The Shift of Optics R&D Funding and Performers over the Past 100 Years

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In the earliest days of the past century, advancements in optics were led by newly created optics companies: Kodak and its research laboratory, Bausch & Lomb, and the American Optical Company. George Eastman led the effort to found the Kodak Research Laboratory in 1912 because he saw the connection between optical science and development of new products. The Institute of Optics at the University of Rochester was not founded until 1929, after ten years of discussions. As for government, Thomas Edison urged in 1915 that a national laboratory be formed to attack issues faced by the U.S. Navy. While this resulted in the establishment of the Naval Research Laboratory in 1923, the (Physical) Optics Division was not formed until after World War II.

In July 1945 during the closing days of World War II, Vannevar Bush, the Director of the Office of Scientific Research and Development, in response to a request from President Franklin Roosevelt issued an extensive report entitled "Science—the Endless Frontier," which urged the government to establish and fund a broad program in science and applied research to fight disease, develop national security, and aid the public welfare. It urged that basic science and long-term applied research be supported in universities, that nearer-term applied research and development be funded in industry, and that military research be increased and tied to university and industry R&D programs as appropriate. It estimated the cost of this program to be $10 million at the outset rising to perhaps $50 million within five years. One of the recommendations was to create the National Science Foundation

Congress created the Office of Naval Research (ONR) in 1946 with the Naval Research Laboratory being its principal operational arm. In light of the wartime success in developing the proximity fuse, the Division of Ordnance Research was transferred from the National Bureau of Standards to create the Army's Diamond Ordnance Fuse Laboratory. The Army also created a laboratory for electronics research at Ft. Monmouth in New Jersey. The Air Force was spun out of the U.S. Army in 1947, leading to the creation of the Wright-Patterson Air Force Base Laboratories in Dayton, Ohio; the Air Force Cambridge Research Laboratory in Cambridge, Massachusetts, which had Infrared Optics as one of its major divisions; and the Air Force Weapons Laboratory in Albuquerque, New Mexico. Further, the MIT Radiation Laboratory at MIT, which was so successful during the war in radar development, was expanded and relocated near the small town of Lincoln, Massachusetts, and renamed the MIT Lincoln Laboratory. All of these played a major role in modern optics and laser development.

Corporate labs were established and grew after the war. Some of them were at GE, Bell Labs, RCA Laboratories, Hughes Research Laboratory, Westinghouse Research Laboratory, Raytheon, Texas Instruments, Perkin-Elmer, and Boeing. Figure 1 is an aerial photo of the iconic Bell Holmdel Laboratory. The growth of corporate labs was aided by fiscal help that resulted from the Vannevar Bush report and two events that accelerated the science and technology of and funding for optics dramatically: the launch of the Soviet *Sputnik* in 1957 and the demonstration of the laser in 1960.

In 1958 in direct response to *Sputnik*, President Eisenhower created the Advanced Research Projects Agency (ARPA) within the Defense Department. One of the U.S.'s limitations was a lack of broad and deep materials capability. Thus, ARPA initiated the Interdisciplinary Laboratories

▲ **Fig. 1.** Aerial view of Bell Holmdel Laboratory. (Courtesy of AT&T/Bell Labs.)

(IDL) program in 1960 to ensure that chemists, physicists, and electrical and mechanical engineers work together to solve the difficult research problems in materials development. This program led to the creation of the field of "materials science." The 12 universities funded in this program were MIT, Harvard, Cornell, Illinois, Stanford, University of Pennsylvania, Maryland, Brown, Chicago, Northwestern, Purdue, and University of North Carolina. A major success of the IDL program was the development of the science and technology of electronic materials, especially III-V materials such as GaAs and ternary and quaternary mixtures of them. These materials systems have been the success story of diode lasers and photonics more generally, and the scientists who went on to industrial laboratories to develop these materials systems for specific applications in optics were likely trained in one of the IDLs.

