A survey of lasers at the birth of holography

Robert A Hess
Point Source Productions, San Jose, California, USA

Abstract. The 50th anniversary of the first hologram made with laser light is an appropriate time to shine some light on the lasers that made it possible. Dubbed “a solution looking for a problem”, the laser emerged from industrial research labs as a new kind of light source for any application requiring coherence. Immediately commercialized by both start-up and well-established corporations, lasers sold in their first year of production left much to be desired but made a good first impression. Their second year of production saw technical improvements that met the requirements for practical holography, and by the end of 1963 were good enough to make holograms of three dimensional, deep and diffuse imagery. Mostly obsolete by the end of the 1960s, very few of the Kennedy era lasers have survived. This survey is intended to identify and celebrate them, so more may be preserved as they are found, to be admired in the future.

1. Introduction
When Ted Maiman's assistant Irnee D'Haenens first proclaimed the laser to be "a solution in search of a problem", he probably wasn't aware of two researchers at the University of Michigan's Willow Run Labs who were exploring Denis Gabor's technique of "wavefront reconstruction", eventually called holography. The laser would however, quickly progress from a device anticipated to be a "death ray" as visualized in pulp fiction throughout the first half of the century, to a commercial product for a wide range of practical applications. Holography is one a technique made practical by the laser. On the 50th anniversary of the first hologram made with laser light, it is appropriate to review the technology of the time that led to its success.

The first period of laser development was dominated by pulsed ruby, and Helium-Neon gas lasers operating in the infrared. Between July 1960 and the end of 1961, lasers were mostly built by those who wanted to study or use them. Starting in early 1962, commercial lasers became increasingly available and by the end of 1963 three dozen models from at least sixteen companies were in production.

It was the continuous visible beam from the He-Ne laser that really enabled holography, but little is known about the actual lasers used by the early holographers. This survey highlights commercial laser development against the background of pre-laser holography, and celebrates the wonderful little devices that made it all possible.

2. Masers to Lasers
The story of lasers begins with masers. Conceived in 1951 by Charles Townes, the first gas maser operated in April 1954 at Columbia University [1]. This was followed by the first solid-state maser at Bell Labs and the first solid-state maser amplifier at MIT's Lincoln Labs [2]. Chihiro Kikuchi's group at the Willow Run Labs started using pink ruby in their maser research in 1957 [3], and Theodore Maiman built a very compact ruby maser at Hughes Research shortly thereafter [4]. The 1959 conference at the Shawanga Lodge brought many maser researchers together, and with a paper by Arthur Schawlow on "Infrared Optical Masers", the stage was set for the laser to emerge.
When Hughes announced operation of the first laser in July 1960, researchers at Willow Run were primed to jump right on it along with all the other groups doing maser research including Bell Labs, TRG, Raytheon, and RCA. Around the same time they all began work to repeat the results of Ted Maiman, Juris Upatnieks started working with Emmet Leith (also at Willow Run) to repeat the results of Denis Gabor [5]. Many had early success repeating Maiman's design. TRG and Bell Labs did it by August (using the larger flashlamp pictured with Maiman in the Hughes press release) [6] and RCA by November [7]. Raytheon went a step further immediately afterward however, by proposing an elliptical pump cavity with the ruby rod and flashlamp at the two foci [8].

Raytheon built a number of laboratory prototype lasers in November 1960 to demonstrate their improvement [9], and one of these lasers was pictured in a number of early books about lasers [10] [11]. The one shown here (Figure 1) differs from the one in previously published pictures by the cylindrical rather than conical rod support on the output end, and placement of the pump cavity reflector seam on the lamp side instead of rod side of the cavity. The rod ends are coated with mirrors to form the resonator as in Maiman's design, and a spring plunger at the rear holds the rod in place (Figure 2). Originally there was a trigger button at the rear end of the housing and a few more electronic components inside a cylindrical housing [12].

