History of Gas Lasers

Part 1—Continuous Wave Gas Lasers

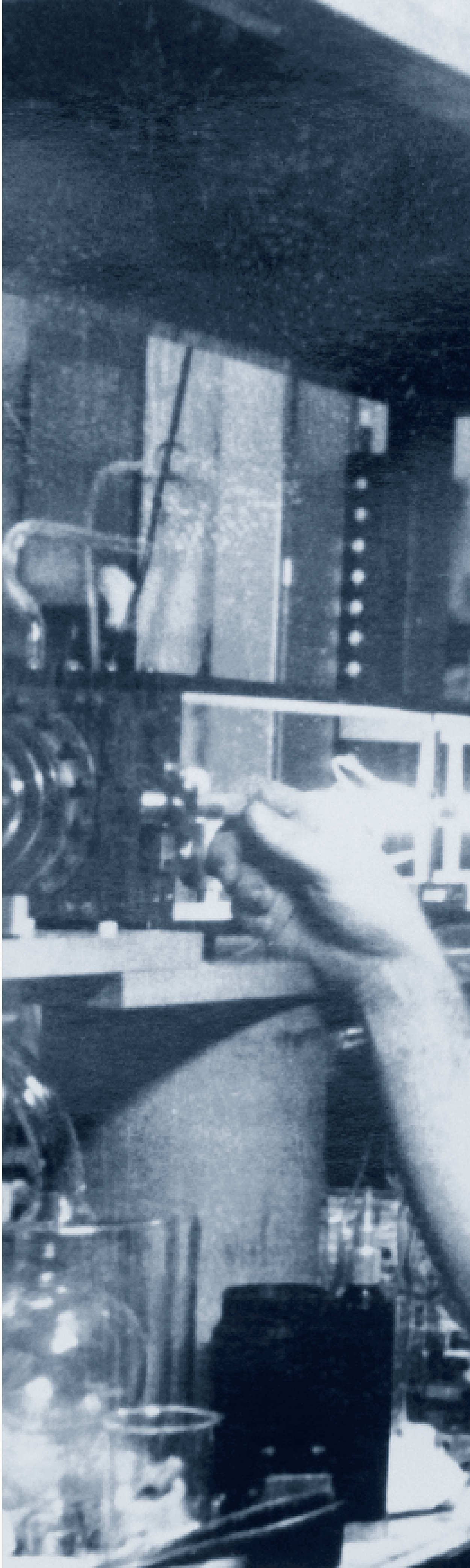
Jeff Hecht

In this first of a two-part series, Jeff Hecht relives the excitement that accompanied the development of the first gas lasers to generate continuous-wave beams.

Developing the concept of "light amplification by the stimulated emission of radiation" in a resonant cavity was a crucial step on the road to the laser. But making a working laser required finding a suitable laser medium. Theodore Maiman's ruby laser proved that optically pumped solids were viable laser materials, but gases were also attractive candidates because their properties were well-understood. Seven months after Maiman's success with ruby, the helium-neon laser became the first type to emit a continuous beam rather than pulses.

The quest for continuous wave lasers

Most early laser developers sought four-level laser materials that could sustain a steady population inversion so that they could generate a continuous-wave (CW) beam. Years of gas spectroscopy experiments had generated extensive tables of spectral lines, which could be mined for promising transitions. Developers studied two approaches to producing population inversions in gases—optical pumping and discharge excitation of the gas.



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Don Herriott, Ali Javan and William Bennett (left to right) with the first helium-neon laser at Bell Labs. (Although Bell Labs officially banned alcohol, the beaker in Herriott's hand holds a celebratory liquid supplied by their technician, Ed Ballik.)

Developed in the early 1950s by Alfred Kastler at the École Normale Supérieure in Paris, optical pumping can directly excite specific transitions. Optical pumping of alkali metal vapors was suggested for laser excitation both in Gordon Gould's patent applications and in the pioneering 1958 paper on infrared and optical masers by Charles Townes and Arthur Schawlow. The concept of optical pumping was attractively simple, but its efficiency was low in low-density gases or metal vapors, and the reactivity of alkali metal vapors created major experimental complications.

Discharge pumping was well established for generating red light in neon tubes and exciting mercury atoms to emit ultraviolet light in fluorescent lamps. Gould suggested discharge excitation in his patent applications, and he eventually received a patent on collisional excitation. Yet discharge pumping posed challenges, including selective excitation of the desired states and assuring gas purity.

