OPTI510R: Photonics

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OPTI 510R - Instructor

Khanh Kieu

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Education:

- Ph.D., University of Arizona, 2007
- M.S., University of Arizona, 2006
- M.S., St. Petersburg State University of Information Technologies, Mechanics and Optics (Russia), 2004
- B.S., St. Petersburg State University of Information Technologies, Mechanics and Optics (Russia), 2002

Specific Research Interests:
Ultrafast fiber lasers
Nonlinear fiber optics
Nonlinear spectroscopy and frequency comb
Microresonators and applications
Biomedical imaging based on supercontinuum and ultrafast fiber light sources
All-optical switching
Micromachining with femtosecond lasers
Fiber optical sensors

OPTI 510R - TA



Amanda Chatterton

Email Address: achatterton@optics.arizona.edu

Office hour: TBD

Grading and Exams

Grading Policy:

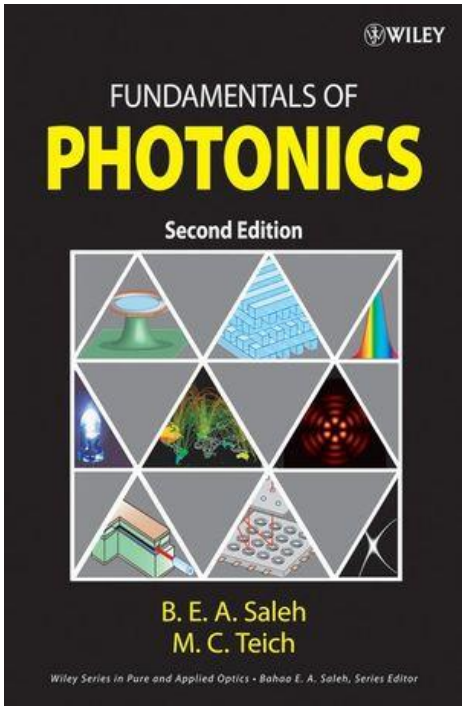
Two Exams	60%
Homework Assignments	40%
TOTAL	**100%**

Lectures Monday and Wednesday: 11am-12:15pm
Homework: Every two weeks
Prerequisite: OPTI501

Class website:
http://wp.optics.arizona.edu/kkieu/opti-510r/

Textbook

B. E. A. Saleh and M. C. Teich, “Fundamentals of Photonics,” 2nd Edition, John Wiley & Sons, Inc. 2007.



Online: www.library.arizona.edu
https://ebookcentral.proquest.com/lib/uaz/detail.action?docID=699744

Goals

- Understand the most important concepts in Photonics
- Learn the working principles of photonics devices
- Identify the remaining challenges in the field
- Think about possible solutions

Topics

Introduction
- Properties of light
- Wave Optics
- Interference and Devices
- Diffraction and Devices
- Polarization Optics

Guided-wave Optics
- Planar Waveguide
- Optical Fibers
- Attenuation and Dispersion
- Dispersion Compensation
- Fiber Fabrication
- Nonlinear Optical Effects
- Optical Amplifiers
- Passive Fiber Components

Lasers

Photodetectors

Fiber optical network

Photonics

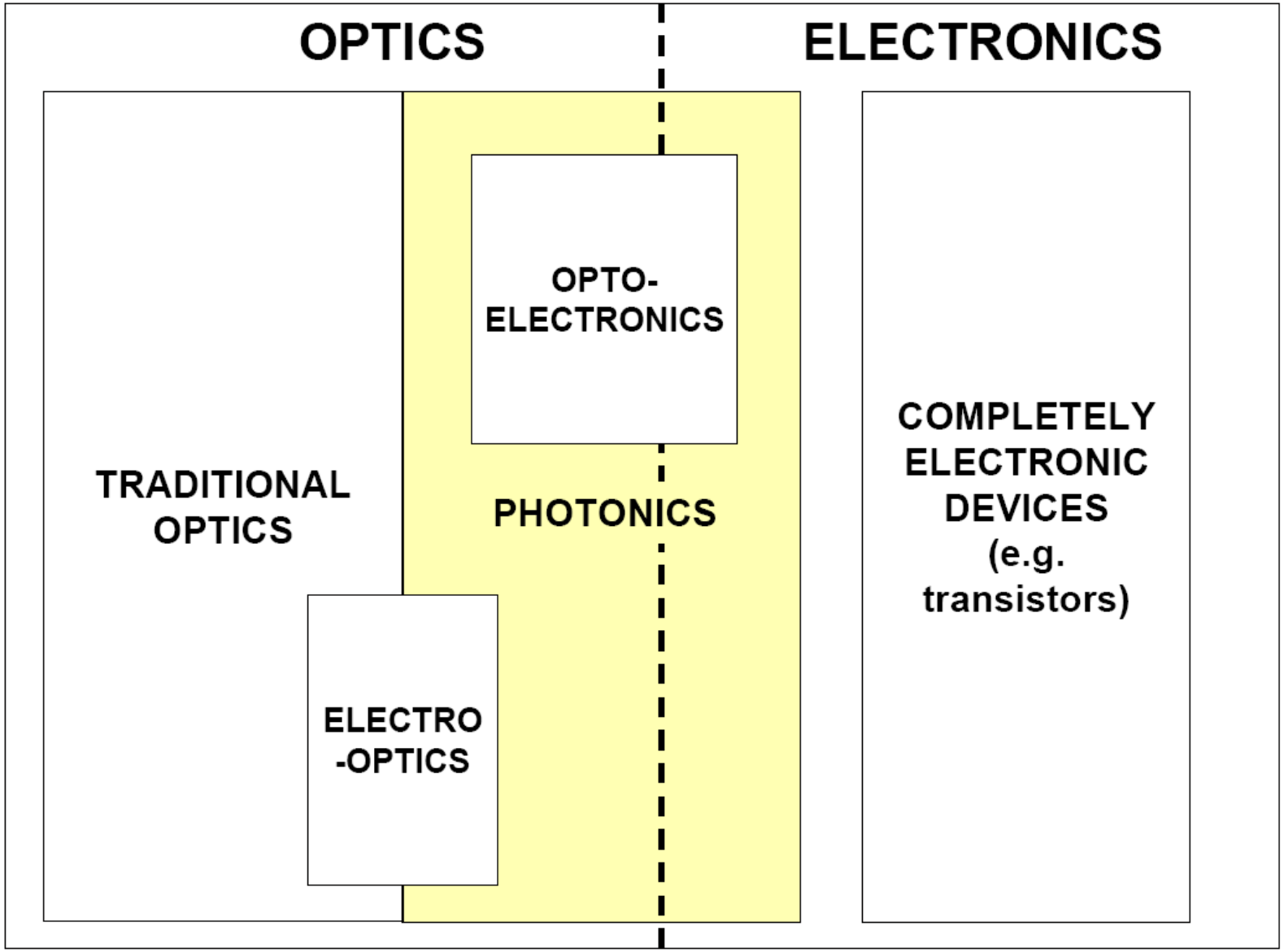
The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The science includes light emission, transmission, deflection, amplification and detection by optical components and instruments, lasers and other light sources, fiber optics, electro-optical instrumentation, related hardware and electronics, and sophisticated systems. The range of applications of photonics extends from energy generation to communications and information processing.