![Figure 1. 1960 Raytheon laboratory prototype ruby laser head with elliptical pump cavity.](image1.png)

![Figure 2. Chrome plated brass reflector opened to show linear flashlamp and ruby rod.](image2.png)

Meanwhile, Bell Labs continued on with dark ruby for pulsed lasers, and invigorated their program toward gas lasers [13]. The latter reached fruition at 4:20 on December 12, 1960 when Ali Javan suggested that Donald Herriot "just wiggle the mirrors" and the first Helium-Neon laser flashed to life [14]. Operating with RF excitation and flat resonator mirrors inside the plasma tube, this laser had an infrared output at 1150nm. But it was a continuous beam, and that's the type of light source researchers working with optical data processing needed.

### 3. Commercial Pulsed Lasers

By February 1961, Leith and Upatnieks had demonstrated their off-axis technique for holography by using a 100W GE high-pressure mercury arc lamp, a grating based recording system, and a wire for the image [5]. But then Juris Upatnieks went into military service, putting further work on hold for the next year and a half. Across the field at Willow Run however, work with lasers was just beginning. After a presentation on the ruby laser there by Robert Collins of Bell Labs, Lloyd G. Cross and Don Gillespie from Kikuchi's maser group (already in business together to make ruby masers) started Trion Instruments to make ruby lasers instead [15].
Trion was the first company formed specifically to make pulsed lasers commercially, but it was a few months until they had their first model LS-1 ready for sale. One of their first systems was rented by Peter Franken at the University of Michigan for his first generation of optical harmonics with laser light [16] (Figure 3). Trion ruby lasers were characterized by their large dewar for a liquid nitrogen cooling system, and were bought by many large organizations near the end of its first year in operation. In the middle of 1962 Lear Siegler acquired them, but despite being a major supplier of lasers throughout the early 1960s, the operation didn’t survive the decade.

The first commercial laser sold however, was built by Raytheon and sold at the March 1961 meeting of the Institute of Radio Engineers in New York City [8]. Their model LH-1 (Figure 4) was a pulsed ruby laser similar to the laboratory prototype described above. It featured a housing designed for easy replacement of the rod and lamp, iron sights on top of the head, and a price of $5850 [17]. This laser operated at room temperature like the prototype before it, but three other models soon followed featuring the capability of cooling with liquid nitrogen, and pumping with multiple lamps bringing output energies up to 50J by the end of the year [18].

Early 1961 also saw the announcement of the q-switch, invented by Robert Hellwarth at Hughes Research [19]. This device eliminates the spiking that occurs in pulsed ruby lasers, and dramatically increases the peak powers achieved by them. Many techniques have been employed for q-switching including the Kerr cell, a rotating mirror, the Pockels cell, and saturable absorbing dyes. Q-switched lasers would eventually be necessary for many successful applications of holography. Another device of great significance to holography that was developed in the middle of 1961 was the intracavity etalon for single longitudinal mode selection, by D.A. Kleinman and P.P. Kisliuk [20].
Other pulsed ruby lasers available for sale near the end of 1961 included the Trion Instruments models LS-2 and LS-4 (which had a 30J output), the Raytheon model LH-2, the Maser Optics model 500, and the model 100 from Optics Technology Incorporated. While Raytheon and Trion lasers were characterized by their high-energy outputs and liquid nitrogen cooling, the initial offerings from Maser Optics and Optics Technology were smaller lab lasers intended for basic experimentation with laser light.

Maser Optics was a major supplier of lasers throughout the 1960s. Headed by Harry E. Franks, they offered ruby lasers, laser photo coagulators, educational kits, He-Ne lasers, and laser accessories from 1961 to 1968. In 1964 they produced a ruby laser rifle for the army, and were reported to be the world's largest consumer of synthetic rubies [21]. Throughout the second half of the '60s however, they were experiencing problems with the SEC, and in April 1968 became Laser Nucleonics (also headed by Franks) [22].

