

A hand wearing a black glove holds a glowing blue digital globe. The globe is composed of a grid of dots and lines, with a fingerprint pattern overlaid on its surface. The background is dark and out of focus, showing a person in a white lab coat and a stethoscope.

# A century of light

Anne Frances Johnson  
and Nancy D. Lamontagne

Since its founding in 1916, The Optical Society has brought together a global community of scientists, engineers, business leaders, and students whose work in optics and photonics has transformed the world.

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**I**n June 1916, exactly one century ago, Albert Einstein predicted the existence of ripples, known as gravitational waves, in the fabric of spacetime. Earlier this year we celebrated the stunning observation of the phenomenon by a worldwide collaboration of more than 1000 scientists using incredibly sensitive antennas built of mirrors and lasers. (See *PHYSICS TODAY*, April 2016, page 14.) As with many scientific achievements, this recent milestone draws on innumerable theoretical, observational, and technological innovations and iterations made along the way. It's worth reflecting on the vast body of knowledge the scientific community has generated, the breakthrough technologies that have allowed us to observe our world with ever-greater depth and precision, and the people who have dedicated their lives and careers to expanding knowledge and applications in diverse branches of science.

This year marks the 100th anniversary of The Optical Society, a worldwide community for optics and photonics professionals and students. Over the past century, the research world and consumers alike enjoyed a dramatic expansion of light-based science and applied technology. In many ways, the growth of optics and photonics has mirrored the birth and expansion of modern physics from the early 20th century through today. Applied optics and spectroscopy have long played a central role in enabling new discoveries in physics; that new physics has fueled advances in optics and photonics that, in turn, have created powerful tools for the study of space, time, and matter. The laser, for instance, has become an indispensable tool of scientific inquiry. Solid-state detectors of incredible density and sensitivity are used for scientific imaging from telescopes on Earth to cameras on Mars. Innovations in laser cooling have given us unprecedented access to the quantum world, and laser frequency comb technology has greatly expanded precision measurements for both fundamental and applied sciences.

But that list is far from complete. This article permits only a sparse survey of the noteworthy advances and trailblazers from the past century of optics and of the innumerable benefits we derive from them. Further highlights are available on the

OSA Centennial webpage at [www.osa.org/en-us/100/osa100](http://www.osa.org/en-us/100/osa100).

### **A field matures, and a society is born**

The 50 years leading up to the birth of The Optical Society in 1916 saw tremendous progress in our understanding of light and its uses. In the 1860s James Clerk Maxwell first established the nature of light as an electromagnetic wave. The late 1800s saw the dawn of practical electric lighting and even rudimentary precursors of modern fiber optics. In 1905 Einstein's description of the photoelectric effect suggested that light was made of discrete packets of energy, later known as photons. That dual understanding of light—as a photon and a wave—sparked a variety of engineering innovations.

As World War I raged in Europe, the demand for technological innovations grew increasingly urgent. Against that backdrop, Perley Nutting, a scientist at the Bureau of Standards in Washington, DC, recognized the need for an organized scientific home for optical engineering and technology. After moving to Rochester, New York, to take a position at Eastman Kodak, Nutting and other local luminaries formed the Rochester Association for the Advancement of Applied Optics. Within a year, the group expanded its ambitions and reach,

# CENTURY OF LIGHT

founding the Optical Society of America (OSA) in 1916 with a focus on advancing applied optics. (The society changed its name to The Optical Society in 2008 in recognition of its global scope.) Initial member dues were only \$5 per year. With its first meeting on 28 December 1916 at Columbia University, the society kicked off a new era in the science of light.

## Optics advances shed new light on the universe

The early 20th century brought significant breakthroughs in scientists' understanding of the universe, thanks in large part to advances in optical technologies used to observe the heavens.

George Ellery Hale, a leading astronomer, served as OSA's first vice president. In 1916 he was awarded OSA honorary membership, the most distinguished of all OSA member categories, typically conferred on only one member per year. Fascinated by the Sun, Hale invented the spectroheliograph while still an undergraduate at MIT and used it to discover solar vortices and other phenomena. Later, he spearheaded the construction of record-breaking telescopes, including the 40-inch (100 cm) refracting telescope at Yerkes Observatory and the 60-inch Hale and 100-inch Hooker reflecting telescopes at Mount Wilson Observatory.