from the Photonics Dictionary at Photonics.com

Areas included in Photonics

- Optoelectronics: Devices that are essentially electronic in nature but involve light (e.g. light emitting diodes, liquid-crystal display, and array photodetectors)
- Electro-optics: Devices in which electrical effects play a role (e.g. diode lasers, and electro-optic modulators and switches)
- Quantum Electronics: Devices and systems that rely principally on the interaction of light with matter (e.g. lasers and nonlinear optical devices used for optical amplification and wave-mixing)
- Lightwave Technology: Devices and systems that are used in optical communication and optical signal processing

Areas included in Photonics

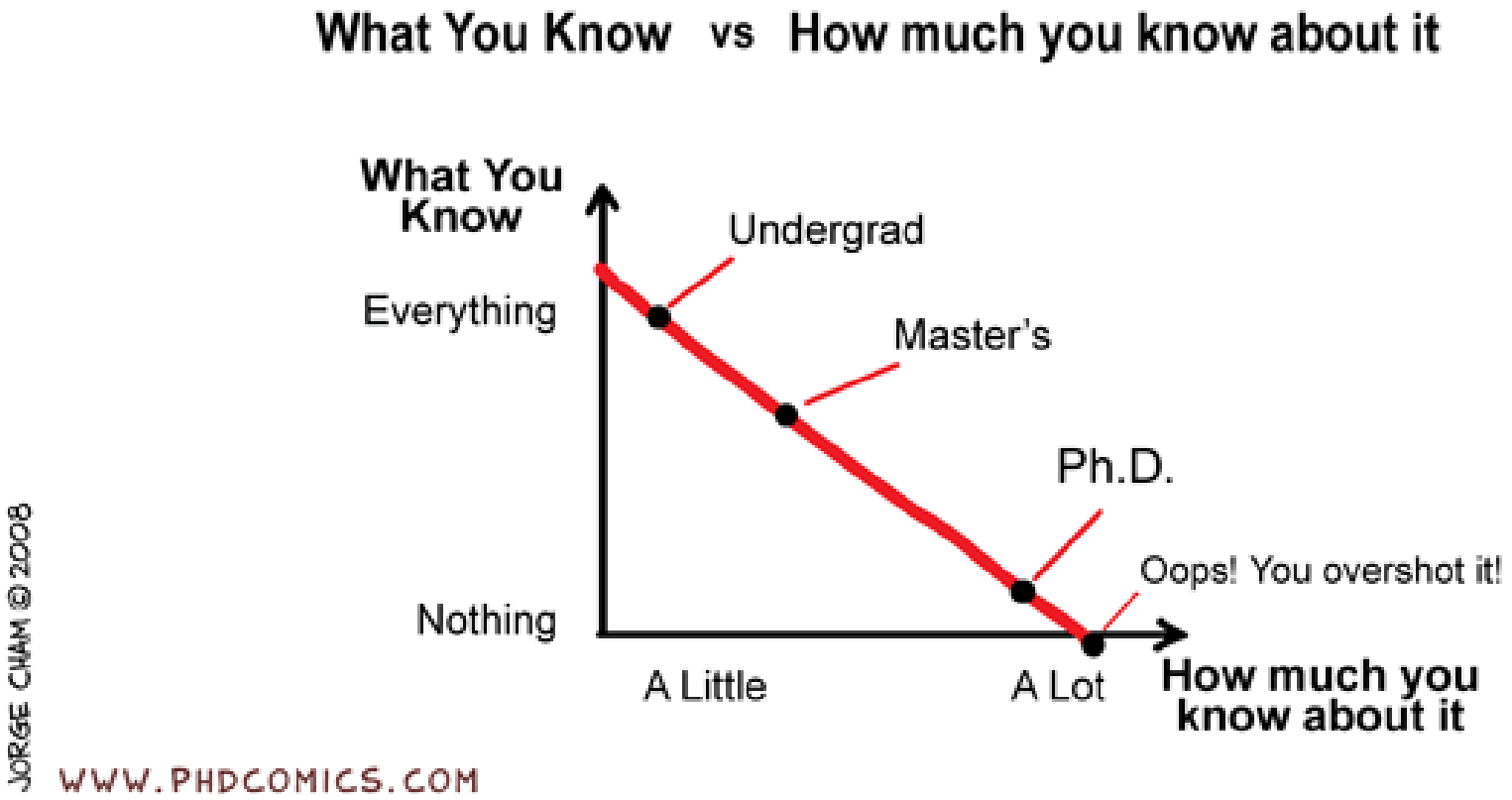


S&T

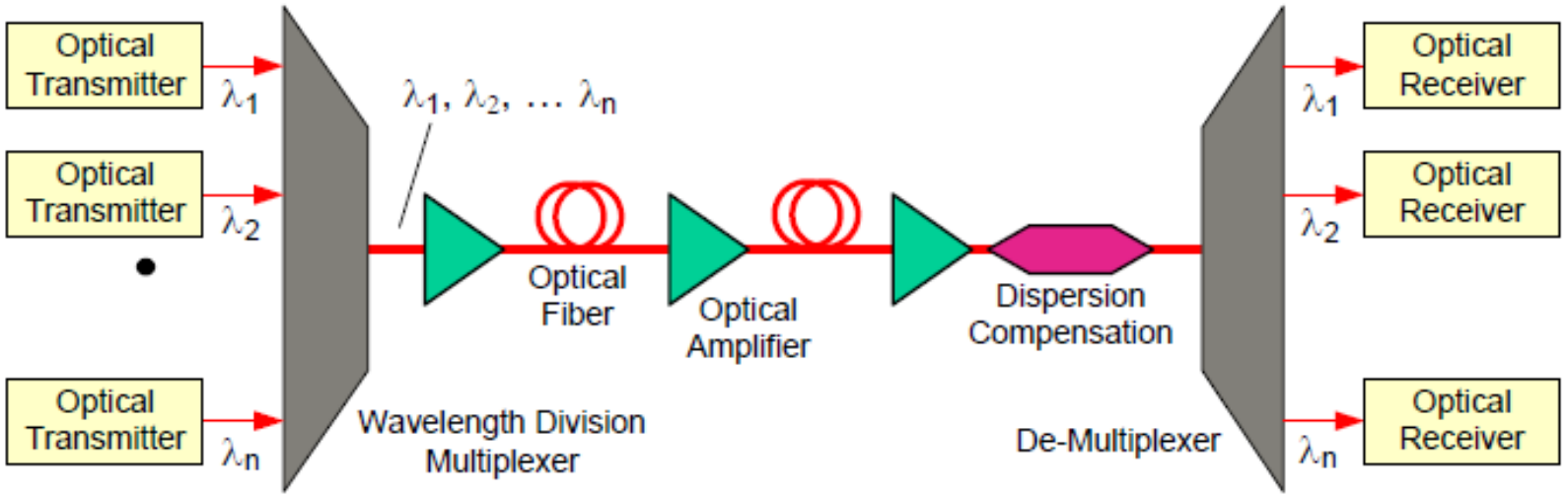
Photonics is all around us!

- Internet is based on fiber optics transmission
- Smart phones, TVs, Laptops…
- Cars
- Optical sensors
- Solar energy sources
- Lighting systems
- Precision measurements
- Imaging systems…

Photonics – is quite broad



Example of a Photonics System



- A wavelength division multiplexed (WDM) link with 80 OC-192 wavelength channels operates at close to 1 Terabit per second and carries just over 10,000,000 simultaneous phone calls

Why it is important?

The Nobel Prize in Physics 2014
Isamu Akasaki, Hiroshi Amano, Shuji Nakamura

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The Nobel Prize in Physics 2014



Photo: A. Mahmoud
Isamu Akasaki
Prize share: 1/3



Photo: A. Mahmoud
Hiroshi Amano
Prize share: 1/3



Photo: A. Mahmoud
Shuji Nakamura
Prize share: 1/3

The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura *"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources".*

Why it is important?

The Nobel Prize in Chemistry 2014
Eric Betzig, Stefan W. Hell, William E. Moerner

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The Nobel Prize in Chemistry 2014



Photo: A. Mahmoud
Eric Betzig
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Photo: A. Mahmoud
Stefan W. Hell
Prize share: 1/3



Photo: A. Mahmoud
William E. Moerner
Prize share: 1/3

The Nobel Prize in Chemistry 2014 was awarded jointly to Eric Betzig, Stefan W. Hell and William E. Moerner *"for the development of super-resolved fluorescence microscopy"*.

Why it is important?

The Nobel Prize in Physics 2018



Ill. Niklas Elmehed. © Nobel Media

Arthur Ashkin

Prize share: 1/2



Ill. Niklas Elmehed. © Nobel Media

Gérard Mourou

Prize share: 1/4



Ill. Niklas Elmehed. © Nobel Media

Donna Strickland

Prize share: 1/4

The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to Arthur Ashkin "for the optical tweezers and their application to biological systems", the other half jointly to Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses."

Why it is important?

European leadership in photonics will deliver these benefits by 2030:

- **Instant diagnosis of major diseases**
  In 2030, healthcare will be fast, precise and cost-effective. Advanced diagnostics, pervasive monitoring and innovative e-health applications will be able to detect body signals, symptoms and diseases early on. Treatment will be highly targeted, minimally invasive and increasingly effective, reducing disability and mortality from cancer, strokes and other major diseases. Diagnosis and treatment will be delivered instantly at the point of care, thanks to the new science of "theranostics." With the help of these and other innovations, Europe will keep an ageing population healthy and fit.