The first researcher to examine discharge pumping for lasers in depth was Ali Javan, who earned his Ph.D. under Townes at Columbia for research on microwave spectroscopy. In mid-1958, he interviewed for a job at Bell Labs, where Schawlow told him about the laser concept. Intrigued, Javan rushed back to Columbia that afternoon and began investigating laser concepts. By the time he started work at Bell in August, Javan had convinced himself that discharge pumping was the best route to practical gas lasers.

Javan proposed a two-step excitation process. First, electrons would collide with helium atoms, exciting them to a higher energy level. Then stimulated helium atoms would transfer their extra energy to the less-abundant neon atoms, exciting them to metastable states with energies close to those of the excited helium—a process called collisions of the second kind. Javan expected this to produce a population inversion on an infrared neon transition. He proposed a step-by-step plan to demonstrate and verify gain, then try to build a laser. To help with the experiments, he persuaded Bell to hire William Bennett, who had recently finished his dissertation on collisions of the second kind at Columbia. However, Bennett couldn't start until the summer of 1959.

As Herriott fiddled restlessly with a mirror adjustment, Javan glanced at an oscilloscope screen and saw the type of signal they had sought all day. Herriott had hit the sweet spot of cavity mirror alignment.

In the meantime, Oxford University physicist John Sanders came to Bell for an eight-month sabbatical and decided to test another idea that Javan had suggested—discharge excitation of pure helium. Lacking time for a detailed analysis, Sanders zapped the gas, but he failed to see the cascade of stimulated emission he had hoped for on a 668-nm helium line. Despite the slow progress, Bell encouraged both Sanders and Javan to publish their preliminary results in the summer of 1959. The company suggested this because it wanted to discourage the Pentagon from classifying all laser research after having awarded TRG Inc. a $1-million contract to build a laser based on Gould's proposals.

Javan and Bennett put in long hours studying the helium-neon system. They enlisted the help of Bell optics specialist Donald Herriott to build a high-reflection optical cavity to push their low-gain laser above threshold. Progress was slow because they were exploring completely new territory. They had to develop ways to measure energy transfer, energy-state lifetimes and laser gain as well as to make high-reflectivity mirrors that could survive within a discharge cavity. Then they had to align a pair of flat mirrors precisely parallel to each other at opposite ends of an 80-cm tube.

They weathered mishaps, including melting a laser tube and destroying mirror coatings. After hours of seemingly fruitless tests on a new tube, the three talked as heavy snow fell outside late in the afternoon of December 13, 1960. As Herriott fiddled restlessly with a mirror adjustment, Javan glanced at an oscilloscope screen and saw the type of signal they had sought all day. Herriott had hit the sweet spot of cavity mirror alignment.

