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Physics Today **63** (1), 40–45 (2010);
https://doi.org/10.1063/1.3293412

feature article

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In 1960 two rival laboratories reported the creation of lasers. Controversy over priority and proper behavior has persisted for half a century. Now three Bell Labs veterans of that confused but exciting summer tell the story as they remember it.

Donald Nelson is an emeritus professor of physics at Worcester Polytechnic Institute in Worcester, Massachusetts. **Robert Collins** is an emeritus professor of electrical engineering at the University of Minnesota in Minneapolis. **Wolfgang Kaiser** is an emeritus professor of physics at the Technical University of Munich in Germany. All three were on the team that developed the first Bell Labs laser in 1960.

With the 50th anniversary of the first laser approaching, its early history once again takes center stage. Several books in recent years have related that history from several points of view.[1–5] Among the authors are Theodore Maiman, who first observed laser action in crystalline pink ruby, and Charles Townes, who invented the original ammonia maser and shared the 1964 Nobel Prize in Physics with Nicolay Basov and Aleksandr Prokhorov for the “maser–laser principle.” But apart from our publication of scientific papers at the time, only our colleague Arthur Schawlow has left an account of the work at Bell Labs in the summer of 1960 that led to the creation of the first ruby laser.[6] This article aims to broaden that account.

At the time, there was uncertainty and confusion about whether laser action had been obtained. That confusion has led to continuing controversy. We hope our account will contribute to understanding the events of the summer of 1960. Some of the confusion can be traced to Maiman’s misfortune in having his first paper rejected by *Physical Review Letters* (*PRL*) in June 1960; some to the fact that the press conference called by his employer, Hughes Research Laboratories, did not coincide with the publication of a scientific paper; some to shortcomings in Maiman’s hastily written initial papers; some to the prestige of the 1958 Schawlow–Townes paper[7] and patent, which laid out design principles for a laser; and some to patent litigation that stretched on for 30 years.

While the basic claim of the Schawlow–Townes patent has survived, Gordon Gould eventually won a basic and lucrative patent on an optically pumped laser amplifier. During 1958–60 Gould was a graduate student in Columbia University’s physics department, where Townes was a professor. Gould had made notebook entries expressing his ideas about extending masers to optical frequencies. His eventual success in the courts led writer Nick Taylor to state unequivocally that “Gould invented the laser.”[5] Scientific credit, however, is not usually determined by what Taylor admits are the “Byzantine twists of patent law.”

The Bell Labs effort to make the first laser began with the 1958 Schawlow–Townes paper, which was entitled “Infrared and Optical Masers.” That paper gave some guidance on how to make a laser: the amount of population inversion needed for laser oscillation in a given material and the need for a rod-shaped excited medium in order to provide adequate mode selection.

Several efforts were soon under way at Bell Labs to realize what was at first called an “optical maser.” The labs hired Ali Javan, who had begun studying helium–neon mixtures as a possible lasing medium at Columbia. He was joined by William Bennett and Donald Herriott in an effort that succeeded in obtaining a continuous-wave gas laser in December 1960. Schawlow began a modest effort at making dark ruby (as distinguished from the pink ruby used by Maiman) lase in a four-level system involving heavier chromium doping. One of us (Kaiser) and Geoffrey Garrett began studying visible emissions from various rare-earth dopants in calcium fluoride as possible laser transitions.

Willard Boyle (one of the 2009 Nobel physics laureates) and David Thomas patented electric pumping of an optical transition in a semiconductor diode. Boyle and another one of us (Nelson) studied the use of the no-phonon component of a bound-exciton transition in silicon in such a system at low temperature. When that approach yielded little encouragement, Nelson began attempts to get lasing in cesium uranyl nitrate, a strongly fluorescent crystal. Our third author (Collins), working with Schawlow and Stanley Geschwind in the fall of 1959, used ruby fluorescence to study paramagnetic resonance of its excited state.