- **Quality food from farm to fork**
  In 2030, we will have the technology to feed the world, push back food-borne illness and reduce the environmental footprint of agriculture, fisheries and aquaculture. Photonics will help supply safe, nutritious and affordable food for all and establish a sustainable value chain from farm to fork. By using ever more precise sensors and measuring devices, farmers, food processors and ordinary consumers will be able to monitor and certify the safety, quality, content and even the origin of food – anytime and anywhere.

- **Accident and congestion-free road transport**
  In 2030, our mobility will be based on multimodal transport. Driving will be automated, connected and electric to maximise safety, efficiency and comfort. Photonics provides essential components, systems and production tools for all aspects of connected mobility, from driver assistance and traffic monitoring to photonics-based IT and telecommunications.

- **A truly circular economy**
  In 2030, Europe's economy will be cleaner, greener and far along its path towards decarbonisation. Photonics technology will help put an end to the depletion of resources by managing material streams in a circular economy, reducing energy consumption in buildings and public spaces, creating efficient industrial processes, developing the next generation of photovoltaics, enabling smart mobility and monitoring our environment in real time.

- **A million new jobs**
  In 2030, European factories will be fast, green and flexible. Photonics technology, including lasers, sensors and 3D displays, will revolutionise industrial production and working environments, making manufacturing more innovative, cost-competitive and resource-efficient. A fully digital value chain from supplier to customer will birth new forms of collaboration and customisation, new services and new business models – all of which will strengthen Europe's industrial base.

- **10% higher productivity**
  By 2030, digital connectivity will create an entirely new quality of urban life. Photonics technology, including lighting, sensors and optical IT, will supply the infrastructure for smart homes and thriving cities, thereby enabling us to live and work in attractive, secure and productive environments tailored to our individual needs.

- **Zero downtime in a terabit economy**
  In 2030, our societies and economies will be fully digital. To make our digital society work and to safeguard trust, comfort and privacy, photonics is the key tool for delivering the necessary performance, resilience and security in data services and network infrastructures. To handle vastly greater flows of data, IT systems will be much more powerful than today while using less energy, thanks to the emerging shift to high-performance optical and quantum computing.

- **Photonics as a flagship science for innovation**
  In 2030, photonics will be a pillar and driver of the knowledge society, playing an instrumental role in the creation and dissemination of knowledge and ideas. At the same time, educators, students, governments, companies and ordinary citizens across all disciplines and sectors will be increasingly aware of the opportunities and potential inherent in utilising light for the benefit of humankind.

https://www.photonics21.org/download/news/2017/Photonics21-Vision-Paper-Final.pdf

Why it is important?

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Why it is important?