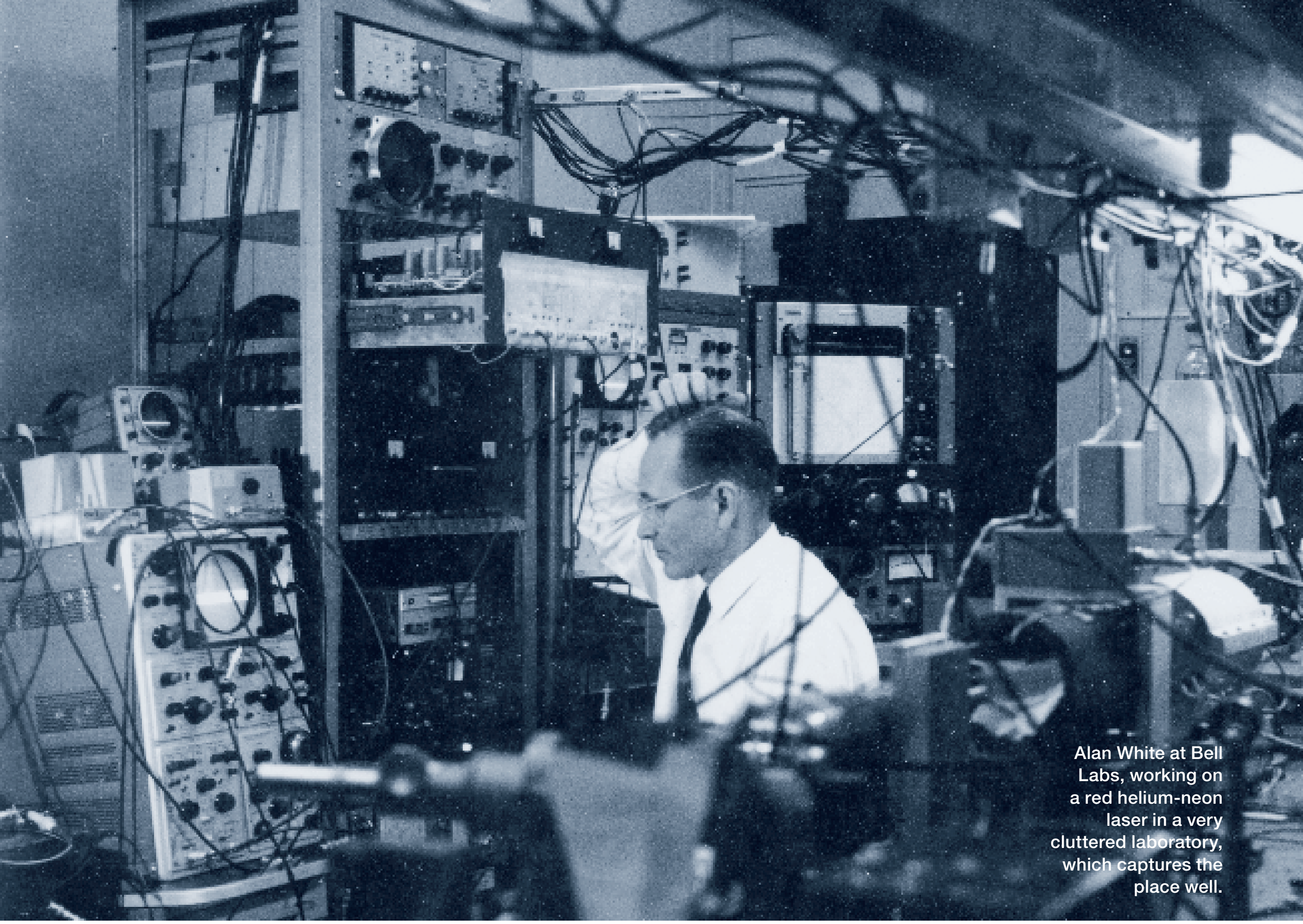
Sometimes such momentary successes vanish as mysteriously as they appear, but this one was stable. Their monochromator showed that the laser was oscillating on a predicted line at 1,153 nm. After they made a few more adjustments, word spread through the lab and a stream of visitors came to see the first continuous-wave gas laser. After a few days of experiments, including sending their voices across the room by speaking close to a cavity mirror, the three submitted a paper to *Physical Review Letters*.

The red helium-neon laser

The *New York Times* relegated the first gas laser to p. 39, next to a story about X-raying a tusk of a baby walrus named Ookie. But the feat generated widespread interest among scientists, and the Army Signal Corps at Fort Monmouth, N.J., contracted Bell to build another helium-neon laser.

Bell's basic research department was busy trying to develop more new lasers, so managers routed the contract to Alan White and Dane Rigden in the exploratory development department. The two had been working on gaseous electronic devices. Thanks to the earlier experiment and the availability of Brewster windows and concave mirrors, they finished the new He-Ne laser much faster and were able to add improvements such as fine-tuning the discharge.

Curious about what more they could do, they began further experiments. "It was all done evenings and weekends, because our regular work had to go on as usual," White recalls. But they didn't



Alan White at Bell Labs, working on a red helium-neon laser in a very cluttered laboratory, which captures the place well.

Courtesy of Alan White

mind because they were excited to be working on lasers and coherent light.

They improved stability and reduced noise, substituting a hot-filament direct-current discharge for the radio-frequency discharge that Javan and Bennett had used. Output power increased, revealing previously unseen details in the laser spectrum—including a new metastable helium state. Thinking that the new state might excite a laser emitting on the 632.8-nm neon line, they ordered mirrors with peak reflectivity in the red. The evening after the mirrors arrived, White recalls, "We put the first gas in the tube, lined up the concave mirrors, and bingo, it went. We were three excited people," including a witness they had invited in case their idea worked.