Hale's lifelong passion for optics was sparked by a small microscope his parents bought him as a child. He built his first telescope at age 14; his last project was the 200-inch Hale reflecting telescope at Palomar Observatory, completed 10 years after his death in 1938.

## Picturing the future with photography

Camera technology has been advancing ever since George Eastman's Kodak camera hit the mass market in 1888 under the slogan "You press the button, we do the rest."

In 1928 OSA established its first and most prestigious award in honor of Frederic Ives, inventor of modern photoengraving and a pioneer in color photography, three-color process printing, and three-dimensional stereoscopic photography. Ives's son Herbert served as OSA president in 1924–25.

Over a 43-year career at Eastman Kodak, C. E. Kenneth

Our centennial is not only an opportunity to capture the legacy of the society and the optics field, but also a chance to explore the future of our exciting scientific and technological breakthroughs. There remains tremendous potential to address challenges such as supporting health and medicine as well as the continued explosive growth of the internet. We are only at the beginning of what optics technology can do, and The Optical Society and its members will continue to be at the forefront of advancing the science of light.

—Alan Willner, 2016 OSA president  
and the Steven and Kathryn Sample Chair  
in Engineering, University of Southern California

Mees, another luminary, brought numerous advances to scientific photography, including the development of sensitive photographic emulsions that allowed the capture of faint astronomical images. An OSA award was named in Mees's memory in 1961, after his death.

Another groundbreaking moment came at a 1947 OSA meeting, when Edwin Land, cofounder of Polaroid, demonstrated his new instant-photography system to the public for the first time. In its heyday from the 1960s through the 1980s, the Polaroid instant camera—which Land said was inspired by his three-year-old daughter's question, "Why can't I see these pictures right now?"—would feature prominently in life's special moments for millions of families. Land was awarded OSA honorary membership in 1972 for his achievements.

## The laser ushers in a new era

Stimulated emission of electromagnetic radiation allows light to be coherently amplified and tightly focused to create a high-energy beam of exceptionally pure color. Those unique attrib-

1916

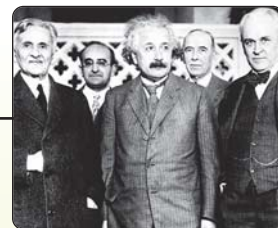
Perley Nutting  
founds the Optical  
Society of America  
and serves as its first  
president.



OSA ARCHIVES

1931

Albert Einstein visits Caltech and is joined by  
Albert Michelson (left), who developed the  
interferometer design used in modern  
astronomical observatories, and Robert  
Millikan (right), who measured the charge of  
the electron and verified the photoelectric effect.



WILLIAM KELLOGG, COURTESY OF  
AIP EMILIO SEGRÉ VISUAL ARCHIVES

1910

1915

1920

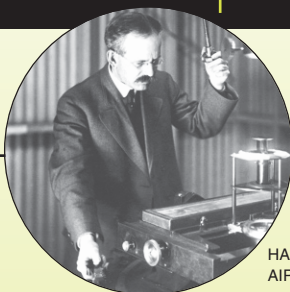
1925

1930

1935

## Early 20<sup>th</sup> century

Influential astronomer and OSA vice  
president George Ellery Hale—shown  
here using a spectroheliograph, which  
he invented as an undergraduate—  
makes Mount Wilson Observatory the  
dominant observatory of its time.



HALE OBSERVATORIES, COURTESY OF  
AIP EMILIO SEGRÉ VISUAL ARCHIVES

**The Optical Society was created in an environment where scientific collaboration was a challenge. Our founders saw the need to bring together the best scientific minds in industry and academia to share ideas in pursuit of technological breakthroughs. Today, the society serves as a global catalyst for the science of light. We are proud of our scientists and corporate leaders, including 34 Nobel laureates, who are inspiring the next generation of scientific discovery.**

**—Elizabeth Rogan, OSA CEO**

utes underlie lasers' wide range of applications, from grocery store scanners and office printers to precision surgery and manufacturing.

