Leading Lights

As the scientific community celebrates the 50th anniversary of the laser, we highlight some of Rochester's contributions to one of the most influential technologies of modern science.

Text by Scott Hauser | Timeline by Steve Boerner

FAMOUSLY DESCRIBED AS A "SOLUTION LOOKING FOR A PROBLEM" BY one of the Nobel Prize-winning pioneers of laser science early in the technology's history, the laser has more than proved its importance over the past 50 years.

Few scientific fields—not to mention commercial ones—have gone untouched by the discovery that a relatively simple device could transform light of the kind that's emitted by an ordinary light bulb into a wave that oscillates so perfectly in sync that the resulting beam could easily be bounced off the moon, or formed into a pulse so brief that a nanosecond seems like a lifetime, or focused so precisely that it produces temperatures and pressures similar to those at the center of the sun.

First demonstrated and reported in the scientific literature in the August 6, 1960, issue of *Nature*, the concepts underlying the laser had been the focus of several scientific groups around the world. (Indeed, the original concept was outlined in 1917 by Albert Einstein, and by 1960, even the name—an acronym for "light amplification by stimulated emission of radiation"—had already been introduced into the literature.)

Out of that discovery have come powerful technologies to manipulate atoms, explore new sources of energy, and diagnose and treat diseases and medical conditions—not to mention new ways to check out groceries, play music and movies, and print documents.

In an address earlier this year to kick off "Laser Fest," a national celebration of the 50th anniversary of the laser, Steven Chu '70, '98 (Honorary), the U.S. Secretary of Energy who received the Nobel Prize in physics for his work to capture atoms using lasers, pointed out that four Nobels in physics in the past five decades have been awarded for work directly involving the technology of lasers.

But he noted that the work behind another eight Nobels would not have been possible without the discovery. "Lasers really are the rock stars of innovation," he said, joking about the seemingly ubiquitous appearance of laser light shows at popular music concerts.

As home to the first academic program devoted to the study of optics (The Institute of Optics was founded in 1929), and to the Laboratory for Laser Energetics (1970), Rochester and its faculty, scientists, and alumni have been key players in the development and commercialization of laser technology. Here are a few sample highlights from that history. Ⓡ

1929

The Institute of Optics founded with the financial assistance of Eastman Kodak and Bausch & Lomb as the first academic program in the country devoted to the study of light and its properties. From 1940 through 1946, the University, through the institute and the associated laboratories supported by the National Defense Research Committee, becomes the leading academic optics center supporting the war effort.

1954

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966

Townes and Arthur Schawlow outline how the concept of the maser could be transferred to the infrared and optical regions of the spectrum. Columbia University graduate student Gordon Gould outlines ideas for a "laser."

Theodore Maiman at Hughes Research Laboratories in California constructs the first working laser, using a synthetic red ruby. He reports his findings in the Aug. 6, 1960, issue of *Nature*. Scholars turn to the "Coherence Theory" chapter of "Born and Wolf," one of the few academic sources that outline how light behaves when it's in phase.

Using microwaves, Bell Labs scientist Charles Townes and his colleagues demonstrate that coherent electromagnetic waves can be produced when atoms are energized in precisely the right way. Townes coins the term "maser" for "microwave amplification by stimulated emission of radiation."

Rochester hosts first **Rochester International Conference on Coherence and Quantum Optics.**

In a laboratory at Rochester, **Mike Hercher** '56, '64 (PhD) uses a red ruby similar to the one used by Maiman to demonstrate that a laser beam can be so intense that it effectively forms its own lens in the air, self-focusing itself into a tiny spot.

The Institute of Optics Director **Robert Hopkins** recruits **Emil Wolf,** a young scientific protégé of Nobelist Max Born, who has been studying the properties of light waves when they are in phase with one another, a concept known as coherence. While Wolf was not working on lasers, Hopkins recognizes coherence as an important new area of research. Wolf, in turn, recruits **Leonard Mandel,** one of the pioneers of quantum optics. Together, Wolf, now the Wilson Professor of Optical Physics, and Mandel, the late Lee A. DuBridge Chair Emeritus of Physics, will establish the Department of Physics and Astronomy as a nationally recognized center for the study of light. Wolf publishes *Principles of Optics,* also known as "Born and Wolf," or the "bible of optics."