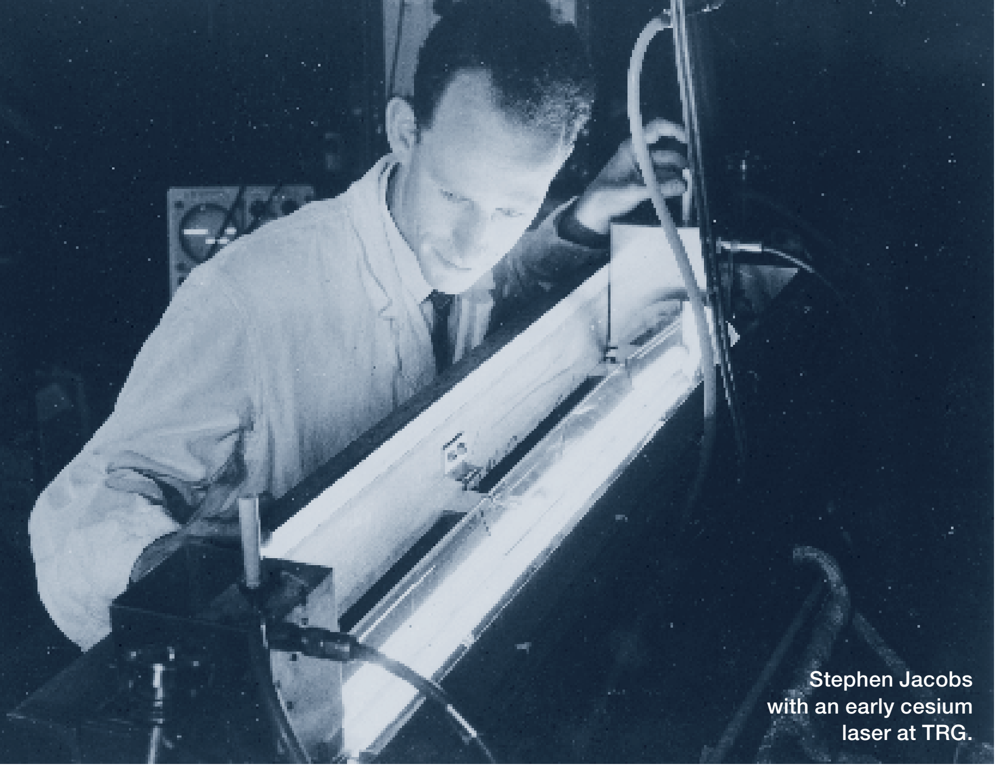
They first saw only a little sparkle when they looked down the laser tube (in a practice that would horrify any modern safety officer). Adjusting the mirrors and the discharge made the multimode beam bright enough to see on the laboratory wall. Unsure how long the tube would last, they called in more witnesses.

The visible red beam excited everyone, including management. "Almost immediately large amounts of money came to us, and there was no need to work nights or weekends," White recalls. Reported in 1962, the red helium-neon laser became the most familiar gas laser, widely used in classroom demonstrations, laboratory experiments, holography and construction alignment.

Other early gas lasers

The basic research group's helium-neon experiments showed that excited neon atoms could transfer energy to oxygen molecules, and so they wondered if a mixture of neon and oxygen could lase. Bennett saw a population inversion in a pure neon discharge after Javan left for an MIT professorship in mid-1961. Then a young Bell physicist, C. Kumar N. Patel reduced helium pressure in a helium-neon laser and observed lasing in pure neon.

Bennett, Walter Faust and Ross McFarlane then joined with Patel to search for more new laser gases and lines. Concave mirrors and the availability of red helium-neons for alignment made experiments easy. They observed laser action on the atomic lines of neon-oxygen, argon-oxygen, and pure argon, krypton and xenon. They measured emission on dozens of lines in the visible and infrared, including some beyond two micrometers. Bennett returned to Yale in the fall of 1962, but by early 1963 Bell had counted more than 150 laser lines and showed that gas discharges could readily produce population inversions. Yet only a tiny fraction of the input energy emerged as light, and output power was limited. It took



Stephen Jacobs with an early cesium laser at TRG.

Courtesy of Stephen Jacobs

a 15-m tube to generate 150 mW from helium-neon.

Optical pumping of alkali-metal vapors proved a disappointment. Townes's students at Columbia quickly abandoned their cesium laser project after Bell demonstrated the helium-neon laser. The Pentagon didn't think TRG's metal-vapor laser research was worth classifying, so it was the only project that Gould could work on after having been denied a security clearance. After painstakingly measuring population inversions and optical amplification in cesium, Steve Jacobs and Paul Rabinowitz detected oscillation on a 7.18-μm cesium line in early 1962. Gould read success on their faces when he walked into his office one Monday morning, saying, "Well, I'll be damned. You made it work!"

Molecular gas lasers

In 1963, Patel realized that molecular lasers might convert more input energy into light than atomic lasers because molecular transitions were much closer to the ground state. He started studying carbon dioxide because he thought the multiple series of vibrational states in three-atom molecules should allow metastable states. He calculated that CO_2 should lase near 10 μm. "It did the first time we tried," he remembered in a 1985 interview, recalling surprise that his calculations were so close to the measured results. "It worked marvelously well," he said. "We got tens of milliwatts on the first shot." He then realized that diatomic molecules should also work, and he tried carbon monoxide, which also lased.