In other labs as well, the Schawlow–Townes paper was a great stimulus to efforts to realize a laser. Conferences in 1959 were quick to include sessions of papers about the quest for an “optical maser.” The first such meeting was the Ann Arbor Conference on Optical Pumping, organized by Peter Franken and Richard Sands at the University of Michigan in June 1959. In a “miscellaneous session” chaired by Schawlow, Gould and Javan presented papers. Gould’s paper, entitled “The LASER: Light Amplification by Stimulated Emission of Radiation,” renamed the optical maser. Nelson, just completing a postdoctoral stay at Michigan before joining Bell Labs, heard Gould’s talk and remembers Schawlow’s comment on Gould’s coinage. With his usual humor, Schawlow opined that such a device would be more important as an oscillator, rather than just an amplifier. So, he suggested, it should be called a *LOSER*, a word he barely got out of his mouth before breaking into belly-shaking laughter. “Art was certainly right that the LASER is usually a LOSER,” Nelson has written, “but as time has amply shown certainly not a loser!”[8]

In September 1959, the first quantum electronics conference, organized by Townes, was held at the Shawanga Lodge in Highview, New York. Though its emphasis was on maser physics and engineering, papers on lasers were presented by Schawlow and Javan. Schawlow discussed the Schawlow–Townes paper and talked about ruby as a possible laser

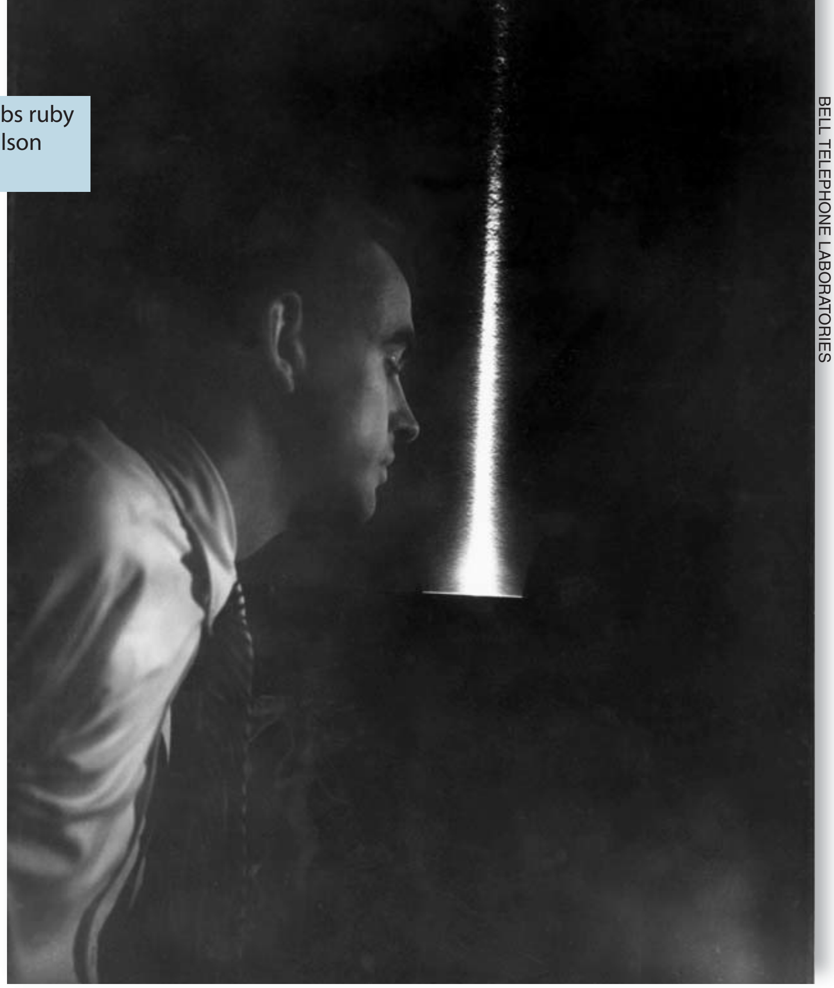

Figure 1. Pencil beam rising from the first Bell Labs ruby laser grazes a rough vertical surface as Donald Nelson looks on in 1960.

