Light, Lasers and the Nobel Prize

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This *Advanced Photonics* special issue on the laser anniversary is an ideal opportunity to review some highlights from its history, at the same time taking us on a tour of over a century of Nobel Prizes.

The Year 2020 represents 60 years since the first successful operation of the laser. This anniversary provides an ideal occasion to reflect on the myriad ways that lasers have revolutionized society, and to consider the many new areas of research that continue to drive photonics in unexpected directions. Yet at the same time as we consider these exciting future perspectives, it is also interesting to see how the development of the laser traces a path that intertwines basic and applied science, and intersects with the recognition of many of the pioneers of optics through the Nobel Prize. Of course, an exhaustive history of such a rich topic cannot be given in a short Perspective, but it is perhaps possible to describe some of the key highlights.

A good point to begin any historical discussion of the laser is the second half of 19th century, and the study of the emission properties of hot objects and the measurements of the characteristic spectrum of black body radiation. In fact, it is not widely appreciated that these studies were not initially motivated by questions of fundamental scientific curiosity, but were rather stimulated by a very practical and economic problem [1]. In particular, the city of Berlin at the time was choosing between gas and electric lighting, essentially the same problem as we have had in recent years in switching from incandescent and fluorescent lights to LEDs. Naturally, when making such a decision, standardizing the spectral content of the different light sources was a critical first step, and it was this that drove experiments to measure precision radiation curves of sources at different temperatures. Theoretical work by Wien was able to connect the peak emission wavelength and the source temperature, but explaining the shape of the emission curve was only possible with the introduction of energy quantization by Max Planck in 1900.

Although the initial measurements of blackbody radiation may have had a strong industrial link, the scientific environment of the time was clearly focused on understanding the deep and fundamental questions concerning the nature of light-matter interactions. Indeed, the Nobel Prize was first awarded only in 1901, and the importance of studying the nature of light was quickly recognized with prizes to Lorentz and Zeeman (1902), Wien (1911), and Planck himself (1918) [2]. It was in 1905 that Albert Einstein revolutionized physics with his four celebrated *Annus Mirabilis* papers. It is perhaps fitting that the first of these concerned the very nature of light itself, where he applied the concept of light quantization to explain the photoelectric effect [3]. In fact, when Einstein was awarded the Nobel Prize (in 1921), it was this only particular contribution that was highlighted in his citation – “for services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect.”

It was in 1917 when Einstein made a key contribution to the laser through his prediction of the process of Stimulated Emission [4]. As well as developing what is now the familiar rate equation theory of emission and absorption, Einstein's insight led him to realize that stimulated emission would be associated with the emitted and incident photon possessing the same direction. It is this directionality characteristic that provides the basis of amplification, and whilst Einstein did not foresee any form of practical laser device, his 1917 paper is nonetheless the foundation of everything that has followed since.

Building on these ideas, researchers extended both theory and experiment of light-matter interactions during the following decades, leading to the development of the concepts such as pumping and resonators, and ultimately the first demonstration of the maser in 1953 by Charles Townes and his PhD student Jim Gordon. With Arthur Schawlow, in 1958 Townes wrote a theoretical paper extending the maser concept into the visible spectrum, although they had yet to build an experimental prototype [5]. These results established an entirely new field of "quantum electronics" and in 1959 Townes organized the first international conference in the field where one of the important goals was to work towards extending the maser to optical wavelengths [6]. Ted Maiman attended this conference, yet as he writes in his memoirs, he made a conscious decision to avoid the complex yet elegant systems that were being widely discussed, and to focus instead on practical simplicity [7]. Of course, there was never any guarantee that Maiman's approach would work out, but on the 16 May 1960, while working at Hughes Research Laboratories, he observed pulsed laser oscillation at 694.3 nm, building on his idea that flashlamp pumping of Ruby would allow for a dynamic population inversion sufficient to reach threshold.

The pioneering work on both masers and lasers was recognized in 1964 with the award of the Nobel Prize to Charles Townes, Nicolay Basov, and Aleksandr Prokhorov "for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle." In fact, although many laser histories tend to focus mainly on the work performed in the USA, Basov and Prokhorov at the Lebedev Institute in Moscow were simultaneously and independently covering exactly the same ground with their own theory and experiments. Two years later in 1966, Albert Kastler received the Nobel Prize for his work on optical pumping techniques, and later Bloembergen and Schawlow shared the 1981 Nobel Prize for laser applications in spectroscopy.

Maiman, despite being the first to see laser emission, never won the Nobel Prize, and neither did Jim Gordon. Whilst it is natural to consider these omissions as major oversights by the Nobel Committee, the availability of the Nobel Prize archives [8] reveal that the lack of any Nobel recognition for Maiman and Gordon is simply linked to the fact that they were not strongly supported by the broader physics community at the time. In particular, starting as early as 1958, Charles Townes had been nominated 75 times for the Nobel Prize, including 30 nominations for the year in which he won. In contrast, based on what we know of the nomination archives (which are accessible until 1966), Gordon was nominated only once in 1963 and Maiman only once in 1964. This said, as far as Jim Gordon is concerned, Charles Townes certainly recognized the role he had played, and in 2014 he explicitly stated that "Jim didn't get the Nobel Prize with me, presumably because he was a student when the maser first worked, but I think he deserved it." [9]

There were of course many other eminent scientists involved in the early years of laser physics, and some excellent personal and historical accounts are available [5,7,10]. Lasers have also been recognized either directly or indirectly in many other Nobel Prizes as well (not just physics). Table I and 2 list a selection of Nobel Prizes related to the physics of light science and applications, before and after the invention of the laser respectively, and it is highly recommended to explore the Nobel Prize website to learn more.

