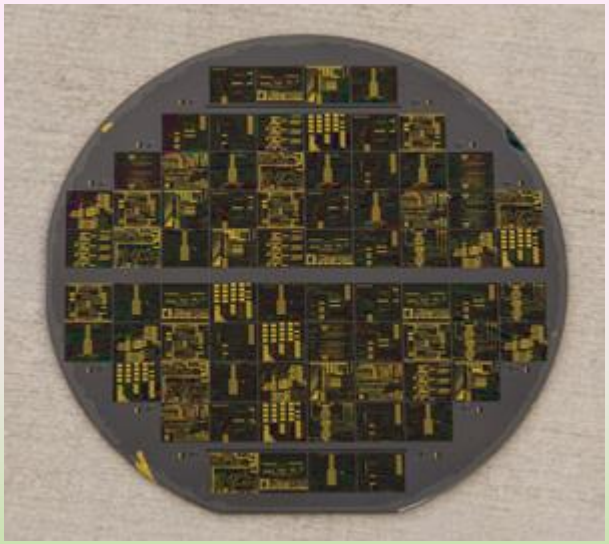

Figure 4. *This multiproject wafer contains 12 user designs. Courtesy of COBRA Research Institute, Eindhoven.*

Photonics integration

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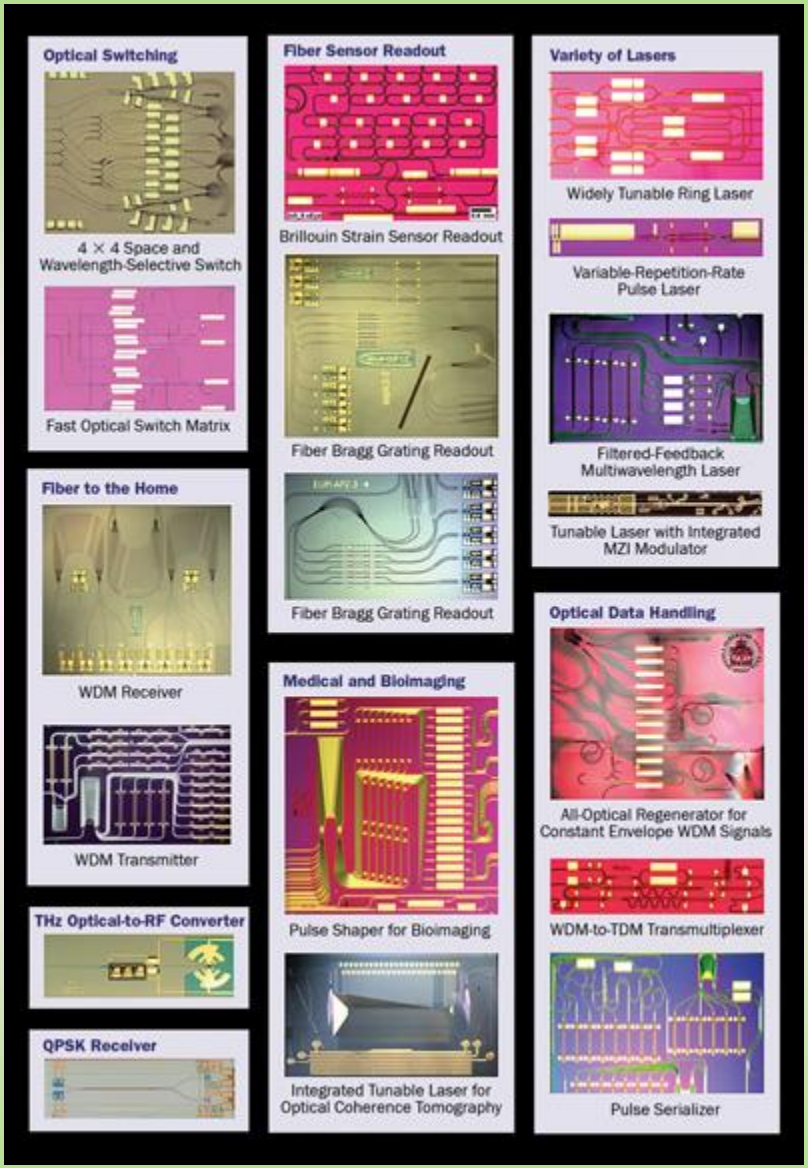

Figure 5. *An example of ASPICs fabricated with generic integration technology. Courtesy of Fraunhofer HHI, Oclaro, COBRA Research Institute, and platform users in EuroPIC and PARADIGM. QPSK = quadrature phase-shift keying; TDM = time division multiplexing.*