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medium.[9] He dismissed pink ruby because its three-level system would require drastically depleting the ground-state population and also because its fluorescence efficiency was then believed to be low. Instead, he spoke favorably of using dark ruby, in which neighbor lines produce a four-level system at low temperature that should, he argued, require less intense pumping.

But Schawlow and coworkers Frank Varsanyi and Darwin Wood found in December that dilute ruby actually has a high fluorescence efficiency. In June 1960 a paper by Maiman also reported the high fluorescence efficiency of ruby and, more important, that he had seen partial ground-state depletion under flash-lamp excitation.[10]

Race over?

On 8 July 1960, a front-page story in the *New York Times* bore the headline "Light Amplification Claimed by Scientist." A Hughes press conference the previous day had announced that Maiman had successfully operated a laser in pink ruby at Hughes's Malibu, California, location. The story was eagerly read at Bell Labs. But a reporter's summary of a scientific press conference leaves much unanswered, and that reporter had carefully written "Claimed." More surprising was the fact that the press conference had not coincided with publication of a scientific paper. Accompanying the story was a photograph of a rod-shaped ruby surrounded by a large helical flash lamp. But a much different picture of Maiman's apparatus soon appeared in other print media: a stubby little ruby in a smaller flash lamp. Which one had Maiman used? Weeks later we learned that his first two publications reported on the second configuration.

Was the race to make the first laser now over? Confusion reigned. When Albert Clogston, who oversaw the various laser efforts at Bell Labs, saw the *Times* piece, he called a meeting of the researchers involved in the Bell efforts. Javan said firmly that he didn't believe the claim. But Schawlow, who knew more about ruby than anyone else at the meeting, was willing to believe it. Boyle said very little, and Nelson felt the information was too sketchy to form a firm opinion. Garrett looked rather glum, as if he felt he had lost the race; he offered no judgment. The meeting broke up with no decisions made or actions recommended. Surprised at the indecisive outcome, Nelson told Boyle, his supervisor, that he wanted to drop everything else and build a ruby laser to see if, in fact, it would work.

With Boyle's approval, Nelson wasted no time. That afternoon he called a photographic equipment dealer in Manhattan. Taking his clue from the misleading *Times* picture, Nelson ordered a General Electric FT524, a powerful, helical xenon flashtube. And to drive it, he ordered a power supply for charging a 400-μF capacitor bank up to 4 kV. At just that point, Collins, also wanting to work on lasers, transferred into Boyle's group. Boyle brought him into Nelson's laboratory and asked whether the two of them could work together on making a ruby laser. Nelson agreed, and they were now a group of two.

They were able to obtain a long, narrow pink ruby rod from Wood, who was in the spectroscopy group. Collins asked Walter Bond, a staff member expert in optical instruments and sample preparation, to lap the rod ends parallel. But Bond and his lapping machine were otherwise occupied. So Collins's technician, James Ammons, did the lapping with a hand-held steel jig. The parallelism of the ends thus obtained turned out to be adequate because the limiting factor for getting Fabry–Perot modes between the ends was, in fact, the ruby's optical inhomogeneity. The rod ends were then silvered by vacuum deposition. One end was made opaque and the other permitted a few percent transmission. The finished rod was held in the center of the flash lamp by a cone through which the output beam could emerge.

The helical lamp being a diffuse source, Nelson and Collins needed a "white box" enclosure for the flash lamp to achieve adequate pumping. To that end, they obtained a glass cylinder and opaquely silvered its inner surface. But the test was a failure. The first firing of the flashtube shredded the silver coating. Apparently it had acted like a shorted secondary of an air-core transformer, with the flash-lamp coil being the primary.The solution was to use powdered magnesium oxide as the reflector, packed between two concentric glass cylinders. But that would take a day or two to put together. So Nelson left on Thursday 28 July for his sister's wedding in Michigan, and Collins put the new MgO white-box reflector together the next day.