Optics Technology Incorporated was formed to be a modern optics research operation in January 1961, when a seven-man group headed by Dr. Narinder Kapany was acquired by Spectracoat Inc., a manufacturer of optical coatings since 1958. Along with coatings, the company produced ruby and He-Ne lasers, power meters and interferometers, and photo coagulators [23]. Similar to the model 100, their model 120 ruby laser system (Figure 5) featured an easily accessible pump cavity, a 3 x 1/4-inch rod, 0.1-J output energy, an iris diaphragm on the output bezel, and threads on the front end for a microscope objective. OTI was a major manufacturer of lasers throughout the 1960s, but by 1973 had fallen on difficult times and ceased all laser production [24].

In 1961 however, Helium-Neon lasers were still built in-house by and/or for researchers at Bell Labs, Hughes and Raytheon (for example), but that would soon end. In September, Spectra-Physics was founded in a deal with Perkin-Elmer making it the first commercial continuous wave laser company. The deal included labeling all lasers with both names, and was to be terminated in two years or upon the sale of the 75th laser, whichever came first [25].
4. The Continuous Wave
In February 1962, Yuri Denisyuk made volume reflection holograms of a convex mirror and a micrometer scale using a high-pressure mercury arc lamp, as was being used by Leith and Upatnieks at Willow Run. Juris Upatnieks was still away in service, but laser technology was quickly expanding.

In March at the west coast meeting of the IEEE, Perkin-Elmer Spectra-Physics (P-E S-P) introduced their model 100 Helium-Neon laser with an infrared output, the first commercial laser with a continuous beam [26]. Its head consisted of an electronics filled box with the plasma tube protruding out both sides. The resonator mirrors were attached to the ends of the plasma tube [27]. Other He-Ne lasers with infrared outputs that became commercially available shortly afterward were the Sylvania model GL-6211 and one from Raytheon. All of these early commercial gas lasers were RF excited with only a few milliWatts of output power, and very delicate.

In May of that year, Hughes Aircraft Company introduced their first commercial laser despite having built the first laser two years earlier [28]. The model 200 pulsed ruby laser was a commercialized version of Maiman’s first device, but with a longer rod having dielectric mirrors coated on its ends (Figure 6). There were two or three other models built after the model 200 and similar to it, then external mirrors were employed, and finally a Kerr cell q-switch to achieve higher energies in later devices [29].

More significant to holography however, was the continuous wave He-Ne gas laser. In August 1962, Alan White and J. Dane Rigdon of Bell Labs achieved laser action in He-Ne at the visible wavelength of 632.8nm. A month later, P-E S-P introduced the model 110, the first commercial laser with a continuous visible beam [30] (Figures 7). Mated with the model 71 power supply, this laser featured a metal resonator rod surrounded by a heat shield to hold the mirrors, a smaller diameter plasma tube, an output of 1.0mW from both ends multimode (with a confocal resonator), 0.3mW output from both ends single mode (with a hemispherical resonator), and cost $7900 new [31] (Figure 8). This was the breakthrough laser that many working with communications, optical processing and optics in general were waiting for. One of those researchers was Anthony VanderLugt at Willow Run, who acquired one immediately for his work on spatial filtering.

Figure 7. 1962 P-E S-P model 110 Helium-Neon laser head, without the cylindrical aluminum covers for both ends.

Figure 8. Uncovered P-E S-P model 110 head showing the RF exciter above the plasma tube.
When Juris Upatnieks returned from military service near the end of 1962, he and Emmet Leith immediately got back to work on wavefront reconstruction of binary images with the mercury arc lamp. Near the end of December however, they borrowed the beam from VanderLugt's P-E S-P model 110 laser and on Christmas Eve made the world's first hologram with laser light and 2D imagery [5].

5. The Birth of Laser Holography
The first commercial laser with a continuously visible beam left much to be desired for making holograms. The output power was very low, especially in single mode operation. The Brewster windows were attached with epoxy instead of being hard sealed, limiting tube lifetime. Mirror coatings were delicate and easily damaged. And finally, the mechanical design of the resonator structure and mirror mounts required frequent adjustment to keep them lasing.