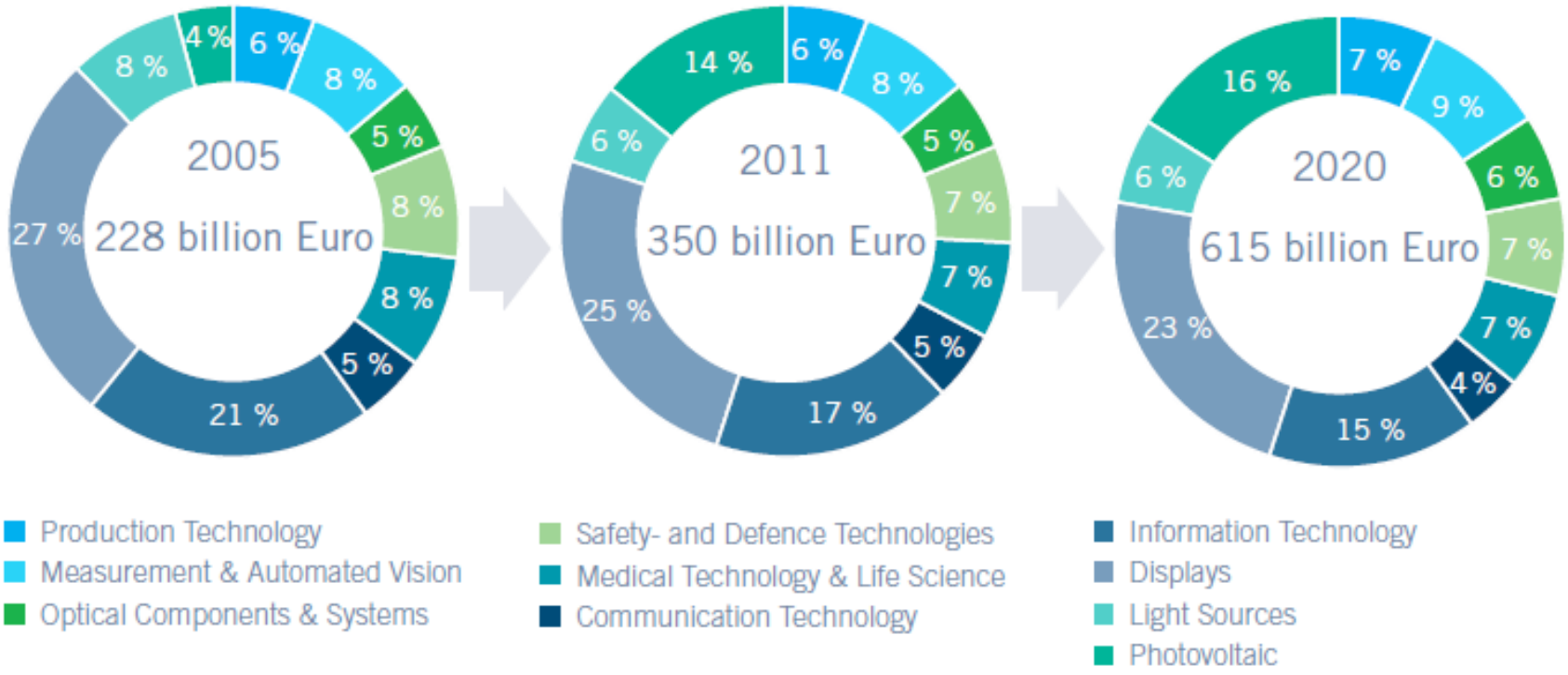
systems and production tools for all aspects of connected mobility, from driver assistance and traffic monitoring to photonics-based IT and telecommunications.

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The Photonics Industry

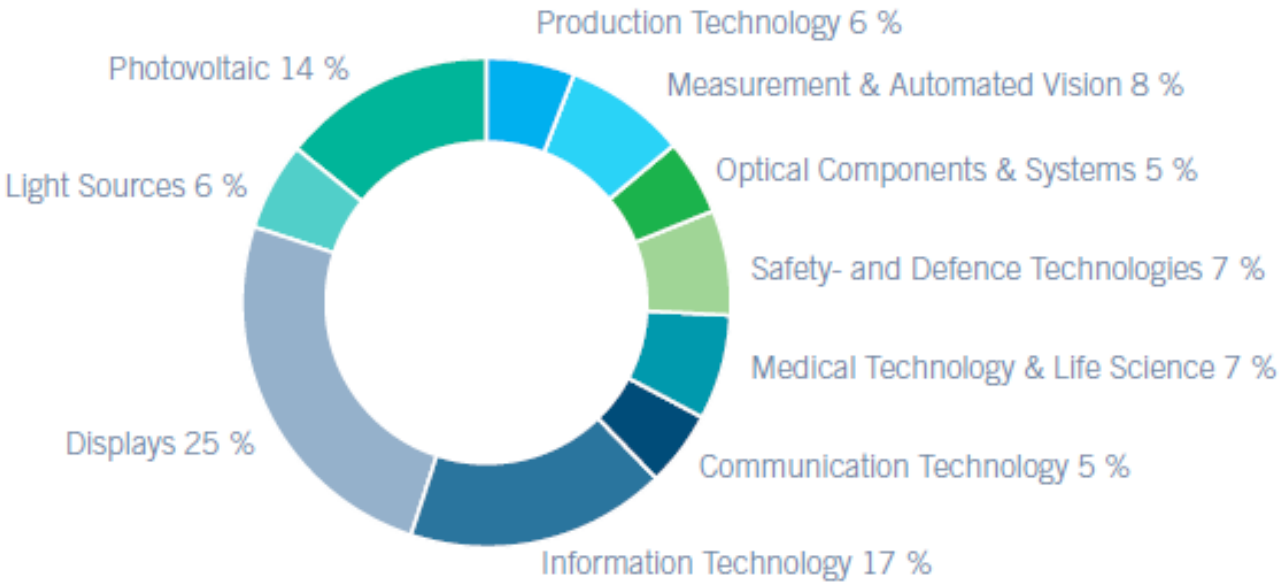
Key Data Photonics World 2005, 2011 and Expectations 2020



Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

The Photonics Industry

Photonics World Market 2011 – Total 350 billion Euro



Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

The Photonics Industry

Photonics End-Use-Sectors By Systems And Components

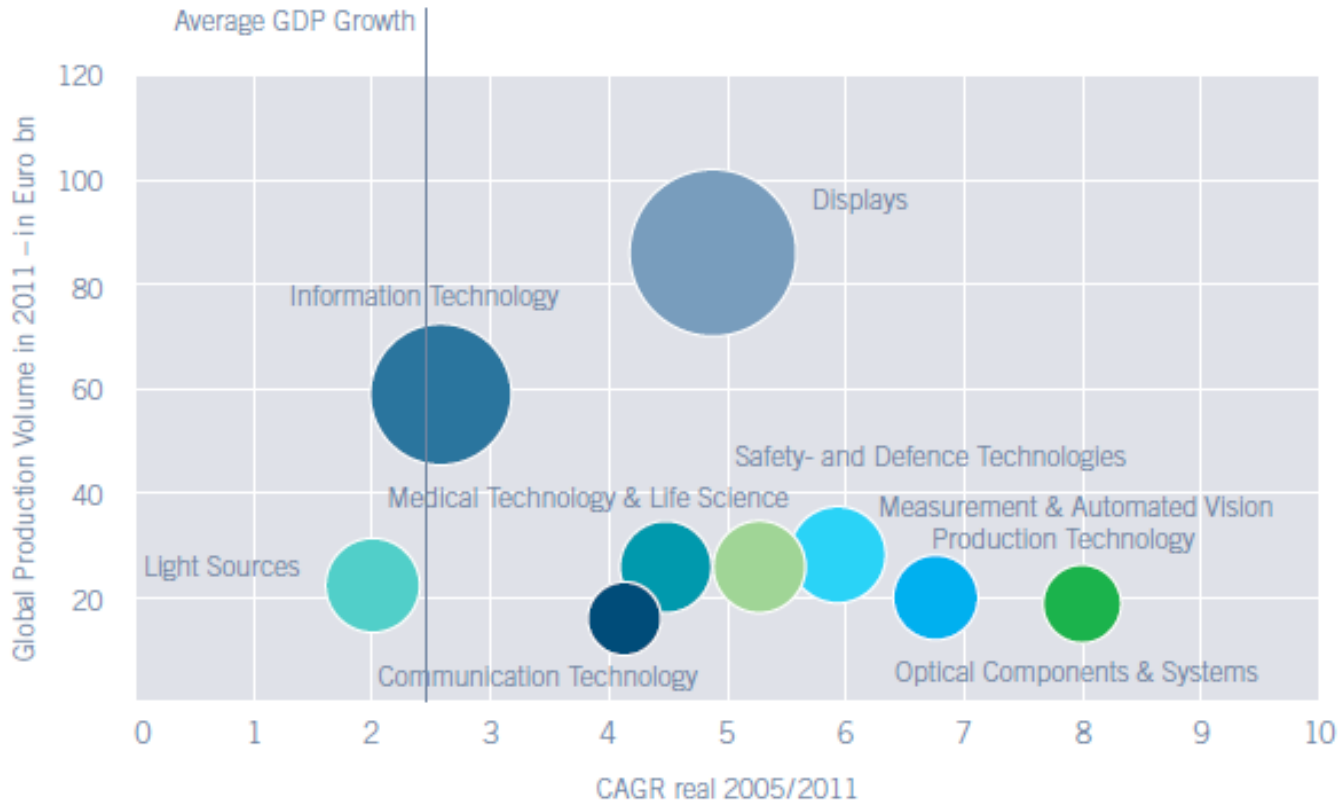
End-use-sectors	Systems	Components
Electro- and Electronicindustry, incl. Semi Conductor- and Displays	Lithography Systems, Laser Materials Processing Systems, Optical Measurement and Machine Vision	Displays, Solar Cells, Optical Drives, Sensors, Lasers, Optical Components
Consumer/Office Automation	Digital Cameras, Laser Printers, Multifunctional Printers	Lamps
Medical sector	Endoscope Systems, Microscopes, Imaging Systems, Diagnostic Systems	Lenses For Eyeglasses And Contact Lenses
Safety & Defence	Infrared and Night Vision Systems, Ranging Systems, Avionics, Sensors	Sensors, Lasers, Displays
Other Manufacturing Industries		
■ Machinery		Lasers, Optical Components
■ Automotive	Laser Materials Processing Systems, Lithography Systems	Optical Components, Sensors, Cameras
■ Others	Laser Materials Processing Systems, Lithography Systems, Measurement	
Other Services		
■ Telecommunication	Optical Networking Systems	
■ Energy Supply	Solar Modules And Cells	
■ Others	Biometric Systems	

Source: Optech Consulting, 2013

Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

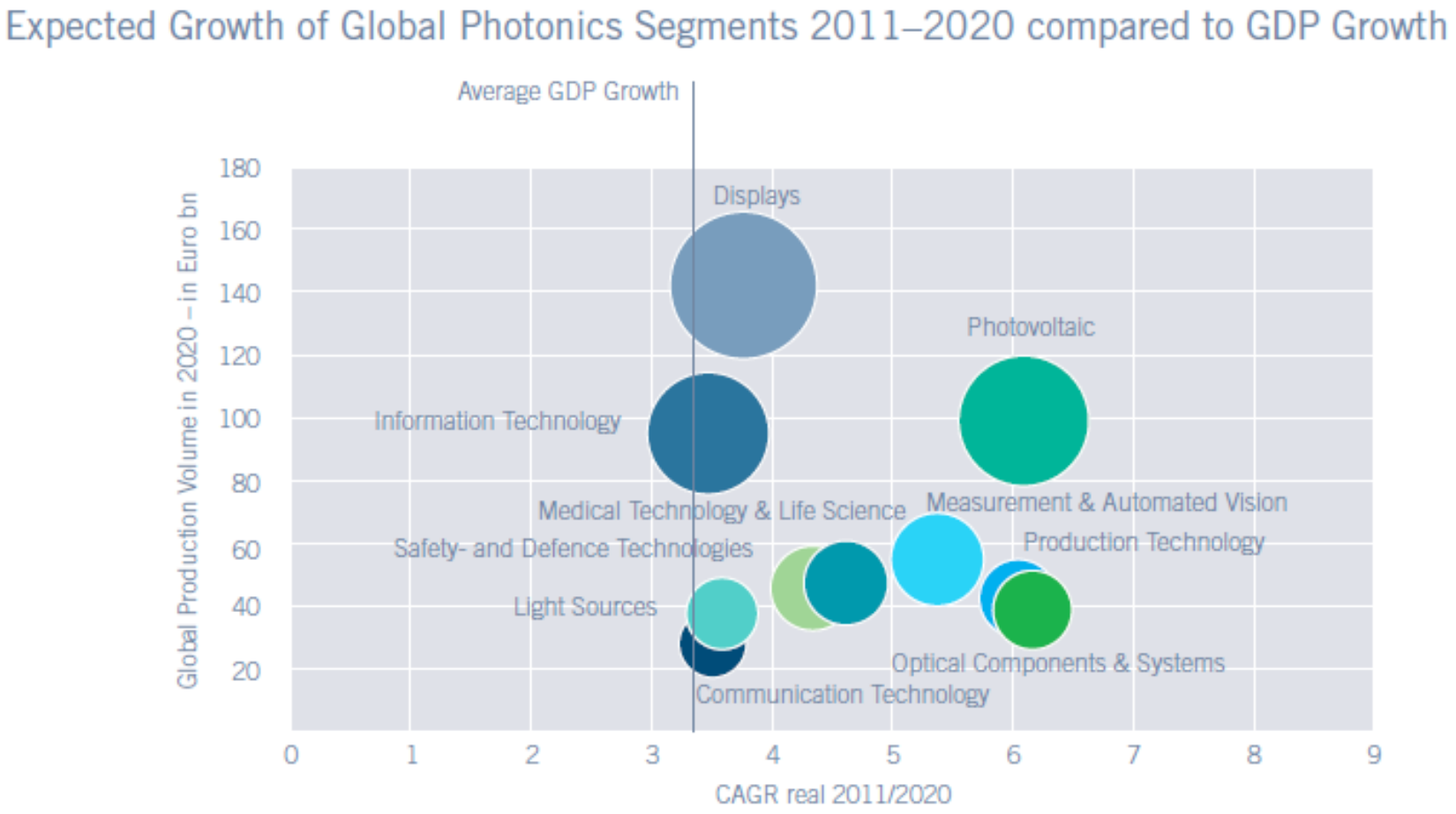
Photonics – a strong Industry with Excellent Prospects