With the ruby rod at room temperature, Collins began firing the flash lamp at increasing energy inputs, looking for laser emission with a phototube. At high input power he saw the monitoring oscilloscope trace act crazily. The system had been hastily constructed. Flash-lamp light leakage was significant, and incoherent ruby fluorescence might be playing an obscuring role. Thinking that a high-resolution spectrograph was necessary to separate the light components and unwilling to await Nelson's return, Collins took the system to Schawlow's lab, which had an appropriate spectrograph.

Oscillation threshold and pencil beam

With Schawlow now involved, the little group had become a triumvirate. Returning Monday morning from Michigan, Nelson found Collins and Schawlow firing the flash lamp in gleeful spirits. The stray-light problem had largely been solved. It was now apparent that starting at a particular flash-lamp input energy, there was a striking increase in the output of the principal R1 spectral line at 6943 Å. We had found a threshold of laser oscillation!

Yes, pink ruby did make an excellent laser. But the wild oscilloscope traces above threshold seemed to show something new. The traces exhibited a train of intense, randomly spaced microsecond pulses. Schawlow immediately suggested that they were relaxation oscillations of a kind previously seen in masers. Nothing like that had been reported at Maiman's press conference nor in the Maiman preprint submitted to the *Journal of Applied Physics* and sent by him to Schawlow. The *New York Times* had reported only that Maiman had observed fivefold amplification of light passed through small holes at each end reflector of his ruby—an observation he never published. How could Maiman have missed the dramatic pulsations seen by the triumvirate? Only, we concluded, if his initial experiments had not exceeded oscillation threshold. The confusion continued. One thing seemed clear: Our observations went beyond Maiman's, and they would be publishable.

We soon observed a very intense red spot on the wall from the characteristic laser pencil beam—a key observation not reported by Maiman and the property now thought to be synonymous with *laser* (see figure 1). We hastened to reproduce the threshold, and the relaxation oscillations that were its unambiguous signature, in other pink ruby rods. Next we set out to study the directional output of the laser beam and measure its coherence.

At that point Garrett asked to borrow one of the rods so that he and Kaiser might examine its output in a Fabry–Perot interferometer using their own flash-lamp system. As a measure of the output's temporal coherence, they found a fringe pattern showing a laser linewidth ($\Delta f/c$) of 0.2 cm^{-1}, narrowed from 6 cm^{-1} (see figure 2). (They also made measurements on a rod Kaiser had gotten from the Bell Labs maser group.)

Our group then looked for spatial coherence by making a small, rectangular (50 by 150 μm) aperture in the opaque silver coating of the ruby rod's reflecting end. We found a Fraunhofer interference pattern emerging from that aperture only when threshold was reached. It was decided that the results of Kaiser and Garrett should be combined with those of Collins, Nelson, and Schawlow for publication. The sixth name on our paper, which was submitted to *PRL* at the end of August,[11] was that of Bond, the group's expert preparer of lasing samples.

Our work had been stimulated by Maiman's press announcement and had confirmed his claim that flash-lamp-pumped pink ruby was a laser. So our paper had to reference his work appropriately. Because we had only the preprint Maiman had sent to Schawlow, it was decided that Collins should call Maiman for the sole purpose of asking whether he had published his ruby results in a journal. Because our paper had not yet been accepted for publication, Collins properly avoided discussing our group's findings with Maiman.