Molecular nitrogen soaks up discharge energy efficiently, so Patel added it to CO_2, hoping for energy transfer from the long-lived first excited state of N_2 to an upper level of CO_2. Power jumped from 10 mW with pure CO_2 to 10 W from the gas mixture, the highest CW power that had then been seen from a laser. Adding helium also helped. "By mid-1965, I had a 200-watt continuous-wave CO_2 laser, which was more than enough power for anything you wanted to do in the laboratory," he recalled.

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Reaching that power level and 20 percent efficiency was enough to interest military laser-weapon developers because it promised much better efficiency, power and heat dissipation than solid-state lasers could deliver. The Pentagon began classifying high-power CO_2 research, so Patel, a non-citizen lacking a clearance, decided to stay with spectroscopic research.

Laser companies and ion lasers

Gas laser development quickly spread beyond Bell Labs, which, under terms of a 1950s consent decree, had to license its inventions to other companies. Soon after being founded in September 1961, Spectra-Physics teamed with the well-established Perkin-Elmer to manufacture helium-neon lasers. They exhibited a 1.15-μm version selling for about $8,000 in March 1962, and sales jumped after they introduced a red version six months later. In June 1963, they sold their 75th laser, and the two companies went their separate ways.

Industry was also quick to recognize the potential of 10.6-μm CO_2 lasers for noncontact cutting and drilling of nonmetals. Spectra-Physics founder Eugene Watson saw the possibilities the first time he saw a CO_2 laser at a 1965 meeting, and when the Spectra-Physics board refused to approve his plans to develop CO_2, Watson quit to establish Coherent Radiation Laboratories (now Coherent Inc.). The new company landed a contract to build a 100-W laser and set up shop in Watson's home. Within months, they had the laser up and running, and they demonstrated it by cooking paint on the garage door of an obnoxious neighbor across the street.

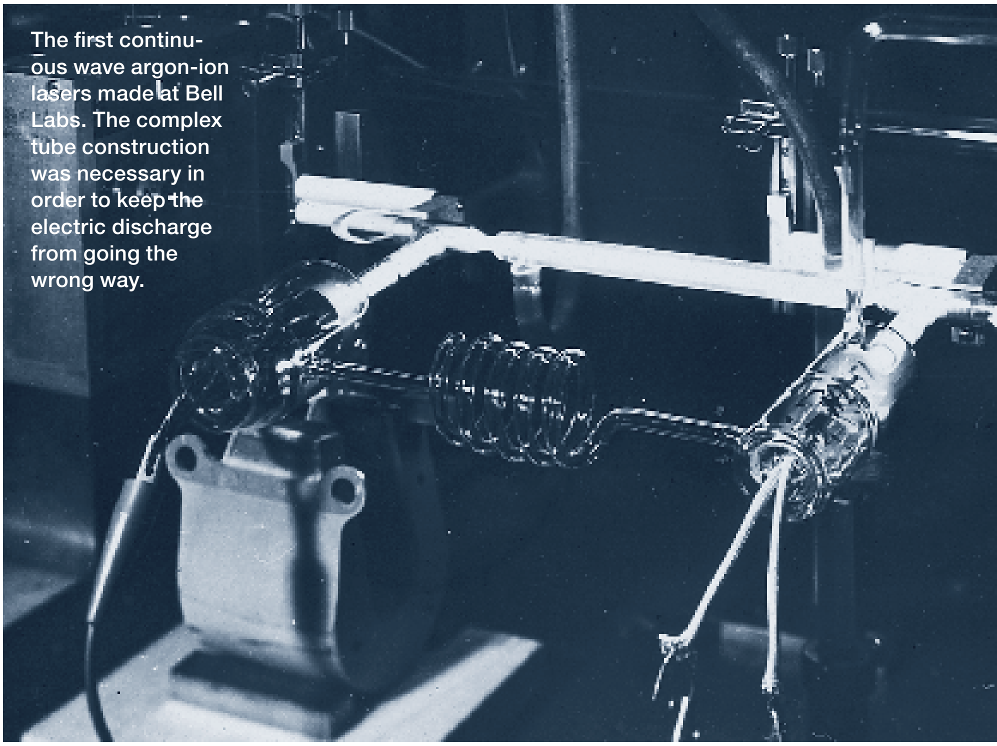
Laser companies contributed their own innovations. Early helium-neon lasers could be short-lived, so Spectra-Physics co-founder Earl Bell tried adding mercury vapor to the gas mixture to extend the laser's lifetime. He saw a green glow near the cathode, which hadn't appeared in ordinary He-Ne lasers, and he thought that might lead to a mercury laser. Applying a standard continuous helium-neon discharge source across a long tube laced with mercury revealed nothing new. He recalled later, "I then decided to discharge a high-voltage capacitor charged by a neon sign transformer through the tube at 120 Hz and—Wow!" First he saw laser emission on a new red-orange line; later in the day, he saw a green laser line. The laser was pulsed, but the power levels were encouragingly high, and, with visible lines few and far between, Bell and his Spectra colleague Arnold Bloom were excited.

