The Discovery of the Laser

Jeff Hecht

Albert Einstein planted the seed that grew into the laser when he realized the possibility of stimulated emission in 1916, the year The Optical Society (OSA) was founded. Experiments in the 1920s confirmed the existence of stimulated emission, then called "negative absorption," but it seemed only a matter of academic interest. Russian physicist Valentin Fabrikant in 1939 proposed using stimulated emission to amplify light but did not pursue the idea at the time.

Charles Townes made the first major step toward the laser at Columbia University in 1951 when he proposed isolating excited ammonia molecules in a resonant cavity so stimulated emission could oscillate at microwave frequencies. In 1954, Townes and his student James Gordon demonstrated the first maser, shown in Fig. 1, a word he coined from "microwave amplification by the stimulated emission of radiation." Microwave masers soon became important as high-frequency oscillators and low-noise amplifiers.

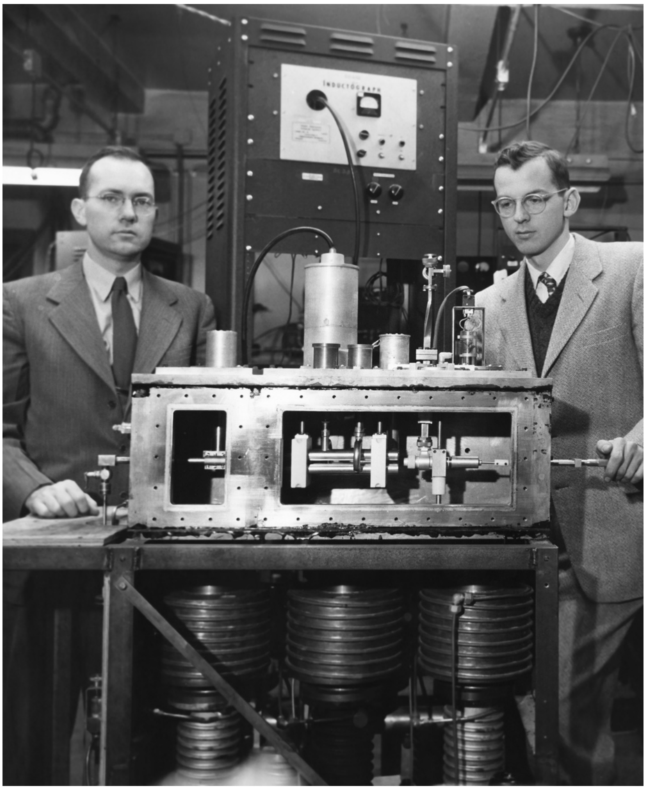
With millimeter waves and the far infrared then vast terra incognita, the next logical step was to develop stimulated emission at infrared and optical wavelengths. The key requirements were a medium with energy levels that could be inverted to produce stimulated emission in the optical band, a way to produce a population inversion, and a cavity in which the light waves could oscillate.

That took some serious rethinking, and in the summer of 1957 Townes began a systematic analysis of how to build what he called an "optical maser." In essence, he formulated the physics problem that had to be solved to develop the laser. As part of his investigation, in late October Townes talked with Gordon Gould, a graduate student under Polykarp Kusch, about optical pumping, which Gould was using to excite thallium vapor for his dissertation research. Optical pumping was new, and Townes thought it might produce an optical population inversion. The two talked twice, then went their separate ways.

Townes enlisted the aid of his brother-in-law, Arthur Schawlow, who worked at Bell Labs and had experience in optics. Schawlow proposed using a pair of parallel mirrors to form a Fabry–Perot resonator for the laser. They initially considered using thallium vapor as the active medium, but Schawlow decided potassium vapor was more promising, so they focused their attention on that system, and also noted that solids could be optically pumped. Reviewers at Bell Labs, where Townes was a consultant, urged them to analyze cavity modes, which they included in their pioneering paper, "Infrared and optical masers," in the 15 December 1958 *Physical Review* [1], which laid the groundwork for early laser development.

They did not know that Gould had jumped on the idea earlier. At age 37, he was growing impatient with his dissertation. Gould had worked with optics before, and within weeks after talking with Townes he described a Fabry–Perot laser resonator in a notebook that he had notarized on 13 November 1957, shown in Fig. 2. Filled with dreams of becoming an inventor, he left Columbia, talked with a patent lawyer, and holed up in his apartment with a pile of references to work out his plans for what he called the LASER. Gould had solved the laser problem on his own, and in time he would develop an extensive catalog of potential laser transitions. But neither he nor Townes and Schawlow were close to building a working laser. They had the blueprint, but finding the right material was a serious problem.

