NEWSLETTER

Commission Internationale d'Optique ● International Commission for Optics

The history of how the laser came to be

Tony Siegman presents his personal view on the early development of the laser and in doing so inaugurates a series of articles on the laser for the upcoming International Year of the Laser.

The first ruby laser is disassembled.

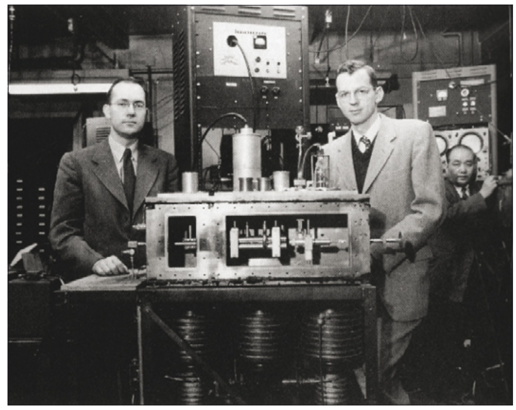
In May 1960 the first successful man-made laser device, a flashlamp-pumped ruby laser with an intense deep red 6943 Angstrom wavelength, flashed into operation, almost on its first try. This took place in a parquet-floored laboratory in the recently opened Hughes Research Laboratories high on a hillside above Malibu, California, looking down on the Pacific beaches and movie stars' homes.

This breakthrough in optics technology – the world's first coherent optical oscillator – had a remarkably simple structure: a short "stubby" cylinder of synthetic ruby with polished and silvered end faces, and a totally standard spiral photography flashlamp. It was the outcome, however, of a year or more of stubborn perseverance, careful analysis and detailed research on the spectroscopic properties of ruby by its inventor, Ted Maiman. He was a self-directed physicist who had progressed from a rather undistinguished undergraduate engineering degree to a sophisticated and successful PhD dissertation working with Willis Lamb at Stanford University just a few years earlier. It immediately set off a firestorm of reproductions of the same experiment and the emergence of similar and then increasingly different lasers in other laboratories around the world.

This laser was not the first man-made stimulated emission device, however. That recognition had gone to the ammonia maser: a very narrowband, low-power 24 GHz oscillator using a beam of ammonia molecules passing through a microwave cavity. It was proposed by Charles Townes in his famous "park bench" invention in 1951 and successfully operated by Townes and colleagues at Columbia University in 1954.

Neither of these devices actually represented the first maser or laser to exist in a broader view of our universe. As astronomers belatedly came to realize only several decades later, Mother Nature had been operating immense, and in some cases incredibly powerful, stellar-pumped molecular masers and mirrorless far-infrared lasers in outer space, and even creating low-gain solar-pumped CO_2 laser amplification in the atmosphere of Mars, for billions of years before Maiman or Townes.

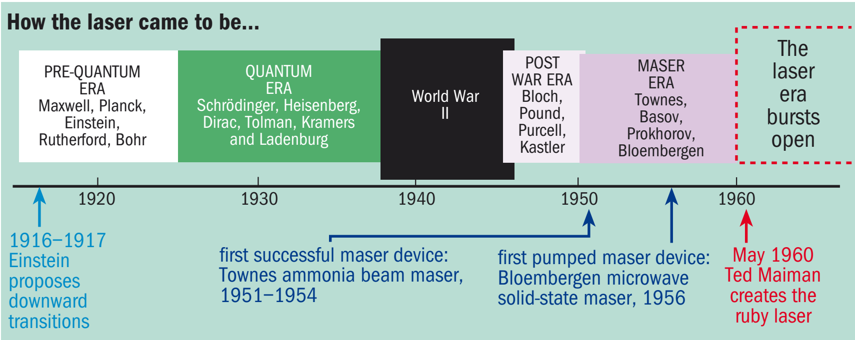
The physical principles that make all of these devices possible have a great deal in common nonetheless. It is interesting and instructive to look back at the intellectual history and some of the personal stories of how the incredible variety of laser devices that we have today came into existence as a result of the steady accumulation of scientific knowledge and practical engineering technologies by individuals and laboratories around the world.