Although Einstein described the principle of stimulated emission in 1917 (see the article by Daniel Kleppner, *PHYSICS TODAY*, February 2005, page 30), it wasn't until 1953 that a device exhibiting the process was built. That was the year Charles Townes, James Gordon, and Herbert Zeiger at Columbia University constructed what they called a maser, an acronym for "microwave amplification by stimulated emission of radiation." The team later discovered they weren't alone: At the Lebedev Physical Institute in the Soviet Union, Aleksandr Prokhorov and Nicolay Basov independently developed an ammonia maser at virtually the same time. Townes, Prokhorov, and Basov shared the 1964 Nobel Prize in Physics. Townes became an OSA fellow in 1963, and both he and Prokhorov were awarded OSA honorary memberships in later years. Today masers are used in atomic clocks, radio telescopes, and ground stations communicating with spacecraft.

In 1960 maser technology was extended from microwaves to visible frequencies when Theodore Maiman at Hughes Research Laboratories developed the ruby laser, an acronym for "light amplification by stimulated emission of radiation." His

invention, based on theoretical work by Townes and Arthur Schawlow, fired successfully on the first try—an auspicious beginning for a technology that would prove a game changer across many fields. (See Donald Nelson, Robert Collins, and Wolfgang Kaiser, *PHYSICS TODAY*, January 2010, page 40, and also May 2010, page 8.)

A wave of new laser technologies quickly followed. Later in 1960 the Bell Labs group of Donald Herriott, an OSA fellow who would later serve as OSA president, invented the first continuously operating laser, an IR helium–neon laser. Semiconductor diode lasers soon appeared as well. Despite being viewed as "a solution looking for a problem" in its early days, the laser has since found a central role in numerous scientific, technological, medical, military, and industrial applications.

## Connecting the world through light

Of all the societal transformations created by the laser, perhaps none is as important as its impact on communications. Lasers are at the heart of the fiber-optic technologies that connect people all over the world. A laser beam traveling down a single strand of glass can encode information for more than half a million telephone conversations or thousands of internet connections and TV channels.

Not long after the laser was invented, scientists first began to investigate how it could interact with waveguides, including glass optical fibers. Fifty years ago OSA member Charles Kao and George Hockham at the UK's Standard Telecommunication Laboratories in Harlow realized that increasing the purity of the glass could allow the transmission of light signals over a distance of 100 km, about five times farther than the best glass fibers available at the time. Kao, known today as the "father of fiber optics," shared the 2009 Nobel Prize in Physics for his work (*PHYSICS TODAY*, December 2009, page 12).

In 1970 Corning Glass Works scientists Peter Schultz, Robert Maurer, and Donald Keck, who was later named an OSA honorary member, created the first telecommunications-grade optical fiber. In the 1980s OSA fellow David Payne of the University

**1947**

Edwin Land, at a meeting of The Optical Society, shows off the film for what will become the Polaroid instant camera.



OSA ARCHIVES

**1960**

Theodore Maiman demonstrates the first laser. The device will become a game changer for developing scientific equipment and will find its way into fields from medicine to consumer electronics.



HUGHES RESEARCH LABORATORIES

**1940**

**1945**

**1950**

**1955**

**1960**

**1965**

**1950s**

For their work on masers and lasers, Aleksandr Prokhorov, Charles Townes, and Nicolay Basov (from left to right) will share the 1964 Nobel Prize in Physics.



AIP EMILIO SEGRÈ VISUAL ARCHIVES, HECHT COLLECTION

**1969**

Elsa Garmire explores ways to generate art with lasers. She will later develop and patent devices—including lasers, waveguides, and detectors—that enhance optical communications. She serves as OSA president in 1993.



OSA ARCHIVES

of Southampton in the UK developed erbium-doped fiber amplifiers, which exploit stimulated emission by excited erbium ions to boost optical signals and allow them to travel even greater distances.

## Probing matter with spectroscopy

Indian physicist and OSA honorary member C. V. Raman found in 1928 that when a transparent substance scatters a beam of monochromatic light, it causes a shift in the scattered light's frequency that is characteristic of the substance. That discovery, which earned him the 1930 Nobel Prize in Physics and came to be known as the Raman effect, is the basis for Raman spectroscopy, a technique used to this day to analyze the chemical makeup or "molecular fingerprint" of materials and biological samples.