Gould introduces the term "laser" in a paper titled "The LASER, Light Amplification by Stimulated Emission of Radiation."

Rochester receives NSF grant to demonstrate laser technology to faculty at other universities.

Moshe Lubin, then an assistant professor of mechanical and aerospace sciences, is invited to a demonstration of the laser by Hercher. Realizing that lasers would be ideal for studying high-energy-density phenomena such as ionized particles, Lubin brings together Rochester scientists to explore laser science initiatives.

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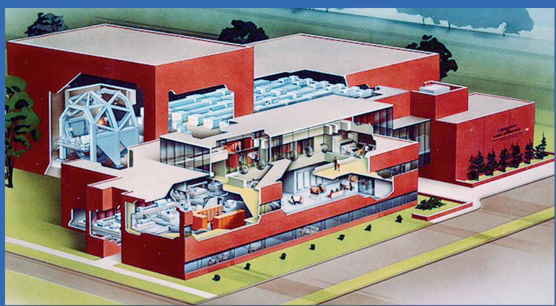
As part of the 50th anniversary celebration, the **Optical Society of America's 94th annual meeting,** to be held in Rochester from Oct. 24 to 28, will focus on optics and laser science. For more, www.frontiersinoptics.com.

The National Ignition Facility becomes operational. **Building on work done at Rochester,** the facility is home to the world's highest energy laser and is expected to be able to demonstrate inertial confinement fusion in a laboratory. At LLE, experiments produce fuel densities equal to that of the core of the sun.

Omega EP dedicated, adding four ultra-high-intensity laser beams to LLE. The highest energy laser in the world at the time, the lab's lasers can unleash more than a petawatt—a million billion watts—of power onto a target less than 45 microns in diameter (about half the diameter of a human hair). Working in conjunction with LLE's original 60-beam Omega laser, the Omega EP will open the door to a new concept called "fast ignition."

Chunlei Guo, an associate professor of optics, demonstrates that ultrabrief pulses from a tabletop laser system can turn any metal pitch black. Guo later demonstrates that the system can change metal into many different colors, a breakthrough that may lead to more precise diagnostic tools for medicine and other fields.

Demonstrating the sometimes counterintuitive properties of light, **Robert Boyd,** then the M. Parker Givens Professor of Optics, documents the mathematical oddity of "negative speed." Boyd and his students demonstrate that a wave can be split in such a way that parts of the wave can travel backward—and travel faster than the speed of light. The breakthrough may have implications for improving optical communications systems.



Ground is broken for LLE's building on the University's South Campus.

Mandel and his students **Mario Dagenais** '79 (PhD) and **H. Jeff Kimble** '78 (PhD) demonstrate photon antibunching, a landmark experiment that establishes that atoms emit single photons.

Working with commercial companies, the **LLE team builds Delta,** a four-beam laser, one of the first used to investigate the interaction of high-power laser radiation with matter. A goal of the project is to study inertial confinement fusion, a process to create a nuclear fusion reaction by imploding a small fuel target with extremely high bursts of energy.

First barcode scanner installed at a supermarket.

The Laboratory for Laser Energetics is founded with Lubin as director. Established as a "national research center for the study of intense radiation with matter," the lab is housed in Gavett Hall and the Hopeman Building.

While a researcher at Xerox's Palo Alto Research Center, **Gary Starkweather** '66 (MS) invents the first laser printer.

Hercher, Stroud, and student **Felix Schuda** '74 (PhD) demonstrate a stable, single-mode, continuous wave dye laser can be used to couple so strongly to a sodium atom that the atom's quantum state—or even the atom's thermal motion—can be controlled. The development will lead to later breakthroughs in atomic cooling and trapping and in work to create a Bose-Einstein condensate in laboratories.

Workers at Kodak Research Laboratories develop the first continuous wave dye laser, and **Hercher** and his students at the University produce a version that can be tuned to any desired color.

SOURCES: *A JEWEL IN THE CROWN; ESSAYS IN HONOR OF THE 75TH ANNIVERSARY OF THE INSTITUTE OF OPTICS*, EDITED BY CARLOS STROUD JR. (MELIORA PRESS: AN IMPRINT OF THE UNIVERSITY OF ROCHESTER PRESS, 2004); *INERTIAL CONFINEMENT FUSION: AN INTRODUCTION*, EDITED BY LOIS GERSH (LABORATORY FOR LASER ENERGETICS, 2008); LASERFEST, WWW.LASERFEST.ORG

First CD player introduced.