Considering the history of the laser is an opportunity to think about many broader issues of science, and particularly the relationship between basic research and technology transfer. The laser is an ideal subject with which to explain the tremendous economic and societal benefits that can arise from basic curiosity-driven scientific research. With all the advances in photonics that continue to be made in many different areas, it is likely that laser-related science will continue to be recognized by Nobel Prizes in the future, and will continue to create revolutions in our lives.

References

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2. The Nobel Prize in Physics has been awarded 113 times to 213 Nobel Laureates between 1901 and 2019. A full listing of laureates, as well as transcripts of the Presentation Speeches which provide important contextual information, can be seen at www.nobelprize.org
3. A. Einsten, Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt" Annalen der Physik **17** 132–148 (1905)
4. A. Einstein, Zur Quantentheorie der Strahlung, Physikalische Zeitschrift, **18**, 121-128 (1917)
5. C. H. Townes. *How the Laser Happened: Adventures of a Scientist.* Oxford University Press (1999)
6. The Shawanga Lodge Conference on Quantum Electronics-Resonance Phenomena 14-16 September 1959, Bloomingburg, New York. See also Physics Today **12**, 5, 72 (1959)
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9. A Historical Perspective on the Maser and Laser presented by Charles Townes, Univ. of California, Berkeley, USA and Tony Heinz, Columbia Univ., USA. The James P Gordon Symposium during CLEO 2014 in San Jose, California, USA.
10. J. Hecht. *Beam: The Race to Make the Laser.* Oxford University Press (2005). See also J. Hecht. *Beam: The Race to Make the Laser.* Optics and Photonics News, **16**(7) 24-29 (2005)

Year	Laureates and Area of Research	Nobel Category
1902	Lorentz & Zeeman The Zeeman Effect, Electron Oscillator Model	Physics
1903	Niels Ryberg Finsen Phototherapy – use of UV light to treat Lupus	Physiology or Medicine
1907	Michelson The Michelson Interferometer & Precision Measurements	Physics
1908	Lippmann Colour Photography based on Interference	Physics
1911	Gullstrand Description of the Refractive Optics of the Eye	Physiology or Medicine
1912	Dalén Solar-based regulator for buoys and lighthouses	Physics
1918	Planck Energy Quanta	Physics
1919	Stark The Stark Effect	Physics
1921	Einstein Photoelectric Effect & services to theoretical physics	Physics
1922	Bohr Atomic Structure and the nature of radiation	Physics
1923	Millikan Elementary Charge and the Photoelectric Effect	Physics
1927	Compton The Compton Effect	Physics
1930	Raman Raman scattering	Physics
1932	Heisenberg Creation of Quantum Mechanics	Physics
1933	Schrodinger & Dirac New Productive Forms of Atomic Theory	Physics
1945	Pauli Pauli Exclusion Principle	Physics
1953	Zernike Phase Contrast Microscope	Physics
1954	Born Statistical Interpretation of the Wavefunction	Physics
1955	Lamb Fine structure of the H Spectrum (Lamb Shift, QED)	Physics

Table 1 A selection of Nobel Prizes related to the physics of light, masers and lasers and related areas prior to the invention of the laser in 1960. For interest, some medical applications are also included. Note that the descriptions provided are highly abridged from the formal citation, and this is only a partial list of laureates; many other Nobel Prizes have been related to light science in some way or another. Particularly absent in this list are the prizes related to crystallography.

1964	Townes, Basov, Prokhorov Laser-Maser Principle	Physics
1966	Kastler Precision studies of optical resonances	Physics
1967	Granit, Hartline, Wald Physiological and chemical visual processes in the eye	Physiology or Medicine
1967	Eigen, Norrish, Porter Flashlamp Pump-Probe Studies of Chemical Reactions (μs)	Chemistry
1971	Gabor Holography	Physics
1981	Bloembergen & Schawlow Laser Spectroscopy	Physics
1981	Hubel & Wiesel Information Processing in the Visual System	Physics
1989	Ramsey, Dehmelt, Paul Atomic Clocks, the Ion Trap	Physics
1997	Chu, Cohen-Tannoudji, Phillips Laser Cooling and Trapping	Physics
1999	Zewail Femtochemistry	Chemistry
2000	Alferov & Kroemer Optoelectronics, Semiconductor Heterostructures	Physics
2005	Glauber, Hall, Haensch Quantum Optics, Spectroscopy, Optical Frequency Comb	Physics
2008	Shimomura, Chalfie, Tsien Green Fluorescent Protein GFP	Chemistry
2009	Kao, Boyle and Smith Optical Fiber Communications ; Imaging and the CCD	Physics
2012	Haroche & Wineland Individual Quantum Systems	Physics
2014	Akasaki, Amano, Nakamura The Blue LED and Energy-Saving White Light Sources	Physics
2014	Betzig, Hell, Moerner Super-resolution microscopy	Chemistry
2018	Ashkin, Mourou, Strickland Optical Tweezers & Biophotonics Chirped Pulse Amplification	Physics

Table 2 A selection of Nobel Prizes related to the physics of light, masers and lasers, and/or their applications dating from the invention of the laser in 1960. Note that the descriptions provided are highly abridged from the formal citation, and this is only a partial list of laureates; many other Nobel Prizes have been related to light science in some way or another. Particularly absent in this list are the prizes related to crystallography.