Maiman informed Collins of his short announcement in the 6 August issue of *Nature*.[12] Thus in the version of our paper submitted to *PRL*, reference 3 cited Maiman's *Nature* announcement followed by "also *J. Appl. Phys.*, in press." In accepting our paper, *PRL* told us that Maiman's submission to the *Journal of Applied Physics* had actually been published elsewhere in September. Our librarian found it in *British Communications and Electronics*,[13] and so we cited both of Maiman's published papers, a fact mistakenly disputed by Jeff Hecht in his book on the invention of the laser.[4]

Our inadequate wording

Our *PRL* paper described Maiman's two main observations: "Recently Maiman has observed a decrease of the lifetime and a narrowing of the line shape for ruby fluorescence." That wording now seems quite inadequate. Maiman would have liked—and he deserved—a more prominent citation as discoverer of the first laser effects. But that precedence was not crystal clear in the uncertainties of the time. He had, after all, not observed threshold or a pencil beam.

On the other hand, the introduction in our paper should have offered a more explicit statement of the crucial observations we had made beyond what Maiman had reported—namely, the relaxation oscillations, which are the unmistakable signature of the laser oscillation threshold, and the pencil beam that signaled mode selection. For lack of such a sufficiently explicit introduction, our contributions were missed by some and forgotten by others. Hindsight has so much more clarity.

Hecht's book is rightly critical of the way our paper referred to Schawlow's Shawanga Lodge paper.[9] Our sentence "The use of a ruby rod for the observation of these effects has been proposed by Schawlow" would seem, in that context, to refer to pink ruby. Actually, in describing the importance of a rod for mode selection, Schawlow had discussed a dark ruby laser. He had explicitly dismissed pink ruby as a viable laser medium.

Our paper was simply adding important information to Maiman's discovery. That's the normal progression of publication in any scientific field, and it should have been clear at the time. In a longer paper the following year, Maiman and coworkers wrote that the crystals reported on in his first two publications exhibited "no clear-cut evidence of a threshold excitation."[14] Indeed, in the longer of the two 1960 papers, Maiman had given his understanding of why his compact 1-cm sample did not exhibit the extreme line narrowing expected of an above-threshold oscillator: "Because of internal reflection in the ruby, the present experimental arrangement shows very little angular discrimination in accepting spontaneous emission noise. A large fraction of the total spontaneous emission power is therefore effective as an input to the amplifier. A [strong] reduction in the spectral width . . . could be obtained in principle by mode selection techniques."[13]

We agree completely. In other words, Maiman was saying that in his small ruby sample so many modes were draining the excited-state population by stimulated emission that no one mode could get enough amplification to exceed oscillation threshold.

We wish to state here that we followed normal procedure in submitting our paper to *PRL*. None of the paper's authors nor anyone else at Bell Labs applied any pressure on the journal's editors or sought any favors from them. And, contrary to an unfounded rumor of that time, no one at Bell Labs had anything to do with the rejection of Maiman's *PRL*

Figure 2. Arthur Schawlow and Geoffrey Garrett (right) aligning the Bell Labs ruby laser to obtain Fabry–Perot interference fringes for measuring the spectral linewidth of its output.

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submission. Later the *PRL* editorial staff revealed that it had been an editorial rejection without any input from an external referee—based on the journal's editorials concerning masers and serial publication.

Our press conference

Interest at Bell Labs in creating a laser had from the start been motivated by the idea that a coherent light beam could serve as a carrier wave for communication with hugely increased bandwidth. Bell Labs management sought to make that point at a 5 October 1960 press conference in New York City (see figure 3), four days after the publication of our *PRL* paper. The press release was entitled "Optical Maser Used in Communications Experiments."

As soon as our paper had been sent off for publication, management realized that we needed to demonstrate some long-distance communications experiment to dramatize the laser's prospective usefulness. So we increased the transmission of the silvered output mirror to obtain a more intense pencil beam. We transmitted test beams down the 1000-foot central hallway at our Murray Hill, New Jersey, lab and then from Murray Hill to Long Hill Ridge, two miles away.

