LASERs at 50—From Death Rays to DVDs

by Alan S. Brown

In the 50 years since their invention, lasers are everywhere. They play DVDs and CDs, scan bar codes at supermarkets, deliver phone and internet service over optical fibers, perform delicate surgeries, manipulate molecules in the lab, and lock smart bombs on their targets.

Yet, the first thing most people ever heard about lasers could be summed up in two words: "death ray."

The death-ray story began, as these things often do, at a press conference. On July 7, 1960, reporters from the world's major papers jammed a room at New York City's Delmonico Hotel to witness the latest triumph of American science. The researcher giving the presentation, Dr. Theodore H. Maiman, was relatively unknown even among those who had vigorously pursued lasers and masers for the past decade.

Graphic shows the experimental Boeing YAL-1 airborne laser testbed, weapons system, a megawatt-class chemical oxygen-iodine laser mounted inside a modified Boeing 747-400F. It is primarily designed as a missile-defense system to destroy tactical ballistic missiles while in boost phase.

Maiman was a slight 33-year-old with a receding hairline. Like many of the top laser researchers, he had a Ph.D. in physics, completed in 1955. Unlike them, he also had an M.S. in electrical engineering and a B.S. in engineering physics.

Maiman had first tested his laser two months earlier. It was an elegant design that consisted of a ruby photon source, a three-coil xenon flash lamp to energize the ruby, and a machined metal tube to contain the parts. The ruby was silvered on both ends to create mirrors, though one of the mirrors was only 95 percent reflective. When the lamp flashed, it produced photons that would bounce between the two mirrors, releasing more photons each time they collided with an energized electron in the ruby. About five percent of those rubies would pass through the partially silvered mirror, creating the first laser beam.

Maiman was a practical engineer who had repaired electrical appliances to pay for his undergraduate education. The laser reflected his pragmatic nature. "One of the things I did, and it did prove successful, was to try to use things that were around. If I had to develop a new lamp, it would have been a whole other research project," he recalled in an interview many years later.

Maiman combed through strobe and flash catalogs for a light source that would meet his needs. He chose the ruby because high-purity chromium-doped aluminum oxide crystals were readily available. He machined many of the other parts.

Maiman had tested the new laser on May 16, and it worked the first time. He immediately submitted a short note describing the invention to *Physical Review Letters*. It was rejected. According to editor Simon Pasternack, the note looked like an extension of a Maiman paper published in June that described how rubies behaved when energized by intense light. Dr. Charles H. Townes, a giant in the field, later wrote, "Pasternack's reaction perhaps reflects the limited understanding at the time of the nature of lasers and their significance."

Maiman then submitted the paper to *Nature*, a more prestigious magazine, which would publish it in August. Still, Maiman's employer, Hughes Research Laboratories, knew others were working on lasers. It organized the July press conference to ensure Maiman (and Hughes) received credit for the breakthrough.

Death Rays

After Maiman finished explaining how the laser worked, a reporter asked if it could be used to make a death ray. Maiman said he couldn't rule that out. The next morning, the papers were filled with headlines like, "LA Man Builds Death Ray."

The inventor himself felt the term misrepresented his work. Yet Maiman and other researchers—many of whom replicated Maiman's simple design after looking

at newspaper photos—cheerfully classified laser power as "one-Gillette" on up, depending on how many razor blades the beam could cut through. By 1964, a laser was slicing a metal table and threatening James Bond's most vital organs in the smash-hit film *Goldfinger*.

Yet the reporter's question about death rays was well grounded. Although it took a convoluted path, the birth of lasers could be traced back to the British military's interest in death rays.