Initially they thought the emission came from neutral mercury, but comparing measurements with wavelength tables revealed the lines were from mercury ions. That was a surprise; ions hadn't been considered suitable for lasers because they were high above the neutral ground state. But it was encouraging because ions tend to have higher transition energies than neutral atoms, offering the potential for shorter-wavelength lasers.

The mercury laser never found a commercial niche because it didn't operate continuously in a conventional discharge. Its lasting impact was what inspired research into other ion lasers by many people, including William Bridges at Hughes Research Laboratories, Bennett at Yale, Dane Rigden at Perkin-Elmer, Gene Gordon of Bell Labs, Steve Jarrett at TRG, Guy Convert at CSF in France, and Grant Fowles and William Silfvast at the University of Utah.

Argon-ion lasers

After Bridges got his own pulsed helium-mercury laser running, he began investigating energy transfer. First he replaced helium with neon and demonstrated a neon-mercury laser. Then he added argon as a buffer gas, but he put in too much and couldn't get the mercury laser lines. On February 14, 1964, he pumped out the tube, flushed it and put helium back into the tube to check mirror alignment. He recalled, "To our surprise, we had a new line going in



The first continuous wave argon-ion lasers made at Bell Labs. The complex tube construction was necessary in order to keep the electric discharge from going the wrong way.

Courtesy of Colin Web

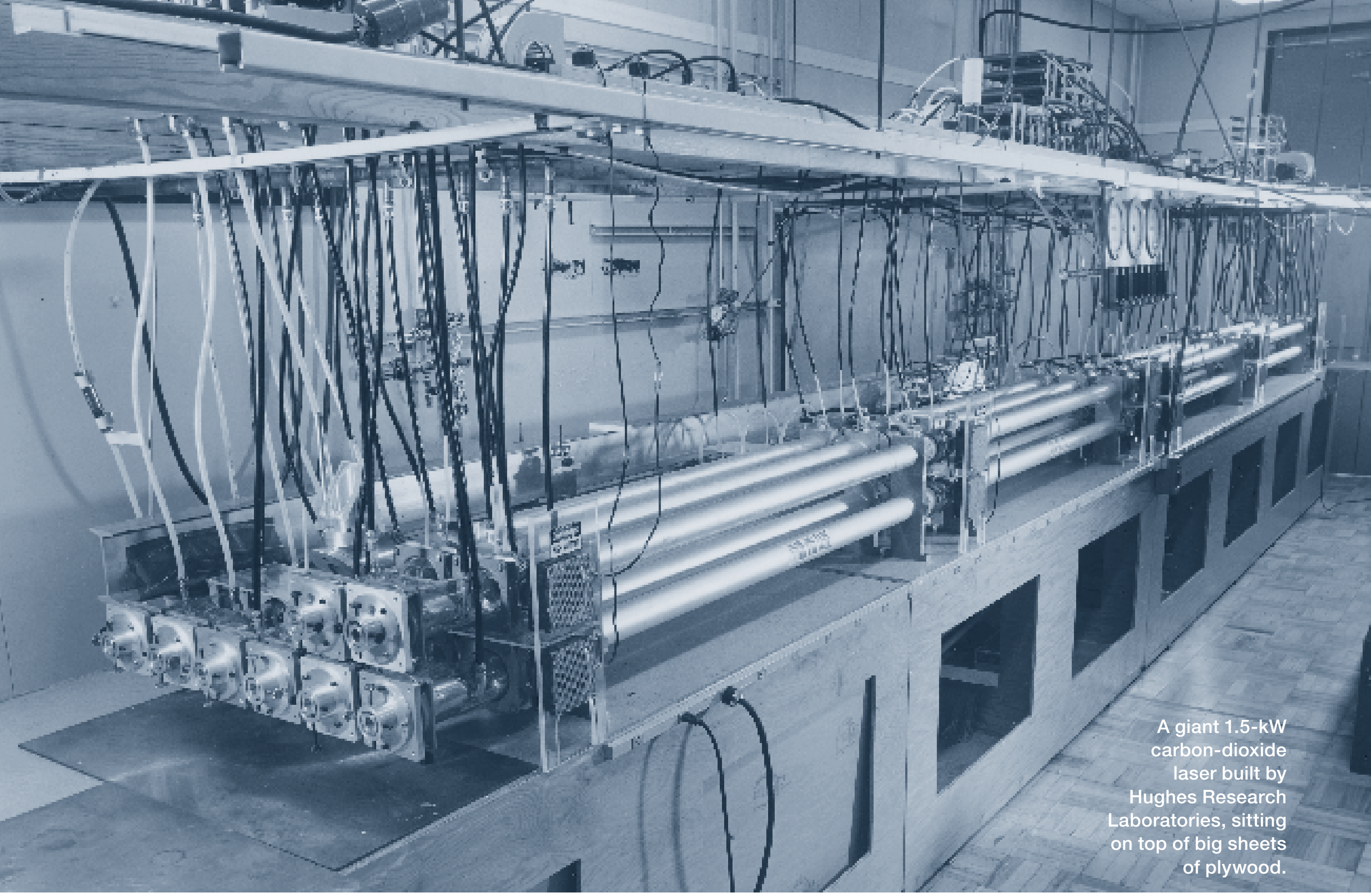
what was ostensibly a helium-mercury laser. We now had a blue line at 4,880 Ångstroms in addition to the red and green lines from mercury."