In the spring of 1963, Leith and Upatnieks acquired a He-Ne laser for their own lab. This could have been a device made by Raytheon, a P-E S-P model 111 (Figure 9), a P-E S-P model 112, and/or the Semi-Elements model SEOG-MK1, all of which were also introduced near the end of the previous year. The P-E S-P model 111 was essentially a longer version of the model 110 with the same mirror mounts and resonator rod (Figure 8), and the model 200 RF exciter powered it. It had an output power of 30mW multimode (with long radius mirrors) and 10mW single mode (with a hemispherical resonator) [31]. The model 112 had the same plasma tube as the model 111, but a larger resonator rod and better mirror mounts. In March and with their larger laser, Upatnieks made an unsuccessful attempt to record a hologram of three-dimensional objects (steel rods), then spent the next five months improving their techniques and testing better equipment [5].

By June, Perkin-Elmer had sold the 75th laser under its deal with Spectra-Physics and the two companies separated. Spectra-Physics continued production with the model 112 and also introduced the models 115 and 130. The model 115 (Figure 10) was an RF excited improved version of the model 110. It featured better mirror mounts and adjusters, a cavity length adjustment knob, a much larger gas reservoir tube, 1mW output power in single mode, and a price of $4650 [32].

The model 130 (Figure 11) was the first laser "pointer", as it was the first continuous wave laser with a visible beam and a self-contained power supply. This was possible because it was also the first commercial laser with DC excitation. It had an output power of approximately 0.5mW, weighed ten
pounds, was 13" long, and cost $1525 [33]. The model 130 was introduced with a hot cathode, but it was apparently replaced with a cold cathode as seen below. This laser was also designed with its resonator structure also serving as the outer case, a feature that may be described as an exoresonator. A ten-pound, 0.5mW laser pointer with a handle attached to the resonator!

Perkin-Elmer introduced their model 5200 He-Ne in 1963 as their first laser product, and it became very popular throughout the rest of the decade (Figure 12). It was the first He-Ne with the now familiar cylindrical head shape, and featured a hot cathode, a double walled plasma tube for increased lifetime inside an exoresonator, and an output power of 0.5mW [34]. This laser was designed to be rugged for reliable operation in factory and construction site settings, and had a very "James Bond" style to its design.

Meanwhile, other researchers applied the laser to holography. Ralph Wuerker learned about Gabor’s wavefront reconstruction technique from Professor Paul Kirkpatrick while at Stanford (at the same time as Ted Maiman). While at Quantatron with Maiman, he helped design their first pulsed ruby and q-switched lasers, but left there to go to TRW in late 1962. There, he built his own q-switched ruby laser to record Gabor holograms for the examination of spray fields from a colloid propulsion system [35]. His recordings were probably the first holograms recorded with a pulsed laser.

Brian Thompson at the University of Rochester was, like Leith and Upatnieks, using coherent light with an optical processing technique, but he was measuring the size of aerosol particles. He chose the pulsed ruby laser for its ability to freeze particle motion for imaging, and because it also had a visible output. He also used a spatial filtering technique to reconstruct his recordings and didn’t credit Gabor’s technique when describing his work initially, but they were nonetheless Gabor holograms made with a pulsed ruby laser. As for Wuerker, the multiple images reconstructed by Gabor’s in-line geometry were not a problem with their application because the depth of focus for the reconstruction system was much smaller than the distances between them. Coherence requirements were also minimal.

The laser Thompson used was q-switched, had a pulse length of about 2 microseconds and a repetition rate of 4-6 seconds [36]. It was probably a Korad model K1-Q, but may also have
been made by Hughes or Trion/Lear Siegler, both of which are known to have offered q-switched lasers at the time. Other pulsed laser manufacturers in 1963 included CSF in France, EG&G, TRG, and Semi-Elements.

Korad was formed when Quantatron, the company started by Ted Maiman after leaving Hughes in early 1961, was acquired by Union Carbide in November 1962. Their first products were the models K1 and K1-Q, the first commercial q-switched laser [37]. With Maiman at the helm, Korad was one of the major suppliers of commercial solid-state lasers for the rest of the decade. It was eventually acquired by Hadron in the early 1970s.