Growth of Global Photonics Segments in 2005–2011 compared to GDP Growth (without PV)



Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

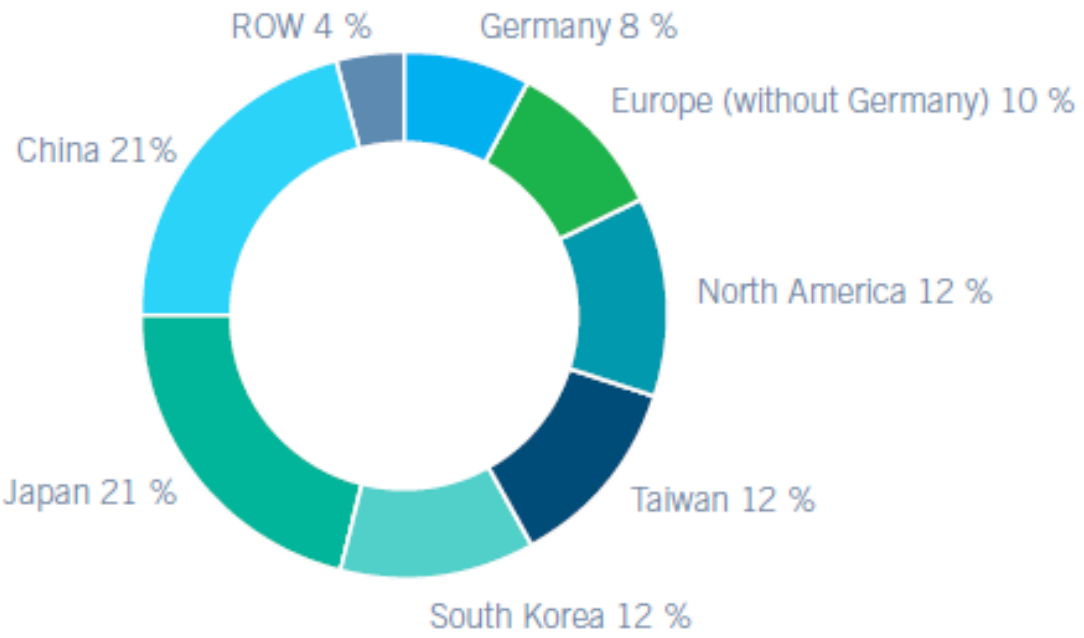
Photonics – a strong Industry with Excellent Prospects



Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

Photonics – a strong Industry with Excellent Prospects

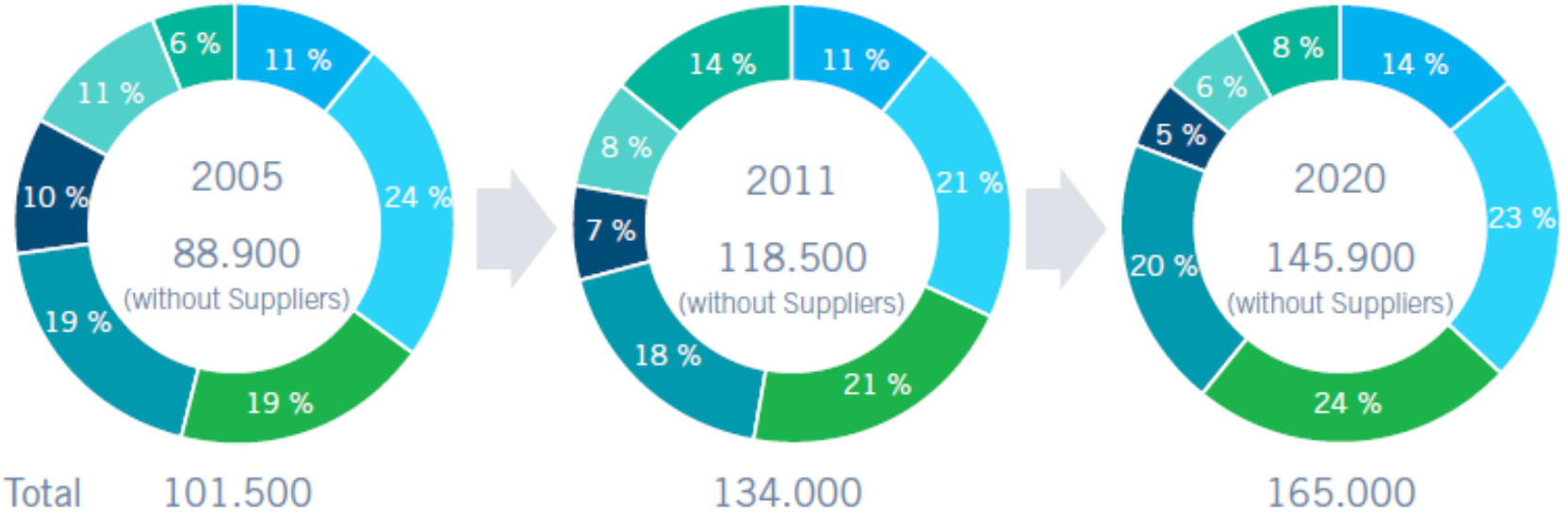
Photonics Production by Countries, 2011



Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

Photonics – a strong Industry with Excellent Prospects

Number of Employees in Photonics Segments in 2005, 2011 and Expectations 2020



Total	101.500	134.000	165.000

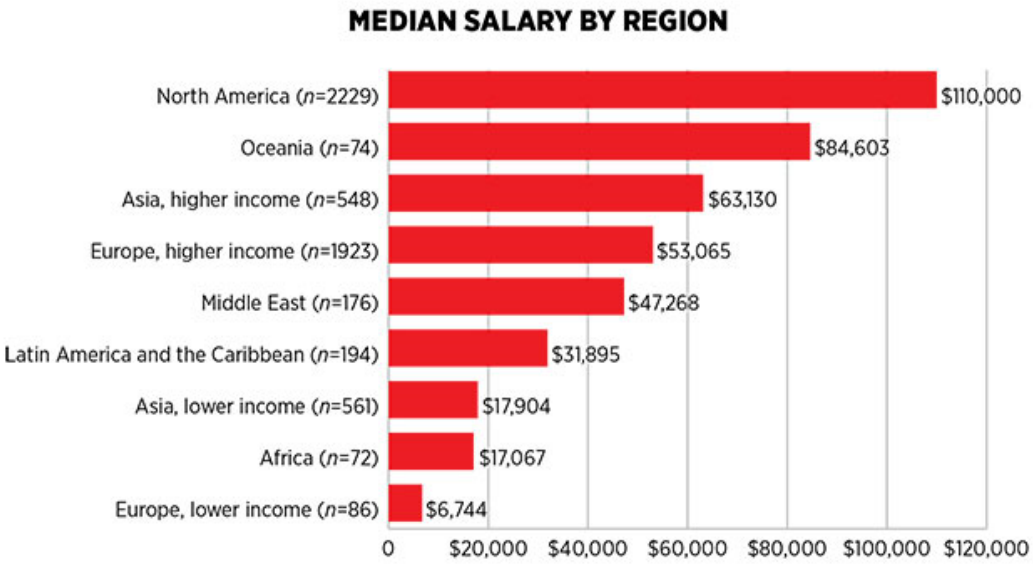
- Production Technology
- Measurement & Automated Vision
- Optical Components & Systems, Safety- and Defence Technologies
- Medical Technology & Life Science
- Communication Technology, Information Technology, Displays
- Light Sources
- Photovoltaic

Source: BMBF, SPECTARIS, VDMA, ZVEI (pub.), 'Branchenreport Photonik 2013', Optech Consulting, Study 'Photonik 2013'/Own calculations

Photonics – a strong Industry with Excellent Prospects

MEDIAN SALARY BY DISCIPLINE: FOR-PROFIT, GOVERNMENT/MILITARY, AND ACADEMIC EMPLOYERS

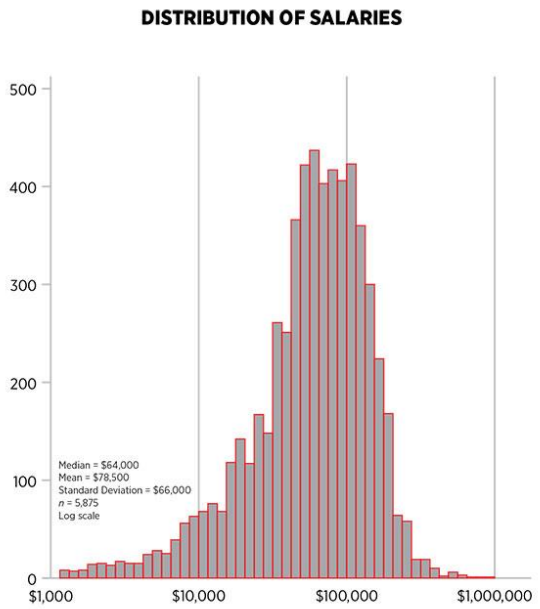
Discipline	For-profit	Government/ Military	Academic
Aerospace	$115,000	$96,648	$42,666
Interdisciplinary engineering or research	$110,000	$62,803	$47,988
Remote sensing	$106,065	$49,940	$31,839
Biomedical/medical/ biology/biophysics/ biotechnology	$101,885	$48,500	$48,331
Photonics	$96,025	$33,132	$45,699
Semiconductor	$95,259	$53,065	$49,977
Systems engineering or research	$95,000	$68,000	$45,165
Astronomy/astrophysics	$93,006	$60,000	$84,000
Chemical	$92,500	$51,186	$55,262
Nanotechnology	$90,000	$41,391	$38,207
Other	$89,607	$55,718	$47,759
Physics	$88,700	$50,943	$51,492
Electrical/electronics	$88,518	$52,146	$37,459
Lasers	$85,000	$56,113	$39,074
Optical systems	$84,952	$62,055	$38,152
Illumination	$84,904	$25,029	$49,881
Materials	$82,422	$41,922	$47,455
Optical design	$82,260	$58,372	$44,930
Manufacturing	$82,000	$67,177	$39,146
Computer science/ software/information technology	$70,554	$56,780	$41,791
Mechanical	$66,942	$22,887	$41,704
Civil/environmental	$65,938	$62,187	$33,420



https://spiecareercenter.org/survey/10#.U62QqvldV8E
https://spiecareercenter.org/survey/SPIESalarySurveyReport2018.pdf