Charles Townes and Jim Gordon with the NH_3 maser.

The best place to begin such a historical review seems to be with Einstein's proposal around 1916 of radiation-stimulated downward transitions in atoms. Quantum mechanics was at that time still almost a decade in the future. As a result of the accumulation of knowledge from previous centuries, however, physicists in 1916 at least knew that atoms had some kind of discrete or quantized energy levels or states, unique to each different atomic species. They were also aware that these atoms, if lifted into upper levels by some kind of excitation process, would drop down spontaneously, emitting characteristic wavelengths of light via spontaneous radiation processes (what we now call fluorescence) and that these atoms, when in their lowest energy states, could also absorb these same wavelengths through some kind of radiation-stimulated upward absorption transitions.

Einstein, who was at that time seeking to understand the already remarkably accurate properties of blackbody radiation, was led to propose that radiation at these same wavelengths could also stimulate atoms that were already in upper energy levels to make downward transitions, releasing additional radiation energy in



the process. He apparently did not use the term "stimulated emission" to describe this behaviour (that came a few years later), and although he stipulated that energy and momentum would both have to be conserved in this process, it is not clear whether he would have thought of this as a meaningful method to achieve "amplification" of light. (Coherent amplifiers of any sort, at any frequency, were just barely emerging in a few engineering labs at that time. Einstein would not have had either a record player or a stereo amplifier at home.)

This revolutionary idea about the interaction of radiation and atoms began to flower in succeeding years, at first slowly, then more rapidly, as quantum mechanics suddenly emerged in two unique but exactly equivalent formulations, beginning in 1925. All of the intricacies of quantum energy levels in atoms and molecules, the quantum properties of electromagnetic radiation and the interactions between these two were then worked out in ever more intricate detail through the late 1920s and 1930s. Tolman and Kramers noted around 1924 that stimulated emission from upper atomic levels implied "negative absorption" or amplification of radiation, as well as negative dispersion on the same transitions. Ladenburg in 1933 clearly showed that these negative or inverted dispersion effects were real, not by producing an inverted population but by showing experimentally that the positive dispersion effects produced by lower-level atoms were visibly reduced or weakened if one simultaneously excited a smaller number of atoms into the upper level of the transition.

More detailed ideas on how to use stimulated emission from an inverted population to achieve practical amplification or oscillation only slowly emerged following these early ideas. Townes noted a conversation that he once had with a German physicist Houtermans who recalled, long after the fact, hearing in 1932 about an unusually strong output from a gas discharge tube on one particular spectral line and thinking at the time that it might be some kind of "photon avalanche". Some time around 1939 a Russian scientist, Fabrikant, working in the chaos of the Soviet Union in the early years of World War II, published an obscure thesis that considered stimulated emission as an amplification mechanism, and SM Levi in the Soviet Union is also said to have anticipated many of the future developments in the use of stimulated emission.

It was World War II, however, which, while it spread death and suffering around much of the world, also laid what might be viewed as the crucial foundations for the emergence of a variety of masers and then lasers in the years and decades immediately following the war. As the clouds of war darkened the skies over Europe and Asia in the late 1930s and then spread to much of the rest of the world in the early 1940s, the governments of many countries that were involved assembled the most capable scientific and engineering talent of their nations into government and industrial laboratories to work on the technologies of radar, communications and weaponry needed to engage in this new kind of warfare.

In the US in particular, distinguished senior physicists with names like Alvarez, Bethe, Bloch, Conant, DuBridge and Rabi, along with younger but later to be equally distinguished physicists with names like Dicke, Pound, Purcell, Ramsey, Schwinger and Townes came together "for the duration" in research laboratories like the MIT Radiation Laboratory and other similar laboratories at Harvard, Columbia and John Hopkins. Working under intense time pressures, they generated massive advances in electronics, radio-frequency and microwave technology, signal detection and processing, and other technologies, and at the same time educated themselves in the techniques and the capabilities of these new technologies.