Trion/Lear Siegler offered a q-switch for their lasers in early 1963 called the Optul. It was a spinning mirror device that could be used with their models LS-1 and LS-4, and was also sold as a separate component.

The third quarter of 1963 also saw the introduction of the Gallium Arsenide semiconductor injection laser to the marketplace. This type of laser was first made to operate a year earlier by Robert Hall's group at General Electric, followed immediately by groups at IBM and MIT's Lincoln Labs. Nick Holonyak Jr. at GE Syracuse operated the first semiconductor laser with a visible output shortly thereafter. The first commercially available GaAs laser however, was the model ILS-1, introduced at the end of that year by ITT Industrial Labs [38]. It was followed within a few months by the Korad model K-S1, the Philco model GAE-404, and the Texas Instruments model SNX-110. All of these early GaAs lasers were cryogenically cooled.

By September however, Leith and Upatnieks had optimized their film and apparatus for making holograms with laser light, and introduced diffuse illumination to their hologram recording systems [5]. Diffuse illumination of 2D objects removed the coherent noise and diffraction ring patterns caused by particles on the optics in the system. Ironically, these artifacts of highly coherent light in optical systems of the day were essentially what Brian Thompson was using to measure the size of the offending particles!

![Figure 13. The 1963 Perkin-Elmer model 5300 Helium-Neon gas laser head.](image)

Around that same time, Perkin-Elmer introduced their second and larger He-Ne laser, the model 5300 (Figure 13). This laser had an output power of 8mW single mode, 15mW multimode, and a DC
excited plasma tube with a hot cathode inside an exoresonator (a 35 pound, 33" long metal tube with 1" walls) [39]. It was apparently more stable and easier to keep aligned than the Spectra-Physics lasers, and became the laser of choice for their next step. So finally, on December 22, 1963 and using the Perkin-Elmer model 5300 Helium-Neon gas laser and a model train for the object, they recorded the world's first hologram of diffuse three dimensional imagery [40].

6. Epilogue
The hologram of that little train made a big splash at the spring meeting of the Optical Society of America in early April, 1964. Its presentation was just a few months after publication of their work with off-axis holography with two dimensional greyscale images, and the phrase "lensless photography" that was coined to describe it [41].

Commercial laser development continued at a rapid pace. Many companies joined those already mentioned making ruby and He-Ne lasers, and they all contributed in greatly increasing the output power, stability, ease of use, and lifetime of them. Spectra-Physics introduced the models 131 and 116 He-Ne lasers near the end of 1963. The model 116 was the first wavelength tunable laser available commercially [42]. Mated with the model 250 exciter, it was DC excited but also used a small amount of RF to quiet and stabilize the discharge, had an output of 25mW [43], and cost a whopping $13,250.

A significant technical improvement that enabled many applications of He-Ne lasers was the invention of the oxide-coated aluminum cold cathode with a large surface area, by Hochuli and Haldeman in 1965 [44]. This advance greatly increased the lifetime of this laser type, and was probably first introduced in the “Stabilite” series of lasers from Spectra-Physics the following year. Another big improvement to He-Ne lasers was the incorporation of internal mirrors, first available on the Optics Technology model 170 also in 1966 [23].

Other laser types made commercially available in the mid 1960s included Nd:Glass and Nd:YAG solid-state lasers, the carbon dioxide molecular laser, the Helium-Cadmium metal vapor laser, and Argon and Krypton ion lasers. Of these, the He-Cd and ion lasers had the most dramatic impact on holography because of their many visible wavelengths and high output powers. First to market with the He-Cd laser late in 1969 was Spectra-Physics with their model 185. It produced 50mW of blue light from a tube specified to last 3000 hours [45]. Raytheon introduced the first commercial Argon ion laser in November 1964, the model LG-12 [8].