In the 1960s the laser brought immediate gains in spectroscopy. Its strong, coherent beam, tunable over a broad wavelength range, opened up new approaches for studying atoms and molecules. Schawlow, who later served as OSA president, pioneered sensitive techniques that led to previously undreamed-of precision in measuring the spectral lines of hydrogen. OSA fellow Nicolaas Bloembergen at Harvard University used four-wave mixing and other nonlinear phenomena to expand the range of wavelengths available for spectrographic study—a crucial step for biological applications in particular. Schawlow and Bloembergen shared half of the 1981 Nobel Prize in Physics. Schawlow became an OSA honorary member in 1983; Bloembergen, in 1984.

## Photography goes digital

The 1969 invention of the electronic light sensor known as the charge-coupled device, or CCD, marked the beginning of a new digital era in photography. OSA members Willard Boyle and George E. Smith at Bell Labs developed the core concepts behind the CCD—work that earned them a share of the 2009 Nobel Prize in Physics. It did not take long for the CCD to find its way into numerous scientific and consumer applications; by the mid 1970s, CCD imaging devices were being installed on satellites and telescopes. Generations of professional digital

The mid-century discoveries in optics created entirely new fields of discovery and technology applications. Advanced manufacturing, for example, deploys high-powered lasers to cut and bond materials. The recent discovery of gravitational waves was made possible with laser technology and has opened up a new realm of possible discoveries, forever changing astrophysics.

—Gregory J. Quarles, OSA chief scientist

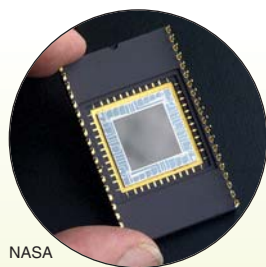
still and video cameras and the consumer-oriented camcorder were also based on the technology.

Although the CCD has now largely been eclipsed by CMOS focal-plane arrays for most consumer electronics, CCDs continue to be used extensively in specialized applications such as biomedical imaging, night-vision devices, and, in particular, astronomy. The Sloan Digital Sky Survey, for example, used 54 CCDs to produce the largest uniform survey of the sky to date.

OSA honorary member Dennis Gabor invented holography in the late 1940s, for which he received the 1971 Nobel Prize in Physics. Following the invention of the laser, OSA fellow Emmett Leith and Juris Upatnieks at the University of Michigan and, independently, Yuri Denisyuk at the Vavilov State Optical Institute in the Soviet Union in 1962 developed modern holographic techniques that allow images of 3D real-world objects to be captured on photographic film. The research quickly created a worldwide interest in holography.

## Laser cooling yields a new state of matter

In 1985 teams led by Steven Chu at Bell Labs, Claude Cohen-Tannoudji at École Normale Supérieure, and William Phillips at NIST devised sophisticated methods for using lasers to cool atoms to microkelvin or even nanokelvin levels. (See Cohen-



NASA

### mid 1970s

CCDs are quickly adopted for consumer and scientific applications, including satellites and telescopes. This one, designed for UV detection, enables the observation of very faint objects in the universe.

### 1993

The development of a practical blue LED represents a significant breakthrough for high-efficiency lighting technology.



GUSSIS/AURIO (WIKIMEDIA COMMONS/CC BY-SA 3.0)

1970

1975

1980

1985

1990

1995

### 1981

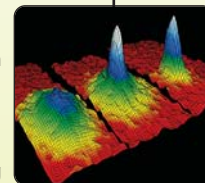
Arthur Schawlow shares the Nobel Prize in Physics. Here the 1975 OSA president is shooting at a double balloon with a toy gun that includes a real laser. The gun pops the inside blue balloon but not the clear outer one.

AIP EMILIO SEGRÈ VISUAL ARCHIVES, PHYSICS TODAY COLLECTION



### 1995

Eric Cornell, Wolfgang Ketterle, and Carl Wieman use laser cooling to achieve a new state of matter, the Bose-Einstein condensate; they will share the 2001 Nobel Prize in Physics. From left to right: the density profile of a cloud of cooling rubidium atoms before the condensate forms, the appearance of the condensate, and the nearly pure condensate after further cooling.



