INTRODUCTION

Introduction

Paul Kelley

This book describes progress in optics during the period from 1916 to 2016, the first hundred years of The Optical Society (OSA). Before we begin, let us consider how much the rate of advancement has increased over this period. A sense of this can be found in the OSA membership and publication statistics. There were 30 Charter Members in 1916, and in 1917 the membership was 74. The Society grew in the 1920s, but in the depression decade of the 1930s the membership was fairly static at about 650. The membership rose sharply with the onset of World War II, roughly doubling by the end of the war. Government funding of science and technology and the increased use of optics in industry stimulated further growth so that by 1960, the year of the laser, the membership stood at 2600. The development of the laser further enhanced this growth, and by the fiftieth anniversary of the Society in 1966 there were 4500 members. In the 1980s, OSA passed the 10,000 member mark, and today the organization has 19,000 members. The Society has endeavored to include all of optics. However, for a number of reasons, including growth and divergence of interests, several subfields have left the organization. Because of this it is hard to do justice here to some topics in optics.

While this volume does not intend to discuss progress in optics before 1916 in any depth, it is useful to consider where the field stood at the beginning of the period. Optics is the science and technology of light. As such, it is concerned with the generation, manipulation, and use of light. Light and the tools of optics are our principal means of directly sensing our world and allow us to vastly expand our knowledge of the universe and the microscopic world. While optics has a very long history, its influence became particularly strong toward the end the nineteenth century. The invention of the electric light changed the way we lived by extending our nighttime activities of work, study, and pleasure. Eyeglasses, still and motion picture cameras, and other optical instruments had widespread impact on our lives. The industries that provided these devices set the stage for the founding of OSA.

The development of optical spectroscopy led in 1913 to Bohr's quantum theory of the atom. At about the same time, Einstein's theory of blackbody radiation and the photoelectric effect gave us an understanding of the quantization of light. The extension of quantum mechanics into molecular physics and condensed matter physics provided the basis for much of the progress in twentieth century physical science and technology, including the invention and development of the laser.

At the start of OSA, principal areas of interest to OSA members included optical instruments, vision, optical materials, lens technology, theoretical optics, and the photographic process. The practical nature of most of these subjects reflected the backgrounds of the founders. In the 1920s and 1930s spectroscopic instrumentation was under rapid development. The use of photocells with vacuum tube amplifiers overcame many of the limitations of photographic recording of spectra. New photocathode materials were developed to extend spectra ranges, and the photomultiplier tube was invented in 1934. Silver-halide-based photographic materials were developed with improved sensitivity and spectral range, and color photography became practical and widespread. CCD image sensors replaced film in the 1990s, bringing further improvement in sensitivity and dynamic range in photography. World War II saw the development of innovative camera lens designs for use in reconnaissance and the widespread use of antireflection coatings. During the war, infrared spectroscopy became vital in the production of artificial rubber and custom fuels. Analytical instrumentation using spectroscopy spread rapidly in the chemical industry at the end of the war. This period also saw the introduction of new civilian applications of optics such as instant photography, the Xerox copier, and the fiber endoscope.

Astronomy has seen a number of innovations in the last hundred years. The Schmidt wide-field-of-view camera was invented in 1930, and early versions were built at Hamburg Observatory and Palomar Observatory in the mid-1930s. The Schmidt camera and various variants are widely used in sky surveys, and a modified version was designed to track earth satellites. As astronomical telescopes became larger to provide greater light-gathering power and resolution, stability and weight of monolithic reflectors became serious problems. A segmented-mirror telescope design was proposed in 1977, two versions of which have been operated at Mauna Kea since the early 1990s. Since then, more segmented telescopes have been deployed by astronomers. Laser guide stars are being used to correct the optical wavefront for effects of atmospheric turbulence. The Hubble telescope, which uses a Ritchey-Chretien Cassegrain wide-field design, has been operating in earth orbit since 1990.

One of the most important uses of light is illumination. While Edison's incandescent lamp was a welcome replacement for gas and oil lamps, it was inefficient and not very long lasting. The fluorescent lamp was commercialized in the 1930s. The need for 24-hour production in wartime factories led to the widespread use of fluorescent lighting, and by the early 1950s it had surpassed incandescent lighting in the United States. In order to reduce energy consumption, new fluorescent lamp configurations were designed in the 1990s to mimic the incandescent lamp. Today fluorescent lighting is being replaced by even more efficient LED lighting. First developed as a cousin of the semiconductor laser in the 1960s, LEDs were not considered useful for illumination because of the absence of a blue source. This problem was solved in the mid-1990s. When fully deployed, the worldwide energy savings will be about 5 PWh/yr.

1960 began the age of the laser. The first laser had ruby as the active medium. Other pulsed solid-state lasers were developed that year, and in December came the He–Ne laser, the first continuously operating system. After that, new lasers were invented at a rapid pace, including high-power gas lasers at wavelengths from the infrared to the ultraviolet as well as continuously operating solid-state lasers. Most lasers used optical or electrical excitation (pumping) of the active medium. Perhaps the most significant early (1962) invention was the semiconductor diode laser, which operated with very high efficiency through electrical excitation. After considerable development, continuous operation was achieved at room temperature, cementing the great practical value of this system. While individual semiconductor lasers were not particularly powerful, they were small and could be fabricated in one- and two-dimensional arrays for use in optical pumping. Broadly tunable lasers were invented; early ones used dyes but were supplanted by solid-state systems. The tunable laser was valuable for general spectroscopy and is essential in ultrafast science. Diode-pumped rare-earth fiber lasers have successfully competed with gas lasers for a number of high-power industrial applications.

Because of the availability of lasers as sources of very intense light, it became possible to induce a nonlinear response of material to radiation. Following the first report of second harmonic generation in 1961, many nonlinear phenomena were observed, including stimulated inelastic light scattering, parametric oscillation and amplification, and self-action (four-wave mixing) effects. Parametric processes have been important in the understanding of entanglement and other quantum optics phenomena. Octave frequency combs and optical solitons are a consequence of self-action. Nonlinear frequency conversion is often used to extend the wavelength range of laser radiation.

Over the fifty-plus years since 1960, the laser has seen a wide variety of applications. Military uses include laser targeting and tracking; laser weapons have also been tested. In nuclear energy, lasers have been built to test concepts in inertial confinement fusion and for uranium isotope separation. Industrial lasers such as CO_2, diode-pumped solid-state, and diode-pumped fiber lasers are used for welding, marking, machining, and other industrial processes, representing business of greater than \$2 billion dollars per year. This is about 25% of the laser market. Applications such as fiber optical communication, optical storage, photolithography, and laser printing are on a similar scale. Access to worldwide information at very high bandwidth has changed the way people work and live in many ways. The Internet, cable television, video on demand, cell phone networks, and many other information sources depend on fiber optical connectivity. Fabrication of microelectronic devices with feature sizes approaching 10 nm using excimer laser lithography has led to a mass market for inexpensive, powerful computers. Sales of microprocessor-based devices approach a trillion dollars per year. In medical optics, lasers are used in a variety of diagnostic and therapeutic applications, including refractive surgery of the eye (LASIK) and optical coherence tomography.

While it is hard to predict the future, it is apparent that rapid progress in optical science and technology is continuing. New ways of generating and applying ultrashort pulses are being found. Novel fiber structures and plasmonic devices are being actively studied. As nanofabrication techniques are developed, it seems possible that a variety of sub-wavelength optical devices will be made. Such devices would function much like electronic devices. Optics should continue to play an important role in our understanding of the theory of entangled states and the development of quantum computing and quantum cryptography.