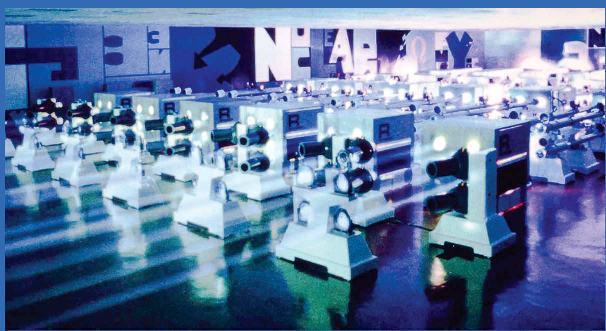
Omega converted to ultraviolet and becomes the highest energy laser in the world, producing 3 kilojoules of ultraviolet laser light in pulses lasting 1 billionth of a second. A "tabletop terawatt laser" is demonstrated at LLE by **Mourou** and his student **Donna Strickland** '89 (PhD). The laser uses "chirped-pulse amplification," which will become the standard process for all lasers with more than a petawatt of power. Rochester becomes the "cradle of the ultrafast."

Graduate student **Wayne Knox** '79, '84 (PhD) and faculty member **Gerard Mourou** demonstrate a jitter-free optical streak camera, an instrument that measures ultrashort light signals created by lasers. Working on the scale of picoseconds, Mourou and his student **Steven Williamson** '82 measure the optical phenomenon of electron diffraction and Mourou and his student **Janis Valdmanis** '84 (PhD) sample optoelectrical signals.

Leonard Mandel and his students invent the Hong-Ou-Mandel interferometer, a fundamental tool for the emerging field of quantum computing.

Stroud and his students **John Yeazell** '89 (PhD) and **Mark Mallalieu** '94 (PhD) demonstrate that a short laser pulse can convert the quantum mechanical cloud around an atomic nucleus into a miniature planetary system as predicted by classical physics.

LLE dedicated with a six-beam Zeta laser. More than 40 universities, government agencies, and private corporations use the facility.



24-beam Omega laser becomes operational at LLE. Senior scientists Steve Craxton and Wolf Seka pioneer a technique that effectively boosts the laser's energy by a factor of 10. Patented by LLE, the technique becomes the standard for fusion lasers.

Charles Munnerlyn '69 (PhD) outlines a new formula to refine how measurements are taken to enable precise calibration of laser surgery. Thanks to Munnerlyn's work, procedures involving Lasik vision-correction surgery become available to millions of people. At Rochester, using a new technique, LLE scientists demonstrate that they can compress the density of target fuels as much as 100 to 200 times greater than the previous record. The milestone, documented in a *Nature* article, met a condition set by the National Academy of Sciences to upgrade the Omega laser.

Steven Chu '70, '98 (Honorary), now U.S. Secretary of Energy, is named a corecipient of the Nobel Prize for demonstrating in a 1985 experiment at Bell Labs that lasers can be used to cool atoms to just millionths of a degree above absolute zero (-460 Fahrenheit). Effectively trapping the atoms in what Chu nicknames "optical molasses," the experiment succeeds in slowing the atoms from their room-temperature vibrational speed of about 2,500 miles an hour to a virtual (in atomic terms) standstill. The breakthrough has led to the development of the world's most precise atomic clocks and to more effective measures of the acceleration of gravity.

Lukas Novotny, a professor of optics, and his students measure carbon nanotubes at the highest resolution ever, earning a spot in the *Guiness Book of World Records*.

Omega is converted to a 60-beam laser, capable of producing 30 kilojoules of ultraviolet laser light. Initial experiments produce the highest thermonuclear fusion yield attained in an inertial fusion reaction. (The record of more than 1 trillion neutrons is expected to be broken this year in experiments led by LLE and National Ignition Facility scientists.)

The Institute of Optics appoints **Knox** as director. In 1985, as a researcher at Bell Labs, Knox and his colleagues set the record for briefest light burst ever recorded up to that point at 8 femtoseconds (eight quadrillionths of a second). The feat was noted in the *Guiness Book of World Records*.

EUGENE KOWALUK '70/LABORATORY FOR LASER ENERGETICS (LASER LAB)