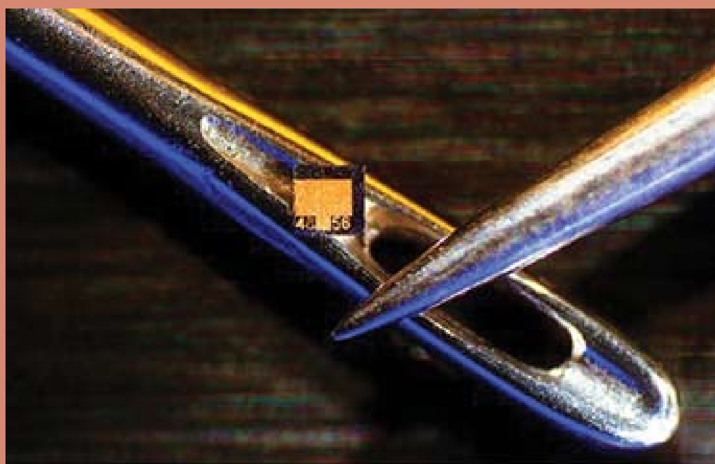
In the mid-1930s, rumors began circulating that Nazi Germany was developing a radio-frequency death ray that could incinerate cities and people. In January 1935, the British Air Ministry asked Sir Robert A. Watson-Watt, an engineer, if he could build an electromagnetic death ray to use against aircraft. Watson-Watt calculated that the weapon would be impractical, but noted that radio waves could detect enemy aircraft long before they reached their targets. One month later, he demonstrated the first modern radar system.

Britain later shared radar with the United States. The allies achieved massive advances in radio-frequency and microwave technology, signal detection, and electronics, said Arthur Siegelman, a Stanford University electrical engineer and microwave and laser optics pioneer. He noted that the United States recruited many top academic physicists to work on these problems at labs at MIT, Harvard, Columbia, Bell, and other locations.

By the end of World War II, it was clear that engineers and scientists had not only saved Great Britain from the blitz with radar, but had ended the war with the atomic bomb. Policymakers continued to fund many research laboratories, hoping for the next breakthrough.

It's All a Matter of Scale

Lasers range in size from microscopic diode lasers, top, with numerous applications, to football-field-sized neodymium glass lasers, bottom, used for inertial confinement fusion, nuclear-weapons research and other high-energy-density physics experiments.



Columbia University, for example, had worked on radar magnetrons during the war. After 1945, the newly created Office of Naval Research left the lab's microwave equipment in place and provided funds to continue its research. In 1948, Townes joined the lab. He had spent WWII developing a 1.25-centimeter-wavelength microwave radar bombing system. At Columbia, he hoped to use governmental surplus microwave equipment to probe the structure of molecules and atoms.

The Navy was pushing for higher frequencies in the millimeter range so it could reduce the size of its radar systems to make them easier to mount on ships. This was a high priority project, because aircraft had become a decisive factor in projecting sea power during World War II. Unfortunately, the electronic techniques used to generate the relatively long microwaves used in radar could not oscillate higher-frequency microwaves. The Navy pushed researchers to find an answer.

"Enough Meetings"

The Columbia Radiation Laboratory, where Townes was now director, was a major recipient of this largess. Yet by 1951, Townes was ready to give up. "We'd had enough meetings, that we had really surveyed everything that was going on, surveyed our own ideas. And so I was beginning to feel that, well, we may be coming to an end as to what we could usefully do immediately," he recalled in an interview years later.

Dejected, Townes went to Washington, DC, for a final meeting of the Office of Naval Research's microwave panel. He was an early riser. While sitting on a park bench waiting for a restaurant to open for breakfast, he found the way forward. Instead of trying to make electronic devices small enough to generate short wavelengths, Townes realized he could generate high-frequency radiation by pumping energy into atoms and molecules and then stimulating them to emit energy.

Townes whipped out—what else?—an envelope and calculated that ammonia molecules could emit short-wavelength microwaves. Moreover, the output would be coherent—that is, it would produce only a single frequency of radiation.

It took another three years for Townes and two graduate students to develop their device. He called it a maser, for *microwave amplification by stimulated emission of radiation*. The science behind the maser would eventually lead to what Townes called the optical maser, or laser.

The maser essentially trapped energized ammonia gas in a resonant cavity, then hit it with microwaves. This stimulated the emission of microwave radiation, which the cavity prevented from escaping until it built up sufficient intensity. Researchers eventually learned to generate photons from other materials, including rubies.

Masers did not solve the Navy's radar problem, but they did find some interesting applications. Used in amplifiers, they helped to capture satellite data and to discover the background temperature of the universe. They formed the heart of the first atomic clocks. Meanwhile, researchers kept looking for ways to work with shorter wavelengths.

Lighting the Way

Townes kept gnawing at the problem. At first, he focused on infrared rays, the next shortest wavelengths in the spectrum, but they proved intractable. In 1957, he realized that he could bypass across the infrared entirely and work with much higher frequency visible light.