As the war ended, many of these scientists returned to their home laboratories, carrying with them not only these new skills and concepts but in many cases pieces of their wartime apparatus – waveguides, cavities, signal generators and receivers, sensitive detection methods – which they were eager to apply to more basic scientific pursuits. At the same time, the wartime experience of the US government and others led to unprecedented post-war government funding for university and industrial research, both basic and applied, along with the founding in the US of the three Department of Defense funding agencies: the Office of Naval Research, the Army Research Office and the Air Force Office of Scientific Research.

The immediate result of this was a rapid flowering of many areas of scientific and engineering technologies, including atomic and molecular physics in general, and masers and lasers in particular. Indeed the events and advances in these fields in the two decades from 1946 to 1966 are so numerous and extensive that it is only possible to list a few here. A compressed list of these highlights up to 1960 include:

- The development of nuclear magnetic resonance research and the very clear demonstra-

Charles and Frances Townes, both in their nineties, seated on a larger-than-life-size reproduction of the real park bench in Franklin Park, Washington DC, where Townes, sitting outside in the cool of a morning nearly 60 years earlier, waiting for his colleague and future brother-in-law Arthur Schawlow to awaken in their shared hotel room, invented the concept of the ammonia beam maser and jotted down a quick calculation of the idea in his notebook. The statue sits in the downtown plaza of the pleasant small southern town of Greenville, South Carolina, where Townes was born and raised.

tion of population inversion and "negative temperature" by Bloch, Purcell and Pound between 1946 and 1950.

- The demonstration of optical pumping by Kastler around 1949.
- The successful operation of the ammonia maser by Gordon, Zeiger and Townes in 1954.
- Related accomplishments in the same area by Basov and Prokhorov around 1954 or 1955.
- Bloembergen's invention of the continuously pumped microwave solid-state maser and a far-reaching (if little recognized) patent by Robert Dicke in 1956.
- A detailed and much cited analysis of laser possibilities by Schawlow and Townes published in *Physical Review* in 1959, which attracted much attention to this topic.
- Analyses of a possible inversion mechanism in He-Ne and other gas-discharge lasers by Javan and Sanders published in 1959.
- The first Quantum Electronics Conference, organized by Townes at Shawanga Lodge in 1959, which included at least eight future Nobel Laureates among its 180 attendees.
- The brilliant and intense red beam from Ted Maiman's laser at the start of 1960.

I will leave it to others to summarize the veritable explosion of laser technology that occurred immediately following this final, breakthrough event, and only note here that after Maiman's announcement of his results, two rare-earth-doped solid-state lasers were demonstrated within just a few months by Peter Sorokin and colleagues at IBM, and the first gas laser to result from the long and careful program at Bell Laboratories was successfully demonstrated just before the end of 1960. Six years later, by the end of 1966, essentially every major type and variety of laser that we have today – including the fibre laser and semiconductor diode lasers – plus more or less all of the major techniques of nonlinear optics that we now employ so widely, had been demonstrated at least in crude and early form. This was made possible by the flood of laser and laser-related research and technology that burst forth then and continues today.

For my own part I will say just a bit more about the microwave solid-state maser concept presented in an exceedingly compact, elegant and far-reaching publication by Nico Bloembergen in 1956. Not only was this the start of my involvement in the maser and laser field, but it seems to me that this proposal, as much as any of the other highlights listed above, really opened the doors to much of what has come since. From a personal viewpoint, when I look back to that era I can also always look with pleasure at the picture of a 1959 Steering Committee meeting for the Shawanga Lodge meeting (p4). Starting at the back corner of the room and continuing clockwise around the table, the participants are G J Stanley from Cal Tech, Irving Rowe from the Office of Naval Research, George Birnbaum from the Hughes Research Labs (Ted Maiman's boss), Rudy Kompfner from Bell Laboratories, Charles Kittel, M W P Strandberg from MIT, Nico Bloembergen, Bejamin Lax from MIT/Lincoln Labs, Robert Dicke, and a young (and naive) me. It was only through the courtesy and kindness of Charles Townes that I was in this group, and I must express my continuing gratitude for this. I only wish that I had understood better at the time what remarkable company I was in.