NIST/JILL ACU-BOULDER

Tannoudji and Phillips's article, *PHYSICS TODAY*, October 1990, page 33.) Their methods opened the door to new, important experiments in quantum physics because they allowed researchers to slow atoms and observe them at temperatures near absolute zero. Chu, Cohen-Tannoudji, and Phillips received the 1997 Nobel Prize in Physics for their work; Chu later served as the 12th US secretary of energy. All are OSA honorary members.

Laser cooling was central to the ability of OSA members Eric Cornell and Carl Wieman at JILA and Wolfgang Ketterle at MIT to create a new state of matter known as a Bose–Einstein condensate in 1995. Bose–Einstein condensates, first predicted by Satyendra Bose and Einstein in the 1920s, exhibit macroscopic quantum phenomena and pave the way for new experimental approaches for basic physics and for potential technological innovations. (See Ketterle's article in *PHYSICS TODAY*, December 1999, page 30, and December 2001, page 14.) The researchers attained their condensates by cooling alkali atoms to just a few billionths of a degree above absolute zero; the work garnered them the 2001 Nobel Prize in Physics. Condensates have since been produced for many isotopes and for molecules, quasiparticles, and photons.

### Frequency combs raise precision to a new level

Advances in ultrafast lasers paved the way for OSA fellows Theodor Hänsch at the Max Planck Institute for Quantum Optics and John Hall at JILA to create ultraprecise optical frequency combs, which earned them half of the Nobel Prize in Physics in 2005 (*PHYSICS TODAY*, December 2005, page 19). Those tools for measuring the frequency of light have found numerous applications in areas requiring high precision; they are the basis of optical atomic clocks, high-precision spectroscopy, and GPS technology. Their unique attributes have also been a boon for experiments in basic physics, such as highly sensitive tests focused on measuring fundamental constants, and for tracking how chemical reactions unfold. Hänsch was awarded an OSA honorary membership in 2008.

The other half of the 2005 physics Nobel went to OSA fellow Roy Glauber at Harvard, whose work on formulating a quan-

tum mechanical theory of optical coherence laid the foundation for the extraordinarily productive discipline of quantum optics, which focuses on the interactions between light and matter at submicroscopic levels.

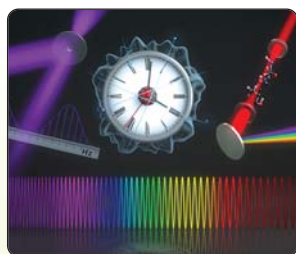
### Microscopy reveals the invisible

The 20th century saw tremendous advances in microscopy. In the 1930s, OSA honorary member Frits Zernike at Groningen University developed the phase-contrast microscope, which combines the light scattered by a transparent specimen and the background, unscattered light in a way that creates high-contrast images of structures previously visible only when cells were killed and stained. The microscope was thus instrumental in enabling researchers to directly observe living cells and their organelles. Although the importance of the Dutch physicist's invention was not immediately recognized, when the German military took stock in 1941 of all inventions that might serve in World War II, the phase-contrast microscope was at the top of the list. After the war many thousands of phase-contrast microscopes were manufactured and quickly became standard equipment for biomedical research. Zernike was awarded the 1953 Nobel Prize in Physics.

The advent of the laser and the development of techniques for using fluorescent proteins as tags led to new microscopy methods for watching intricate biological processes such as gene expression, the development of neurons, and the spread of cancer cells. OSA fellow W. E. Moerner and OSA members Stefan Hell and Eric Betzig built on those advances by developing superresolution microscopy, a family of techniques that use laser-excited fluorescence to overcome diffraction's inherent resolution limit and produce images of single molecules. They shared the 2014 Nobel Prize in Chemistry for their work (*PHYSICS TODAY*, December 2014, page 18).