With government funding enabling universities to supply highly skilled people to industry who would lead in the revolution in optics brought on by the laser, we will concentrate on that history because it is in many ways symbolic of the transitions that took place in basic research in optics. This is not to say that other subjects such as advances in still and motion picture photography, CCD cameras, polaroid photography, electrophotographic (xerographic) copiers, laser printers, point-of-sale scanners, optical storage devices, laser machining, and optical communication systems could not show the same transitions; it is just that the laser revolution presents the changes most powerfully.

Simultaneously with the initiation of the IDL program was the demonstration of the first laser. This occurred at an industrial research laboratory using internal funds—the Hughes Research Laboratory (HRL) in Malibu, California, on 16 May 1960. As soon as other corporate labs heard in July of Ted Maiman's success, their efforts accelerated. TRG, a small company on Long Island, New York, had been funded by ARPA in 1959 to the tune of $990,000 for laser development and is thought to be the first to duplicate Maiman's result. A number of military labs including MIT Lincoln Laboratory immediately initiated laser programs. The author was a 1st lieutenant in the U.S. Air Force at that time stationed at the Air Force Cambridge Research Laboratory (AFCRL) in Bedford, Massachusetts. He and Rudolph Bradbury had a ruby laser like Maiman's operating by November 1960. A request of $392 was made for the purchase of capacitors and flashlamps. This request was immediately approved, as everyone was excited about the prospects of having an operating red laser!

Military labs like AFCRL, Wright-Patterson Air Force Base, and Air Force Weapons Laboratory (AFWL) typically had sufficient funding not only to fund their own projects but also to fund industrial and university proposals in areas of laser R&D that they deemed important. So the decade of the 1960s was one of intense laser activity, especially in the development of laser range finders and target designators at HRL and other companies, coherence studies of partially coherent lasers at Rochester and Brandeis and at TRG, the phenomenon of mode locking that was discovered in Nd:glass lasers by Tony DeMaria of United Technology Research Center in Connecticut, the development of parametric oscillators using $LiNbO_3$ at Bell Labs by J. Giordmaine and R. C. Miller and at Stanford by Steve Harris, the study of the dynamics of laser operation at the University of Rochester's Institute of Optics by Mike Hercher, and laser-induced damage to ruby and glass at HRL by Connie Guiliano and at American Optical Company by Charles Koester. These damage studies were funded by ARPA, but the other efforts (with the exception of the research on parametric oscillators at Bell Labs) were funded with military laboratory and ONR monies.

Meanwhile, with corporate funding at Bell Labs, Kumar Patel developed the CO_2 laser in 1964, and Joe Geusic developed the Nd:YAG laser in the same year; both lasers are still workhorses today.

At American Optical Company, Elias Snitzer developed the first Nd:glass rod laser as well as a Nd:glass fiber laser. About that same time, Bill Bridges of HRL achieved lasing of argon and krypton. While these achievements were extremely noteworthy, looking back at that decade, the most significant achievements for the U.S. telecommunications industry were the developments of GaAs homojunction (diode) lasers in 1962 at GE by Robert N. Hall and N. Holonyak, Jr., and at IBM by Marshall Nathan using corporate funds, and by T. M. Quist and R. J. Keyes at MIT Lincoln Laboratory, which had block funding by the U.S. Air Force. Initially, these lasers had to be cooled to liquid N_2 temperatures or below and could operate only as pulsed devices. It took the insight of Herb Kroemer of Varian Associates in Palo Alto, California, using corporate funds, to realize that if one formed a heterojunction at both sides of the homojunction where lasing was occurring, the greater bandgap at the heterojuction would prevent carrier diffusion away from the homojunction, thus leading to the first continuous-wave diode laser a year later. Kroemer received the Nobel Prize in 2000 for this achievement. Figure 2 is an aerial photo of the IBM Watson Laboratory.