Alkali metal vapors were attractive because they are simple systems easy to describe in theory. They did not offer much gain, but they looked promising for a proof-of-principle physics experiment. Townes thought it would make a good dissertation project, as the microwave maser



▲ **Fig. 1.** Townes and Gordon with ammonia maser. (AIP Emilio Segre Visual Archives, Physics Today Collection.)

had been for Gordon, and put two of his students, Herman Cummins and Isaac Abella, to work on it.

Schawlow pursued optical pumping of solids, a natural because Bell Labs was deeply involved in solid-state physics. Schawlow initially focused on synthetic ruby, which was also being used in solid-state microwave masers and was readily available at Bell. However, the spectroscopy of ruby discouraged him. The red transitions which had looked attractive turned out to be three-level transitions terminating in the ground state, making it hard to invert the population. Moreover, other Bell researchers had found that the red emission was inefficient, so he began looking for other candidates.

As word of the laser circulated around Bell, others developed their own ideas. Ali Javan proposed a novel scheme for exciting a gas laser with an electric discharge in a mixture of helium and neon. The helium would absorb energy from the discharge, producing an excited state with energy very close to a neon transition. Collisions would excite the neon to a metastable upper laser level, which would then emit on a transition to a level well above the ground state—a four-level system that looked attractive for continuous laser emission.

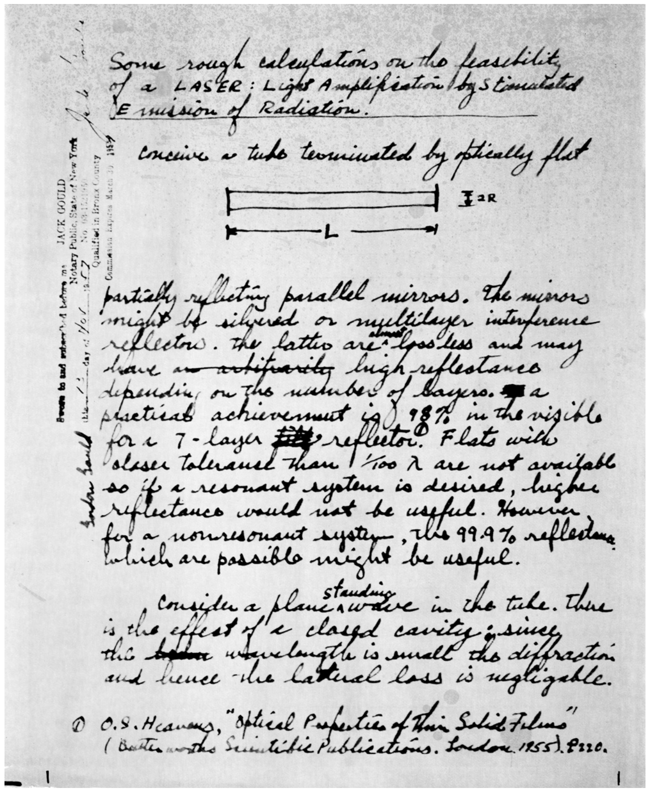
Gould, meanwhile, had gone to work at a defense contractor, Technical Research Group Inc., to support himself while working on his laser ideas. He had hoped to keep his ideas secret, but eventually worked out a deal to share patent rights with TRG, which helped him develop a patent and write a grant for research on building a laser. In early 1959, Gould and TRG president Larry Goldmuntz pitched their proposal to the Advanced Research Projects Agency, then less than a year old and chartered to explore daring new ideas. ARPA was so impressed that they approved a contract for $999,000—more than triple the $300,000 TRG had requested.

By then, publication of the Schawlow–Townes paper had put the laser into public view, interesting other researchers in trying to make one. The ARPA contract was serious money at the time, intended to support efforts to demonstrate laser action in a number of media. Laser development was becoming a race, but it would not be an easy one.

The first public reports on laser experiments came at a 15–18 June 1959 conference on optical pumping at the University of Michigan. Worried that the Pentagon might classify all laser research, not just its TRG project, Bell Labs management encouraged Javan to describe his work both at the meeting and in *Physical Review Letters*. Javan reported some progress in understanding energy transfer in helium-neon discharges in experiments he had begun with William Bennett. Gould described his ideas and hinted at the size of TRG's military program but was vague on details. Meanwhile, Gould was having trouble getting the security clearance he needed to work on the TRG project because of his past involvement with communists.