### LEDs light the way to sustainability

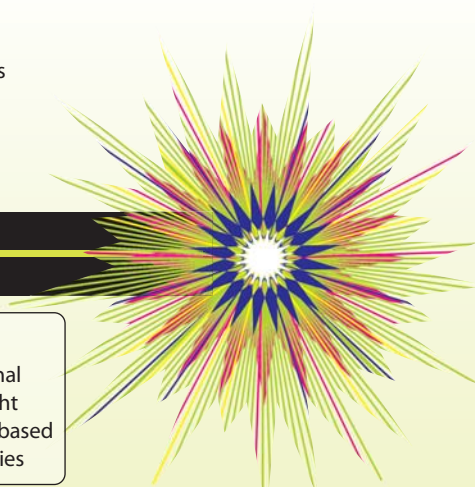
The long-lasting, energy-efficient LEDs that today provide light for scientific equipment, consumer electronics, general solid-state lighting, and many other technologies were many decades in the making. Building on discoveries made in the



**2005**

The Nobel Prize in Physics recognizes frequency combs, whose stunningly precise measurements yield gains for timekeeping, spatial navigation, basic physics, spectroscopy, and more.

YE GROUP AND STEVE BURROWS, JILA



**2000**

**2005**

**2010**

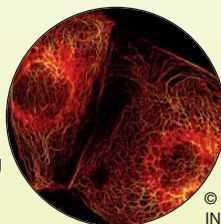
**2015**

**2008**

In recognition of its global scope, OSA renames itself as The Optical Society.

**2014**

Eric Betzig, Stefan Hell, and W. E. Moerner share the Nobel Prize in Chemistry for developing superresolution microscopy techniques.



**2015**

International Year of Light and Light-based Technologies

© ANDRIY CHMYROV, STEFAN HELL, MAX PLANCK INSTITUTE FOR BIOPHYSICAL CHEMISTRY

## CENTURY OF LIGHT

early 20th century, engineers at Texas Instruments patented the first practical LED in the early 1960s. Because they were only available in red for their first decade on the commercial market, those early LEDs mostly found use as indicator lights.

The emergence of new semiconductor materials in the 1970s made green, orange, and yellow LEDs possible, but blue—a key color for making white light—remained elusive. It wasn't until 1993 that OSA member Hiroshi Amano, Isamu Akasaki, and Shuji Nakamura created the first practical blue LEDs. White LEDs that combined LEDs of different colors came along soon after. Later, researchers developed several other methods to produce white light using LEDs, including a technique in which blue or UV LEDs are coated with phosphors that emit multiple colors of light. For their development of efficient blue LEDs, Amano, Akasaki, and Nakamura received the 2014 Nobel Prize in Physics (PHYSICS TODAY, December 2014, page 14).

Today, LEDs are integral components in a wide range of equipment and consumer products, from data transmission systems to traffic lights to smartphone screens. Their remarkable efficiency, small size, and long lifespans make them well suited for many uses and give them a low environmental cost in terms of energy and materials. They are changing how we light up our homes, offices, and streets.

### A bright future for the science of light

One hundred years after its founding, OSA has grown from a small group of luminaries to a diverse worldwide community

of 19 275 scientists, engineers, and other professionals dedicated to advancing knowledge and applications of optics and photonics.

The recent observation of gravitational waves is just one of many remarkable scientific achievements that have been made possible by advances in optics research and light-based technology. Imagine what OSA's founders would have thought if they could have glimpsed, in 1916, the incredible developments the next 100 years would bring. Although some of today's capabilities might have seemed like logical extensions of the basic principles and precursor technologies of the early 20th century, many of the tools and techniques we now take for granted would have seemed like pure science fiction.

From the practical to the fantastical, a plethora of exciting new advances can be expected in the coming years. Communications and information technology remain active areas of development, with researchers and engineers pursuing low-loss optical fibers, astonishingly high-speed networks, and related technologies. The biomedical realm is on the cusp of terrific innovations in imaging, therapeutics, and minimally invasive surgery. As light-based sensors grow ever more sophisticated, their uses seem almost limitless. Even light-manipulating "invisibility cloaks" and laser-propelled satellites may be closer at hand than we think.

If the lessons from the past are any indication of what's to come, we can anticipate breathtaking progress in basic physics, astronomy, Earth science, and more as OSA begins its second century. PT



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