That same year, Townes and his colleague and brother-in-law, Arthur L. Schawlow of Bell Labs, wrote a landmark paper that described (at least in theory) the components needed to make an optical maser. It involved many elements used in the maser, such as pumping a suitable material to a higher energy level and containing the stimulated photons in a resonant cavity prior to release.

That set the race for the laser in motion. In addition to Columbia, the major contenders included Bell Labs, IBM, Westinghouse, and defense contractor TRG.

Gordon Gould, a doctoral student at Columbia, had discussed some of his ideas about optical pumping—using light to energize a photon source—with Townes in 1956. This proved the key to energizing photon sources. In November 1957, Gould bought a dime-store notebook and in one weekend filled it with details of how to energize a lasing material with light and build a resonator using mirrors to amplify the photons. He called his optically pumped resonating device a laser, the first use of the word.

Gould took his notebook to a nearby candy store and had it notarized. It took 30 years, but on the basis of those early jottings, Gould overturned Townes and Schawlow's patent on the laser. Yet Gould was not the first to build a working laser. Although he had left Columbia to work on the project at TRG, he was barred from the top-secret program because he had participated in a Marxist study group while at college.

Instead, the honors fell to Maiman, the darkest of dark horses. Most top U.S. researchers clustered around New York City. Maiman worked at Hughes Research Laboratories in Malibu, CA, overlooking the Pacific Ocean. He was certainly not a star on the meeting circuit, though he had published papers. Maiman's advantage lay in the strength of his convictions and the clever ways he found to navigate around barriers.

His choice of ruby showed his willingness to go against the crowd. In 1959, Schawlow had delivered a conference paper that showed that ruby would not make a good photon source for lasers. Maiman was not convinced. He had worked with ruby-based masers at Hughes and understood the material and its properties better than most. Well enough, in fact, to spot flaws in Schawlow's calculations.

Maiman also knew how to slip past problems. While others worked to develop a continuous-light source powerful enough to pump their photon source, Maiman opted for pulsed power. He found what he was looking for in an off-the-shelf coiled xenon flash lamp. While he would not be able to operate his laser continuously, he could produce a beam of coherent light. This allowed him to move past others, such as Westinghouse's Irwin Wieder, who worked with rubies but

Why Lasers Work

Albert Einstein is ordinarily associated with the type of chain reaction that releases energy in an atomic bomb. Less well known, he also developed the theory of stimulated emission that is the basis of the chain reaction that releases photons in a laser.

The laser story began in 1916, when Einstein turned his attention to how light (which is really a form of energy) interacted with matter. When an atom absorbed a photon, the added energy would push one of its outermost electrons up to the next highest energy level. The electron would then spontaneously emit a photon and would return to a lower energy level. This is what creates ordinary light when, say, passing an electrical current through a light bulb's filament.

But what happens when a photon strikes an already excited electron that cannot move to a higher energy state? According to Einstein, if the photon had the right amount of energy, it would pop a photon loose from the electron. Equally important, the two photons would have the same energy and momentum. In other words, they would be coherent.

Those two photons could then interact with other excited electrons, releasing additional photons. This constant doubling of photons is the chain reaction that generates massive amounts of coherent light in lasers.

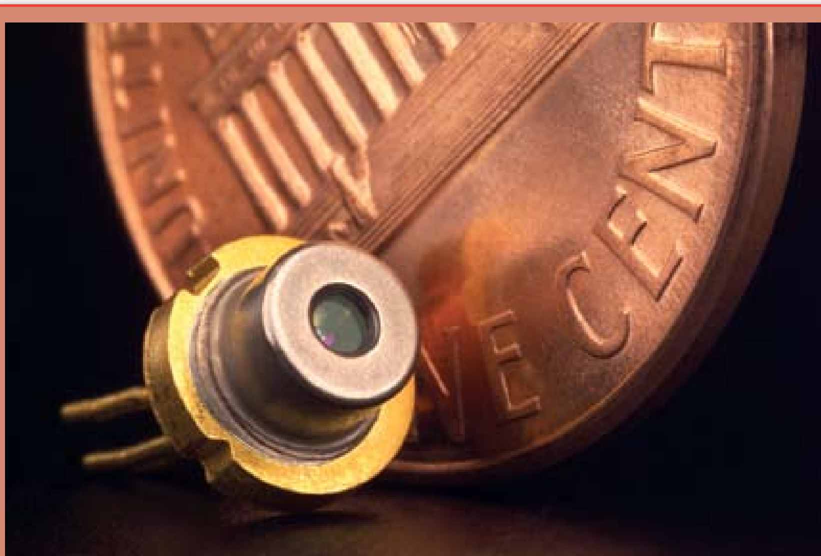
As the 1950s ended, many research groups using light sources to pump the electrons in their photon sources—often rubies, semiconductors, or gases—to higher energy levels. Many had found a way to contain the chain reaction in a mirrored resonator, so light could reflect back and forth as the chain reaction built. Finally, in May 1960, Theodore Maiman of Hughes Research Laboratories built the first laser to reduce Einstein's insights to practice.