September saw a meeting much better remembered, the first Quantum Electronics Conference at Shawanga Lodge in High View, New York. Sponsored by the Office of Naval Research, it was the first in a series of biennial meetings that became the International Quantum Electronics Conference. Only two speakers at the 1959 meeting talked about lasers. Javan described the early stages of his helium-neon research, but had little to say beyond his *Physical Review Letters* report [2]. Schawlow wrote off pink ruby, with low chromium concentration, because as a three-level system he thought it would emit light too inefficiently for use in a laser.

Most speakers described microwave maser research. Among them was Theodore Maiman, who had built a surprisingly compact ruby maser at Hughes Research Laboratories in California, and was looking around for a new project. He had thought about optically pumping a microwave maser, but the optical laser caught his eye. Despite Schawlow's doubts, Maiman decided to start with ruby because he was familiar with it. He thought studying where ruby's energy went would help him identify a better material. But his careful measurements showed the quantum efficiency of ruby fluorescence was nearly 100%.



Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation.

Conceive a tube terminated by optically flat

partially reflecting parallel mirrors. the mirrors might be silvered or multilayer interference reflectors. the latter are almost lossless and may have an ~~arbitrarily~~ high reflectance depending on the number of layers. a practical achievement is 98% in the visible for a 7-layer reflector. Flats with closer tolerance than 1/100 λ are not available so if a resonant system is desired, higher reflectance would not be useful. However for a nonresonant system, the 99.9% reflectance which are possible might be useful.

Consider a plane standing wave in the tube. there is the effect of a closed cavity; since the wavelength is small the diffraction and hence the lateral loss is negligible.

① O.S. Heavens, "Optical Properties of Thin Solid Films" (Butterworths Scientific Publications. London 1955). P.220.

JACK GOULD
Notary Public, State of New York
Qualified in Bronx County

▲ **Fig. 2.** First page of Gould's notebook defines LASER. (AIP Emilio Segre Visual Archives, Hecht Collection.)

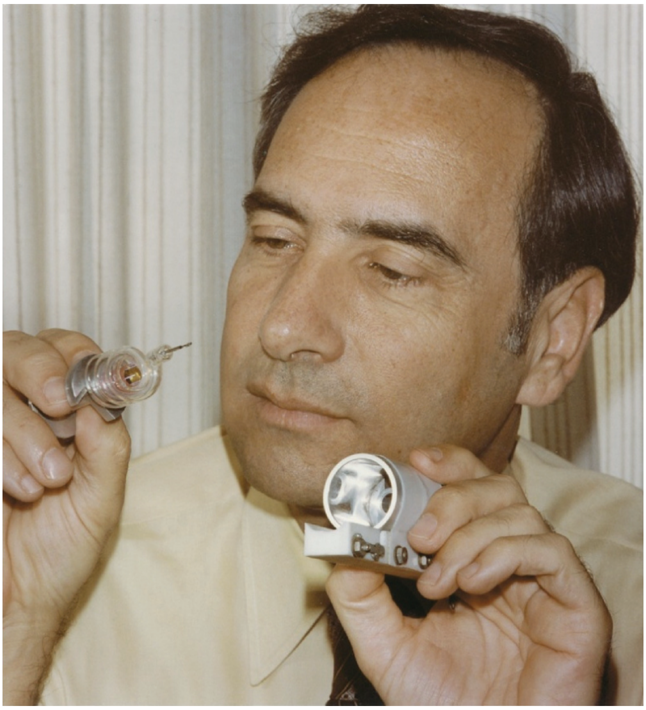
Ruby did have another problem: it was a three-level laser, with the ground state as the lower laser level. Four-level lasers were better for the continuous-wave lasers that most groups were trying to make. When Maiman sat down and calculated the pump power requirements for ruby, he found that even the brightest arc lamp available would make only a marginal continuous-wave laser.

Instead of giving up, he shifted gears and thought about making a pulsed laser to demonstrate the principle. He soon found that photographic flashlamps could emit peak power much higher than the brightest arc lamp and ordered a few coiled flashlamps in three different sizes, all of which he calculated could pump a ruby laser.