▲ **Fig. 2.** Aerial view of IBM Watson Laboratory. (Courtesy of IBM Research—Zurich. Unauthorized use not permitted. Copyright owner is IBM Zurich at http://www.zurich.ibm.com/imagegallery/.)

With ARPA funding, Roy Paanenen at Raytheon demonstrated a 100-W argon laser that required a huge flow of cooling water. Also at Raytheon, Dave Whitehouse was the first to demonstrate a 1-kW laser with a longitudinal gas-flow CO_2 system that seemed as large as a tennis court. Ed Gerry, with ARPA funding, at AVCO/Everett Research Laboratory developed a flowing gas-dynamic CO_2 laser that had the potential for smaller size and ultra-high power because the waste heat in the gaseous medium could be removed by flowing the gas transversely out of the laser resonator. AVCO/Everett with continued ARPA funding went on to achieve very-high-power operation of the CO_2 laser as well as high-peak-power pulsed operation of rare gas lasers.

As the powers that were achieved by the CO_2 laser were high enough to fracture the "transparent" materials that were then available, a new effort had to be made to develop better optics for such lasers. Consequently, the author departed AFCRL in 1971 for ARPA to lead efforts to develop highly transparent windows and reflecting and anti-reflecting coatings. The best of the window materials that were developed were ZnSe and ZnS, and BaF_2 by Raytheon (Jim Pappis). Coating development was led by Maurice Braunstein at HRL and resulted in thorium-containing coatings with reflection coefficients exceeding 99%. Supporting university and industrial contractors were involved in these programs, with their roles ranging from modeling of optical distortions in high-power windows to development of techniques to measure absorption coefficients as low as 0.00001 cm^{-1}.

In the 1970s and 1980s, changes began to occur in the corporate world that led the corporations to reduce funding of research. First, Wall Street and the stock market expected companies to "make their numbers" on a quarterly basis as failure to do so would result in stock prices dropping. This led to corporations investing their money in the short term to the detriment of funding research that paid off mostly in the long term. Second, it was becoming apparent to management that these labs were perhaps more of a drain on profits than the corporation could afford as the research labs did not seem able to convert research results to products that would boost sales. Third, the rise of globalization meant that these companies faced competition around the world that had not mattered previously. Fourth, the U.S. Congress had initiated the Small Business Innovative Research Program to fund product development at businesses with fewer than 500 employees. Each agency of the federal government that had R&D funds was (and is) required to set aside 2.5% of these funds for such awards. In 1995 this amounted to \$950 million for product development by small businesses. While this is small compared to what U.S.

corporations spend annually for R&D, the availability of such funding attracted people to leave corporate research laboratories to develop their new ideas rather than attempt to do so in the corporate environment.

At this point, it is natural to ask, “Why weren’t the research labs more efficient at developing new products?” It seems that the researchers were just not close enough to the companies’ customers to know what was needed or what could be improved upon [1]. So large companies began cutting back their research laboratories in the 1970s–1990s, if not eliminating them altogether, and moving their best R&D people nearer to the front line. Instead of looking for major breakthroughs such as a laser, they concentrated instead on, as the *Economist* writes, “tinkering with today’s products rather than pay researchers to think big thoughts. More often than not, firms hungry for innovation look to mergers and acquisitions with their peers, partnerships with universities, and takeovers of venture-capital-backed start-ups” [1].

The several changes mentioned above led to a shift of basic research and long-term applied research to universities and, to a smaller extent, government laboratories. While various government agencies still fund individual investigator proposals in optics, there has been a dramatic growth in Multi-University Research Initiatives (MURIs)—designed to tackle important long-range development objectives. MURIs involve universities and private companies that would be likely to commercialize the developments of the research done in the MURI. These MURIs thus take on development efforts that, 30 years ago, would have been done by a company that had its own research laboratory to perform the fundamental work necessary to develop the new product.

Reference

1. http://www.economist.com/node/8769863.