Anxiety mixed with his excitement. "You see something unexpected and furthermore you don't quite know how you produced it. Maybe it will go away, and you won't get it back again." Worried that the new line might be from an unknown contaminant in his welding-grade argon, he left technician Bob Hodges to watch the laser run as he searched Hughes's library, where he found the line probably came from ionized argon.

Unable to remove all the mercury from the tube, Bridges rush-ordered a new tube and tested it with pure argon. Identifying the 10 argon lines he observed required mounting a series of relay mirrors in the halls to route the beam through a few hundred feet of halls separating the immobile laser from the equally immobile high-resolution spectrometer. Working at night when the lab and the halls were empty, he and Hodges measured wavelengths to a few hundredths of an angstrom, enough to identify all 10 lines. Bennett and Convert discovered the argon lines independently, but Bridges published first. "Lines just tumbled out all over the place" in tests of krypton, xenon and rare-gas mixtures, he says, but he lacked cavity optics to produce the ultraviolet lines of neon ions.

Even before his paper appeared in print, Bridges told Gordon at Bell Labs about the pulsed argon-ion laser. A few weeks later, Gordon stunned him by calling to announce that "we've got ours going continuous wave." Bell had used its own high-performance mirrors and a capillary discharge only a millimeter in diameter, yielding current densities 25 times higher than the 5-mm Hughes tubes.

However, Bell's success came only after the intense heat from the discharge melted uncooled glass and quartz tubes. Water cooling quartz solved that problem, but the discharge then pumped the gas all to one end of the tube. When they added a return loop, the discharge went the wrong way, so a Bell glassmaker devised an elaborately curved return to block the discharge, allowing CW laser



A giant 1.5-kW carbon-dioxide laser built by Hughes Research Laboratories, sitting on top of big sheets of plywood.

Courtesy of Bill Bridges

action, recalls Colin Webb, who worked with Gordon.

Bennett made a long-pulse argon laser, and when he described it at a New York conference, he said CW operation would require impossible amounts of power. Gordon, who was in the audience, stood up to announce that Bell had made its own argon-ion laser pulsed with a one-in-three duty cycle. “We switch it on in the morning and switch it off at night,” he said. Bridges then used the Bell design with a larger power supply to generate 80-mW CW from krypton and xenon at Hughes.

The argon laser was off and running. However, commercial development was a challenge for an ion laser with transitions so far above the ground state that only about 0.05 percent of the input energy emerges in the beam. Jarrett, who developed a segmented graphite bore for a white-light krypton-ion laser as a co-founder of Coherent, recalled that initial tests were discouraging: “There were signs of erosion and graphite powder everywhere: The disks looked like nothing so much as burned barbecue briquettes.” Indeed, the graphite had burned, because it hadn’t been degassed properly, but that was solved by induction heating in a high vacuum.