To test his ideas, Maiman silvered the ends of a fingertip-size stubby ruby rod and scraped a hole in the silver on one end for the beam to emerge. He slipped the ruby inside the coil of the smallest flashlamp, then slid the lamp inside a hollow metal cylinder, to reflect pump light back onto the rod and separate the pump light from the red pulse he hoped the ruby would emit (see Fig. 3). Then, on 16 May 1960, he and his assistant Irnee D'Haenens cranked up the voltage on the flashlamp power supply step by step. Initially, the ruby fluoresced when the flashlamp pulsed, growing brighter as voltage increased. When they exceeded 950 volts, the red pulses grew much brighter, and an oscilloscope screen displaying the pulse shape showed Maiman the changes he had expected for a laser.

Word of the success spread quickly through the lab, but Maiman insisted on performing further experiments to verify the results. When those tests confirmed the laser, word went up the management ladder, and Maiman wrote a paper, which he airmailed to *Physical Review Letters* on 22 June. PRL had just published his report of ruby fluorescence, and he was confident that the laser paper—a far more important achievement—would be quickly accepted.

He was stunned when editor Samuel Goudsmit summarily rejected the laser paper without sending it to referees. Maiman had violated two of Goudsmit's pet peeves. Tired of reports of minor progress on microwave masers, Goudsmit said he would run no more maser papers, but Maiman had titled his paper "Optical maser action in ruby." Goudsmit also disapproved of serial publication, and *Physics Review Letters* had just published Maiman's report on ruby fluorescence. Maiman protested that the paper was a major advance, but Goudsmit would not listen.



▲ **Fig. 3.** Maiman shows the simple structure of the world's first laser. (Reproduced by permission of Kathleen Maiman.)

Rejection by *Physical Review Letters* was a serious blow in 1960, when it was the only physics journal offering rapid publication. To stake his claim to the laser, Maiman dashed off a short note to the weekly *Nature*, which quickly scheduled it for publication on 6 August [3]. He sent a longer paper to the letters section of the *Journal of Applied Physics*, which accepted it, but could not publish it for six months. (*Applied Physics Letters* did not begin publication until 1962.)

Hughes managers knew others were working on lasers, and were thinking about holding a press conference when Malcolm Stitch called from a Rochester conference warning that Columbia was close to making their laser work. In fact, they were not at all close; Oliver Heavens, on sabbatical at Columbia, had waxed much too enthusiastic at the meeting. But it was enough for Hughes to schedule a press conference in New York on 7 July.

The news made page 1 of the *New York Times*, and stunned other laser developers. Reached on the phone by a reporter, Abella did not believe ruby could have lased, until the reporter explained Maiman had used a flashlamp. The laser quickly passed the acid test of replication; within three weeks, TRG had used press reports to demonstrate their own ruby laser—although they all showed Maiman with a laser design different than the one that worked. Bell Labs followed. By then, Maiman had received a ruby rod of much better optical quality that projected a bright spot on the wall.

The ruby laser excited the optics community, and The Optical Society invited Maiman to talk at the 1960 OSA Annual Meeting, held 12–14 October in Boston. It was his first report on the laser at a scientific conference, and the *New York Times* sent its top science writer, Walter Sullivan, to cover it.

His demonstration of flashlamp pumping inspired others. At the IBM Watson Research Center, Peter Sorokin and Mirek Stevenson had been trying to make four-level solid-state lasers with elaborate total-internal-reflection cavities. They bought flashlamps, had their crystals cut into rods, and soon demonstrated the second and third lasers, on lines of uranium and scandium in calcium fluoride. They were the first four-level lasers.

Bell Labs was close behind. On 12 December, Javan, Bennett, and Donald Herriott demonstrated the first helium-neon laser on a near-infrared line at 1.15 μm. By the end of 1960, the laser age was launched.

Note: This essay is based on material from Ref. [4].

References

1. A. L. Schawlow and C. H. Townes, "Infrared and optical masers," Phys. Rev. **112**, 1940–1949 (1958).
2. A. Javan, W. R. Bennett, Jr., and D. R. Herriott, "Population inversion and continuous optical maser oscillation in a gas discharge containing a He–Ne mixture," Phys. Rev. Lett. **63**, 106–110 (1961).
3. T. Maiman, "Stimulated optical radiation in ruby," Nature **187**, 493 (1960).
4. J. Hecht, *Beam: The Race to Make the Laser* (Oxford, 2005).