Next, with a newly fabricated rod producing a beam divergence of less than a milliradian, we propagated the beam to Murray Hill from Crawford Hill 25 miles away. Collins and Boyle had taken the laser to Crawford Hill and, with the aid of a telescope, aimed it at an old, very tall radar tower behind the Murray Hill facility. On top of the tower, Nelson and Bond observed the laser pulses, in full daylight, with a photomultiplier and narrow-band filter looking through a tube centered on the beamline (see figure 4). A description of that demonstration became the centerpiece of the press release.

The Bell Labs press release cited Schawlow and Townes for describing "the principles of an optical maser." But its first paragraph, discussing our *PRL* results, gave credit where credit was due: "It [ruby] was used in the manner originated by T. H. Maiman of Hughes Research Laboratories, who first observed optical maser effects in ruby." At the press conference, the team members gave brief talks on the various properties of the Bell Labs laser. We then demonstrated the ruby laser's pencil beam by making a small intense red spot on a screen across the auditorium.

Another highlight of the press conference was Nelson's demonstration of Young's double-slit interference. We had realized that such a classic interference pattern, produced with the two slits directly on the laser source, would definitively prove spatial coherence. So in September Nelson and Collins had done the experiment and found excellent agreement with the theory of a spatially coherent source.[15]

At the luncheon following the presentations, Nelson happened to sit next to *Time* magazine's science reporter, who remarked that he had attended the Hughes press conference in July and had been unconvinced of the claims made there. But now, he said, having seen our laser demonstrated, he was convinced. Appearing in the 17 October issue of *Time* (page 47), the reporter's story was accurate, as far as it went. But despite the acknowledgment of Maiman's priority in our press release, Maiman was never mentioned in the *Time* story. Nor, indeed, were any of the Bell Labs scientists.

Talk of "death rays"

In his book,[2] Maiman describes how difficult it was in 1960 to avoid all the unwanted talk at his press conference about the laser becoming a death ray. Such thinking reflected Buck Rogers fantasies and very real cold war tensions. Sensitive to those public concerns, Bell Labs management prepared us to avoid such talk with words that deflected death-ray questions without saying anything quotable.

The strategy worked well. But in March 1961, Nelson was invited to give a lecture on the laser (one of 25 such lec-

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Figure 3. Press conference on 5 October 1960 in New York, announcing and demonstrating the Bell Labs ruby laser. At the two tables are (left to right) Walter Bond, Wolfgang Kaiser, Donald Nelson, Willard Boyle, Robert Collins, George Dacey, Charles Townes, Arthur Schawlow, and Geoffrey Garrett. The laser is between the tables.

tures he eventually gave) to the Detroit chapter of the Institute of Radio Engineers. Michigan Bell Telephone Company, informed of the upcoming lecture, decided to use it for publicity. The firm arranged a press conference, which went quite well. There was the usual question about laser death rays, which Nelson deflected and negated with the rehearsed wording. But to his surprise, the front page story in the next day's *Detroit News* featured a bulleted list of applications—of which the death ray was first! Schawlow, ever the comedian, found a solution. During such public lectures he would say that he was considering possible countermeasures against the laser death ray, at which point he would flash a slide of a medieval knight in shining armor.

The shortcomings in Maiman's two hastily written 1960 papers contributed to the confusion in the summer of 1960. Because of his lack of specificity about the experiments—even the shape of the ruby was described only as "of 1-cm. dimensions"—we could never have reproduced his results. Our work took its major clue from a Hughes press release photograph, which, it turned out, was not of the laser discussed in Maiman's two 1960 papers!

In an article in *Laser Focus World* (*LFW*) commemorating the 30th anniversary of the laser's advent, a picture shows Maiman receiving as an award "a replica of his historic ruby laser."[16] The trophy contains a long rod-shaped ruby, described as a "100-mm-long Cr^{3+}-doped ruby rod." That struck Nelson as rather counterhistorical.