could not pump enough energy using tungsten lamps.

While Hughes moved its laboratories from its air hangers in Culver City to a new research facility in Malibu, Maiman worked at home on the design. He was very secretive. "He writes a paper to show management he's doing something, while not telling anyone of the design," noted science writer Jeff Hecht, who wrote *Beam: The Race to Make the Laser.*

Back in the lab, Maiman built his laser. "It worked the first time, though the beam quality was modest," said Hecht. "TRG replicated it within two or three weeks. Bell Labs followed a few weeks later. They were all working from a press release using a picture different from the actual laser, since the photographer had thought it looked prettier with five coils and a thinner rod."

Others adapted Maiman's design to their own devices. At IBM, Peter P. Sorokin added mirrored ends to the calcium fluoride crystals and created a laser that needed less input power. At Bell Labs, Schawlow created a laser from a different type of ruby crystal. Another group at Bell used a combination of helium and neon to produce the first gas laser. Neodymium-glass and gallium-arsenide diode lasers followed within a couple of years.


A 5.6 mm *closed-can* commercial laser diode, of the kind used for CD or DVD players. *Photo: NASA*

Bell researchers were the first with a paper on lasers in the United States, and their publicity machine implied that they had invented the laser.

Maiman later called the laser "a solution looking for a problem." It did not take long to find. Lasers took the research world by storm. Many investigators were attracted by one unexpected property of Maiman's laser: high power. Unlike masers, lasers put out tremendous energy. This opened the door to entirely new applications.

Roughly 18 months after Maiman's press conference, surgeons at Columbia-Presbyterian Hospital in New York City used a laser to destroy a retinal tumor. Today, lasers act as scalpels for all kinds of surgery and to burn off tumors and treat cosmetic blemishes.

The early "eight-Gillette" lasers morphed into laser cutting, etching, and welding tools. Many retail stores have laser barcode readers. Lasers create holographs, imprint circuitry on semiconductor wafers, align precision machinery, and weld together metals or plastics to make three-dimensional parts from CAD drawings.

At home, they read music and movies from CDs and DVDs, and transmit telephone, television, and internet service over optical fibers. No boardroom presentation is complete without a laser pointer.

Many laser researchers earned renown for their discoveries. In 1964, Dr. Townes and two Russian scientists, Alexandr M. Prokhorov and Dr. Nicolay G. Basov, won the Nobel prize in physics for fundamental work in quantum electronics and laser theory. Schawlow and Dr. Nicolaas Bloembergen (who built the first ruby maser) shared the prize in 1981 for contributions to laser spectroscopy and nonlinear optics.

Gould won his first major patent victory in 1987, and laser manufacturers began to settle their cases against him. He was elected to the National Inventors Hall of Fame in 1991.

Maiman was nominated twice for a Nobel prize but never won. He did win other prestigious awards, including the Japan prize, Wolf prize in physics, and Oliver E. Buckley condensed matter prize. He was inducted into the National Inventors Hall of Fame in 1984.

In March 1962, General Curtis E. LeMay, *Ohio Gamma '32,* Air Force chief of staff, told a crowd at Assumption College in Worcester, MA, that the Air Force wanted to develop light-beam weapons that could divert satellites in orbit and perhaps even knock down incoming missiles. It was not exactly a death ray, but in the public mind, it was close enough. The military continues to investigate beam weapons.

Alan S. Brown has been an editor and freelance writer for more than 25 years and lives in Dayton, NJ (*insight01@verizon.net*). A member of the National Association of Science Writers and former co-chair of the Science Writers in New York, he graduated *magna cum laude* from New College at Hofstra University in 1974. He is an associate editor of *Mechanical Engineering* and contributes to a wide range of engineering and scientific publications.