Tony Siegman, Stanford CA, September 2009

Anthony E Siegman is author of the monumental laser textbook and reference work Lasers *(University Science Books, 1986). He is an expert on unstable optical laser resonators, former OSA president, member of the US National Academy of Engineering and the US National Academy of Sciences, and recipient of the Schawlow Medal of the Laser Institute of America.*

Book list

The following books might be of interest to readers who wish to obtain more information about the technical developments or about some of the individuals mentioned above.

- For those seeking more detailed discussions of any of the scientific and technical topics, *Masers and Lasers: an Historical Approach* by Mario Bertolotti (Adam Hilger, 1983) provides a well written, detailed, carefully referenced and scholarly history of most of this material.
- Charles Townes is an immensely distinguished individual and his memoir *How the*

The first Quantum Electronics Conference committee meeting.

Laser Happened: Adventures of a Scientist (Oxford University Press, 1999) is an equally readable book describing his early life and family background, his invention and operation of the ammonia maser, his major contributions to the subsequent development of the laser, and his many additional scientific contributions in spectroscopy, astronomy and radio astronomy, along with his many contributions to public and government service and academic administration.

- Theodore H (Ted) Maiman was a personable but very much self-directed individual and self-described maverick scientist, willing to defy conventional wisdom, blaze his own trail and describe events as he saw them. As a result, his personal memoir *The Laser Odyssey* (Laser Press, 2000) is a very readable chronicle with many entertaining anecdotes of his early life, of how his own laser came to be despite obstacles and of his subsequent adventures that resulted from this.
- Not mentioned in the chronology above is Gordon Gould, a lifelong independent inventor and considerably older than usual graduate student pursuing a PhD in the same Columbia laboratory as Townes in the late 1950s, but working in a different research group. In the late 1950s Gould recorded a number of ideas related to potential laser devices in a series of notebooks and subsequent patent applications, which then became the basis of an unusually prolonged patent dispute with Townes. The book *LASER: The Inventor, the Nobel Laureate, and the Thirty-Year Patent War* (Simon & Schuster, 2000) by professional journalist Nick Taylor presents a sympathetic portrayal of Gould's life and professional career, including the prolonged legal conflict that he waged over patent rights to the laser – a battle that Gould eventually "won", at least in some fairly limited sense. The book itself was favorably reviewed in the June 2001 issue of *Optics and Photonics News* by Colin Webb.
- Finally, Jeff Hecht, a scientific historian and technical journalist who has had a long involvement with lasers and laser scientists, has written *BEAM: The Race to Make the Laser* (Oxford University Press, 2005), providing the general reader with a richly detailed and meticulous historical chronology of "the three intense years from the birth of the laser idea to its demonstration in a California laboratory". One of his personal conclusions in the epilogue to his study is: "Maiman should most certainly have received a Nobel prize for his accomplishment."

Melbourne hosts nanophotonics event

The Nanophotonics Down Under 2009 conference attracts participants from 18 countries.

Nanophotonics Down Under 2009: Devices and Applications (SMONP 2009) was held at the Melbourne Convention Centre, Melbourne, on 21–24 June, under the banner of the Sir Mark Oliphant (SMO) conferences – International Frontiers of Science and Technology, a conference series under the Australian Government's International Science Linkages Programme. The SMO conferences are designed to stage strategically significant international conferences in Australia on high-priority, cutting-edge, multidisciplinary themes, and Nanophotonics Down Under 2009 fulfilled its aim. It attracted leaders in the interdisciplinary field of solar cells, nanoplasmonics, biophotonics and photonics crystals, as well as 120 presentations from 18 countries (totalling 165 participants) to provide a forum for emerging applications of nanophotonics.