Nelson's letter to the editor, published eight months later, pointed out the discrepancy and its importance. A compact laser "of 1-cm. dimensions," he argued, could show stimulated emission but not a laser oscillation threshold.[17] Maiman's reply, in the same issue of *LFW*, did not address Nelson's assertion of historical inconsistency.[17] Instead, in contradiction of the statements we have quoted above from his 1960 and 1961 papers, Maiman sought to rebut Nelson's threshold argument.

Not long after Townes's chronicle of the laser's history was published[3] in 1999, he gave a public lecture based on the book to a large audience at Harvard University. He talked about Maiman's initial ruby experiments—the observations, their priority, and their shortcomings—but he did not mention any of the Bell Labs work. Nelson was in the audience and, surprised at the omissions, he rose during the question period and summarized them. That led to a conversation between them afterwards and an exchange of letters that included the *LFW* exchange with Maiman.

In his letter to Nelson, Townes wrote, "I was not aware of your careful discussion of reservations about oscillations on Maiman's first announcement, nor of his response. It's an interesting piece of history and shows at least that Ted was not clearly aware of the most striking qualities of a laser. If I had known of your work, I might have made a slight modification in the story given by 'How the Laser Happened.' However, even what I have there evoked some heated remarks from Ted. In any case he certainly deserves credit for hitting on a relatively easy and good solution for lasers."

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Figure 4. Sending a laser beam 25 miles from Crawford Hill, New Jersey (left) to Murray Hill (right) in 1960. At Crawford Hill, Robert Collins (left) aims a Bell Labs ruby laser at the top of the radar tower in Murray Hill as Willard Boyle prepares to fire it. Atop the tower in Murray Hill, Walter Bond (right) checks the alignment of the photomultiplier detector while Donald Nelson maintains phone contact with Crawford Hill.

The pumping of the pulsed ruby laser of 1960 typically required megawatts of flash-lamp power. It was thus considered a sufficiently dramatic accomplishment when Nelson and Boyle, late in 1961, made a ruby laser operate continuously with 850-watt pumping that the American Physical Society arranged a press-conference announcement at its January 1962 New York meeting.

Let us summarize: Maiman, who died in 2007, deserves credit for discovering the first laser by choosing pink ruby as the laser medium, by believing that emptying the ground state of a three-level system was possible, and by using a flash lamp in a white-box pumping arrangement to do it. That has been, from the start, our position and the position of Bell Labs—as stated in the October 1960 press release.

Also, the official history of Bell Labs states, "When T. H. Maiman announced the operation of the first laser in mid-1960, he reported a lifetime shortening from 3.8 to 0.6 milliseconds and an R1 to R2 line-intensity change from 2:1 to 50:1 as evidence of laser action in ruby crystals."[18] It then states that Collins and coworkers "gave confirmation of laser action." It thus seems only fair that our first laser observations—the laser oscillation threshold, accompanied by relaxation oscillations, and the pencil beam—should also be recognized as having been crucial new contributions to laser properties.

Our work in the summer of 1960 was done in a context of uncertainty and confusion. Nonetheless, we acted with honorable intentions in a difficult and hurried situation. By describing that summer of a half century ago to the best of our memories and records, we hope to bring understanding and a modicum of peace to discussions of this bit of history.

We end with a lighter note. In 1960, Satoru Sugano from Tokyo University was on sabbatical at Bell Labs. A theoretical paper of his was then the last word on the chromium-ion spectrum in ruby. One day Nelson asked him the technical meaning of his spectroscopic notation: U for the green absorption band and Y for the ultraviolet band. Without a word, Sugano turned to the blackboard and sketched the ruby absorption, with frequency increasing to the right. First on the left came the pair of sharp Red lines, then the broad green band, then the pair of weak, sharp Blue lines, and finally the broad UV band. He labeled, in order, those four features R U B Y, then turned around with an impish smile. Nelson had unwittingly been the perfect straight man for Sugano's secret spectroscopic humor.

We wish to thank Geoffrey Garrett for sharing his memories of these developments.

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