This first generation of lasers was obsolete before the end of the 1960s, and are now highly collectable [46]. The Spectra-Physics model 125 was introduced in 1966 with an output power of 50-100mW at 633nm. Despite its six-foot length, it became the He-Ne laser of choice for holographers until the end of the century. The vast majority of the Kennedy-era lasers however, were scrapped long ago. But holography found its way into many and varied applications as lasers and recording materials improved, and it truly was one of the problems that lasers solved.

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8. References

[1] Townes C 1999 How the Laser Happened (Oxford: Oxford University Press) p 66
[2] Meyer J 25Apr1958 The Solid State Maser A Supercooled Amplifier Electronics 31 66
[3] Bromberg J 1991 The Laser in America (Cambridge: MIT Press) p 40
[4] Townes C 1960 Quantum Electronics (New York: Columbia University Press) p 330
[5] Johnston S 2006 Holographic Visions (Oxford: Oxford University Press) pp 96-108
[6] Hecht J 2005 Beam (Oxford: Oxford University Press) p 199
[7] Shore B 1962 Lasers: New Power from Light Electronic Age 21 10
[8] Bushor W (ed) 15Jun1966 Laser Focus 2 11
[9] Ciftan M, Luck C, Shafer C and Statz H May 1961 Proc. I. R. E. 49 960
[10] Klein H 1963 Masers and Lasers (Philadelphia: Lippincott) p 133
[11] Carroll J 1964 The Story of the Laser (New York: E.P. Dutton) p 167
[12] Hoaglin C 25Jun2010 Private communication
[13] Maiman T 2000 The Laser Odyssey (Blaine: Laser Press) p 143
[14] Hecht J 1992 Laser Pioneers (San Diego: Academic Press) p 160
[15] Johnston S 2006 Holographic Visions (Oxford: Oxford University Press) p170
[16] Bromberg J 1991 The Laser in America (Cambridge: MIT Press) p 117
[17] Luck C July/August1961 Optical Masers Electronic Progress 6 13
[18] Lehr C 8May1962 Principles and Applications of Lasers (Lexington: Raytheon Company) 10
[19] Smith G 1984 IEEE J Quant Elect QE-20 579
[20] Kaminow I, Siegman A (ed) 1973 Laser Devices and Applications (New York: IEEE Press) 190
[21] Bushor W (ed) June1964 The Laser Letter 23
[22] Pasek R (ed) July1968 Laser Newsletter 5 1
[23] Bushor W (ed) 15Aug1966 Laser Focus 2 7-16
[24] Bushor W (ed) March1973 Laser Focus 9 30
[25] Bushor W (ed) 15Jul1966 Laser Focus 2 9
[26] Bromberg J 1991 The Laser in America (Cambridge: MIT Press) p 121
[27] Levine A October 1962 The Exchange 23 4
[28] Staff 1May1962 Hughes Aircraft Adding New Line New York Times 49
[29] Buddenhagen D 26Nov2006 Private communication
[30] Stocklin W (ed) December1962 Electronics World 68 37
[31] Ekstrand J 2Jul2010 Private communication, owners manual
[32] Kuper H (ed) June1963 Rev. Sci. Instr. 34 727
[33] Kuper H (ed) August1963 Rev. Sci. Instr. 34 953
[34] Bushor W (ed) 1Aug1966 Laser Focus 2 14
[35] Wuerker R 21June2012 Private communication
[36] Thompson B 1963 J. Soc. Photo-Opt. Instr. Eng. 2 p 43
[37] Wixom C (ed) May1966 The Laser Letter 3 6
[38] Abelson P (ed) 27Sep1963 Science 141 1227
[39] Bushor W July/August1964 The Laser Letter 1 21
[40] Upatnieks J November2011 Private communication
[41] Berland T March1964 Popular Mechanics 121 105
[42] Kuper H (ed) December1963 Rev. Sci. Instr. 34 1464
[43] Ekstrand J June2012 Private communication
[44] Hochuli U and Haldeman P 1965 Rev. Sci. Instr. 36 1493-4
[45] Pasek R (ed) 1Sept1969 *The Laser Weekly* 4
[46] Hess R December2010 *Photonics Spectra* 44 51