The programme of SMONP 2009 was preceded by a public lecture and a workshop for high-school teachers on Sunday 21 June. The lecture and workshop aimed to expose the general public to the current research in nanophotonics, and the speakers (Martin Green, Masud Mansuripur, Paul Mulvaney and Tim Senden) did not disappoint. Their lectures were delivered to integrate the audience members who had varying scientific backgrounds.

The delegates at the SMONP 2009 conference.

The main event was opened with Suntech Co. Ltd CEO Dr Zhengrong Shi from China, who gave an excellent overview of the solar-cell industries and how Suntech is prepared to move forward by fusing nanophotonics in next-generation solar cells. Prof. Susumu

Nanophotonics Down Under 2009: Devices and Applications (SMONP 2009) was held at the Melbourne Convention Centre on 21–24 June.

MELBOURNE CONVENTION CENTRE

Noda from Kyoto University was the second plenary speaker, who presented equally exciting developments in dynamic photonic crystals and lasers for ultra-capacity communications. Sessions followed on photovoltaics, nanomaterials, nanoplasmonics, plasmonics, optical circuits, biophotonics, metamaterials, optical storage and optical tweezers. Throughout the sessions it was evident that efforts had been made to integrate optically addressable nanostructured materials for enhancing performance of solar cells, photovoltaics, communications, storage and medical applications.

The conference also featured Rachel Won from *Nature Photonics* giving a promotional talk, in which she announced the first inaugural impact factor of the journal – a massive twenty something that got everyone talking. It is a great achievement for the journal to reach such a level in a short period of time. The winery tour at Domain Chandon and conference dinner at the Stone of the Yarray Valley on the Tuesday night was a lively event. The wine-tasting game at the Stone provided the opportunity to taste a great variety of wines produced locally. It was perhaps a little biased towards the locals as evidenced by the winners (Ben Eggleton, David Moss and the Aussie cohorts) and losers (Masud Mansuripur, Nikolay Zheludev, Rachel Won and their international cohorts), but it was nevertheless a great social event for everyone.

Min Gu and James W M Chon, Swinburne University of Technology

Symposium celebrates the MPL opening

The new Max Planck Institute for the Science of Light is opened in Erlangen, Germany.

On 8–9 July an opening ceremony and a scientific symposium celebrated the foundation of the Max Planck Institute for the Science of Light (the MPL). The main speaker for the ceremony was Andrew Parker, who introduced the audience to the origin of natural optics and gave fascinating examples of optical structures in nature.

The one-day scientific symposium offered an impressive list of distinguished speakers and guests: noble laureate Roy Glauber, Elisabeth Giacobino, Ferenc Krausz, Ekmel Ozbay, Miles Padgett, Wolfgang Schleich, Kerry Vahala and Ian Walmsley. Opening addresses were given by the OSA president Tom Baer and by Jürgen Mlynek, the president of the Helmholtz Association. The symposium lectures were moderated by Alain Aspect, Sergey Bagayev, Ulrich Gösele, Roland Sauerbrey, Anthony Siegman, Christine Silberhorn and Joseph Zyss. This shows the attention that the new institute is receiving. It was hosted by the two founding directors, Gerd Leuchs and Philip Russell.

The institute will carry out research into the fundamental properties of light and light–matter interactions in all dimensions (space and time), making full use of classical as well as quantum optics and advanced optical engineering. It will start with two divisions and is expected to grow to four divisions including several junior research groups.