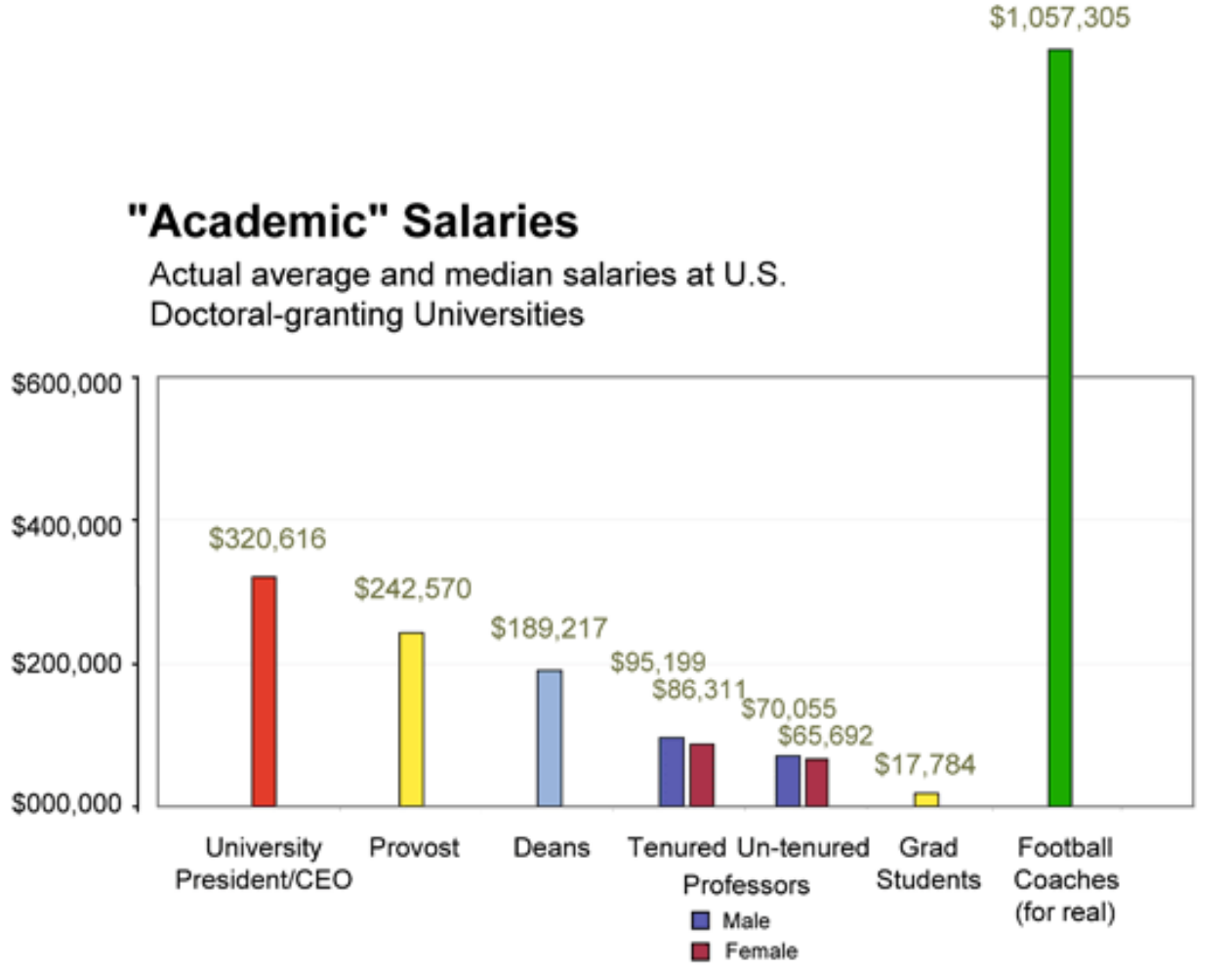
Photonics – a strong Industry with Excellent Prospects

- The median salary for survey respondents is $64,000. Salaries are very widely dispersed, primarily driven by country income level and employer type. The overall median salary is down from $73,000 last year, mainly due to large declines of the euro and yen against the dollar.
- Salaries paid in Chinese yuan have risen by 33% since 2012 versus 5% increases in euro, dollar, and yen earnings.
- 55% of workers in lower-income Asian countries expect a raise of 10% or greater in 2015. Only 10% of higher-income Europeans and 11% of North Americans expect raises of that size.
- The highest-paid discipline is aerospace, with a median income of $105,433.
- Median salaries are 41% higher overall for men than for women, with the largest gap occurring late-career. 49% of women feel that they are paid fairly, versus 57% of men.
- For-profit respondents prioritize team success, while academic and government respondents place highest value on scientific discovery.
- Survey respondents are highly satisfied with their jobs overall: 85% enjoy their work, 86% find their work meaningful, and 90% respect the work of their peers.
- 37% of workers in higher-income Asian countries work 50 or more hours per week. 28% of Romanian workers report working 55 or more hours per week, the largest percentage of any country.



https://spiecareercenter.org/survey/10#.U62QqvldV8E

Photonics – a strong Industry with Excellent Prospects



Photonics – some Milestones

Table 1: Summary of events in the development of photonics.

Year	Event
1802	Demonstration of incandescent light
1917	Stimulated emission proposed by Einstein
1938	First fluorescent lamp sold by General Electric
1951	Development of solar cells
1954	Invention of MASER
1960	Development of LASER (Nobel Prize 1964,1981)
1961	Glass fiber for transmission (Nobel Prize 2009)
1963	Semiconductor heterostructures (Nobel Prize 2000)
1968	Proposal of negative indices of refraction
1969	ARPANET, precursor to modern internet
1970	Invention of CCD (Nobel Prize 2009)
1972	Production of first active matrix liquid crystal display
1975	Development of semiconductor LASER
1977	First quantum well LASER
1979	Development of VCSEL
1980	Installation of fiber optic cable
1982	Optical MEMS for projection display
1987	Development of doped fiber amplifier
	Photonic crystal invention
1988	Installation of first transatlantic fiber cable
1992	First full color plasma display
1993	JPL demonstrated efficient CMOS sensor
1994	First consumer digital camera
1995	Photonic crystal fiber
	First GaN laser
2006	Estimate 92 million websites

McGraw-Hill Encyclopedia of Science & Technology

Question for thoughts

- What will happen in the field of Photonics in 10, 20, 50 years?
- What is the area of Photonics that you are going to work in?
- Can we replace Electronics with Photonics?
- Can you create a new research area in Photonics? New Industry?
- What are the photonics devices that you think have improved your life?
- What is the Photonics device that you think would be great to have but does not exist?

Reading materials

https://www.photonics21.org/download/news/2017/Photonics21-Vision-Paper-Final.pdf

https://spiecareercenter.org/survey/SPIESalarySurveyReport2018.pdf

https://spiecareercenter.org/survey/10#.U62QqvldV8E

https://www.osa.org/en-us/get_involved/public_policy/national_photonics_initiative/harnessing_light/

https://ebookcentral.proquest.com/lib/uaz/detail.action?docID=699744

https://www.nobelprize.org/prizes/physics/2018/summary/