The brightness of ion lasers at visible wavelengths earned ion lasers some important applications, but their tough design requirements caused problems. At Hughes, Bridges developed argon lasers for an Air Force night reconnaissance system; the results were good, but it never went into production because the cooling system didn’t meet requirements for installation in military planes.

Eye surgeon Francis L’Esperance ran into a different problem when he ordered one of the first commercial argon lasers from Raytheon. At more than two meters in length, it was too big to fit into the elevators at the Columbia-Presbyterian Medical Center in New York. They hired a rigger to hoist the massive laser through a window, but he dropped it. When Raytheon shipped a replacement, L’Esperance paid $25 to a nearby crane operator, who slipped it flawlessly inside, where the surgeon used it to develop a laser treatment that has preserved the vision of millions of people with diabetic retinopathy.

Metal vapor lasers

The helium-mercury laser also inspired the discovery of other metal-vapor lasers by Fowles and Silfvast at Utah. They first tried to make a bismuth laser to study hyperfine structure, which is particularly strong in the heavy metal. Silfvast developed a simple quartz tube apparatus to vaporize bismuth and test the vapor for pulsed laser action, but he grew discouraged after a few months of tests found no laser lines. In early 1965, he decided to try zinc and cadmium, which looked like good laser prospects because of their electron configurations.

He tried zinc first. “The very first time I turned it on I got this turquoise, blue-green transition at 492.4 nm to lase,” he recalled. Overjoyed, he hunted down Fowles at a faculty meeting, and the professor came running. After a few days of studying zinc, they tried cadmium, which also lased, although not on the now-familiar 441.6-nm blue cadmium-ion line. Other metals they could vaporize followed, including lead, which emitted a 723-nm line so strong that it lased even with blue-reflecting mirrors on the laser tube. It was the first in a family of high-gain, self-terminating pulsed neutral atom lasers that includes copper and manganese. (For more on pulsed gas lasers, make sure to read the second part of this history in the February OPN.)

The blue He-Cd line came later, when Silfvast tried adding helium and a weaker electric discharge to make a pulsed laser. A few months after moving to Bell Labs in August 1967, he made the first continuous-wave He-Cd laser by running a steady low-current discharge at the proper vapor pressure, using equipment that wasn't available at Utah. In 1972, Silfvast made the helium-selenium laser, which emitted simultaneously on up to 46 lines, but never proved practical.

High-power gas lasers

In the mid-1960s, the Advanced Research Projects Agency had contractors build gigantic pulsed discharge-driven CO_2 lasers with average power well above a kilowatt. The big breakthrough in CW gas laser power—to tens of kilowatts—came in 1966 when Edward Gerry and Arthur Kantrowitz of the Avco Everett Research Laboratory in the Boston suburbs demonstrated a radically new design, the gas dynamic CO_2 laser.

Their inspiration was realizing that extracting only 0.1 percent of the gigawatt-class power from a rocket engine would produce a megawatt-class laser. Their plan was to burn a carbon-containing fuel and expand the hot gas at high velocity through nozzles into a low-pressure laser cavity, producing a population inversion in CO_2 molecules. Their success at generating 50 kW in 1966 inspired a new round of laser weapon development, and it so impressed military brass that they kept the results classified until 1970.

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Gas dynamic lasers eventually topped out at a few hundred kilowatts in the Air Force Airborne Laser Laboratory built in the 1970s. By then, high-energy military laser development had shifted to chemical lasers that produced other vibrationally excited molecules. The first was hydrogen chloride, emitting at 3.7 μm, demonstrated by J.V.V. Kasper and George C. Pimentel in 1965 at the University of California at Berkeley. Military developers preferred hydrogen fluoride emitting at 2.6 to 3.0 μm, and deuterium fluoride emitting at 3.6 to 4.0 μm; the latter wavelengths were better transmitted by the atmosphere. Both have reached megawatt-class powers, but the latest megawatt-class laser testbed, the Airborne Laser, has shifted to the chemical oxygen-iodine laser, which emits at 1.3 μm, allowing smaller optics and better beam transmission.

Looking back

As the first continuous-wave lasers, gas lasers laid the foundation for today's laser industry. The venerable red helium-neon laser was the first to be widely used in industry, and it was the standard demonstration laser for decades. Ion lasers pioneered important applications in ophthalmology, biomedical instruments and printing. CW gas lasers are giving way to diode and solid-state lasers for most visible and near-infrared applications, but the CO_2 laser remains dominant for industrial applications at longer infrared wavelengths. It's been a long and remarkable run. ◭

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