Within the Optics and Information Division of the MPL, led by Gerd Leuchs, research projects range from classical applied optics to quantum communication. The latter includes the generation and application of non-classical light and novel all-optical functional elements for long-distance optical communication links. One special area of information transfer made possible by the quantum properties of light is the secure exchange of cryptographic keys. The research team develops methods allowing for the broadband transfer of secret keys in daylight across a free space link. On the classical optics side is the development of new and ever more accurate methods for the optical measurement of three-dimensional objects. The division also investigates how laser beams can be focused more tightly. The researchers in Erlangen have already achieved a world record for focusing and are now work-

Gerd Leuchs (left) co-hosted the ceremony and Roy Glauber (right) was one of the guest speakers.

Orazio Svelto, Tom Baer, Ferenc Krausz and Philip Russell at the opening ceremony of the MPL.

ing on new laser technologies that permit finer structures in the lithographic production of semiconductors (e.g. chips) and thus greater data density for optical storage media. These methods also involve research on the coupling between light and nano antennas in the form of single atoms.

The Photonics and New Materials Division studies the photonic crystal fibre (PCF) developed by Prof. Russell. PCFs represent a revolution in the optical fibre field. They are capable of transmitting light in a highly concentrated way and with extremely low losses. Their special structure and the use of various glass types allow PCFs to generate new frequencies in the visible and ultraviolet spectral range with much lower input power than conventional glass fibre. This is of particular interest for spectroscopy as well as for the generation of intensive X-radiation. Other potential applications include high-power lasers for cutting materials or highly sensitive sensors for monitoring pollutants in water or in the atmosphere. PCFs also promise new research and diagnostic methods in medical applications. They can be used as biochemical sensors to monitor blood parameters in a patient's body, and the laser beam in the PCF could help to perform biochemical analysis of cells.

On one of the walls of Building 24 on the Siemens site in Erlangen, which hosts the new MPL, amidst the photos of MPL researchers, the sentence "We are the light" appears written in the many languages that are spoken at the institute.

Contacts

International Commission for Optics (www.ico-optics.org).

Forthcoming events with ICO participation

Below is a list of events with ICO participation that are coming up in 2009 and 2010.

7–9 October 2009
ICO Topical Meeting on "Emerging Trends & Novel Materials in Photonics"
Delphi, Greece
Contact: Nikolaos A Vainos, tel +30 2610 969911, fax +30 2610 969368, vainos@eie.gr, www.ico-photonics-delphi2009.org/

30 November – 4 December 2009
V Workshop on Lidar Measurements in Latin America
Buenos Aires, Argentina
Contact: Eduardo Quel, tel +54 11 4709 8217, fax +54 11 4709 8217, equel@citefa.gov.ar, www.lidar.camaguey.cu/wlmla/5w/w5en_main.htm

11–16 January 2010
Optics and Lasers in Science and Technology for Sustainable Development, LAM 9 International Workshop and EBASI 7 Conference
Dakar, Senegal
Contact: Ahmadou Wague, tel +221 77 634 19 61, fax +221 33 824 63 18, wague@refer.sn, www.lamnetwork.org

8–19 February 2010
Winter College on Optics and Energy
Abdus Salam International Center for Theoretical Physics, Miramare, Trieste, Italy
Contact: J Niemela, tel +39 040 2240 607, fax +39 040 2241 63, www.ictp.it/

19–21 April 2010
7th International Conference on Optics–Photonics Design & Fabrication "ODF 10"
Yokohama, Japan
Contact: Tsuyoshi Hayashi, tel +81 78 332 2505, fax +81 78 332 2506, odf10@pac.ne.jp, www.odf.jp/

For further information about forthcoming events with ICO participation, see the events page of the ICO website at www.ico-optics.org/events.html

Responsibility for the accuracy of this information rests with ICO. President: M L Calvo, Universidad Complutense de Madrid, Departamento de Óptica, Facultad de Ciencias Físicas, Ciudad Universitaria s/n, E 28040 Madrid, Spain; mlcalvo@fis.ucm.es. Associate secretary: Gert von Bally, Centrum für Biomedizinische Optik und Photonik, Universitätsklinikum Münster, Robert-Koch-Straße 45, 48149 Münster, Germany; Ce.BOP@uni-muenster.de.

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