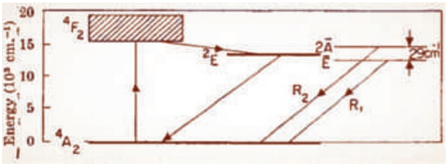
The 'laser'

Nature **187,** 493–494 (1960)



The paper that described the first ever laser was incredibly short, considering the impact it would have on the world. In around 240 words and without using the word 'laser', Theodor Maiman's paper, entitled 'Stimulated Optical Radiation in Ruby', summarized what was to be one of the most important scientific breakthroughs of the twentieth century.

Maiman, a researcher at the Hughes Research Laboratories in Malibu, California, USA, described how he used a fluorescent solid and an optical pumping technique to obtain stimulated optical emission at a wavelength of 6,943 Å. The active material was a piece of ruby 1 cm long and coated on two parallel faces with silver. When the active material was irradiated with energy at a wavelength of around 5,500 Å, the chromium ions in the ruby were excited to a higher state, following which they slowly decayed by spontaneously emitting a sharp doublet, the components of which were 6,943 Å and 6,929 Å, at a temperature of 300 K. Under very intense excitation, the population of this metastable state became greater than that of the ground state. This is the condition for population inversion and hence for amplification by stimulated emission.

At the end of his short paper Maiman stated: "I expect, in principle, a considerably greater (~10^5) reduction in linewidth when mode-selection techniques are used," but did not explain the motivation behind his work or mention any potential future applications.

The gas laser

Phys. Rev. Lett. **6,** 106–110 (1961)

Less than a year after Maiman's paper, researchers at Bell Labs in New Jersey, USA, described the first gas laser. Again, the term 'laser' was not used. Instead, their paper was entitled 'Population Inversion and Continuous Optical Maser Oscillation in a Gas Discharge Containing a He–Ne Mixture'.

Ali Javan and his colleagues described the successful operation of a continuous-wave maser at five different near-infrared wavelengths. The maser oscillation takes place in a narrow beam with a diameter of 0.45 inches. The power of the strongest beam was 15 mW, at a wavelength of 11,530 Å.

This work was so new that the equipment required to confirm it had not yet been developed. Thus, to verify their experimental results, Javan and his colleagues devised several electronic detection schemes. One of these responded only over a small period of the lasing time and was therefore synchronized with the radiofrequency pulsed discharge. The researchers admitted that "in addition to the extreme difficulties encountered in the interpretation of the results, the gain measurement alone was not sufficient to shed light into the nature of the physical processes involved in the discharge." Furthermore, they were not able to measure the linewidth using standard optical techniques as it was many orders of magnitude narrower than the resolution of the best spectrometers or interferometers available at the time. Instead, they analysed the Fourier spectrum of the maser output, which was observed through a photomultiplier tube.

The semiconductor laser

Proc. IEEE **51,** 1782–1783 (1963)

By 1963, researchers all over the world were working on different types of lasers, with the word 'laser' now being commonplace. Herbert Kroemer from the Central Research Lab of Varian Associates in the USA was the first to describe a class of lasers that he called heterojunction injection lasers. He proposed that laser action should be achievable in many of the indirect-gap semiconductors, and also improved in the direct-gap ones, if they were supplied with a pair of heterojunction injectors. He explained that these should consist of heavily doped semiconductor layers with a higher energy gap than the radiating semiconductor, and ideally should be of opposite polarity. Kroemer and his colleagues investigated most of the possible combinations available at the time (containing Ge, Si, III–V and II–VI compounds), and claimed to find at least 27 pairs with lattice misfits below 10^{-2}. Kroemer stated that "besides Ge–GaAs, the most interesting combination appears to be GaP–AlP, which might provide an indirect-gap visible laser."

The fibre laser

Electron. Lett. **22,** 159–160 (1986)

In 1986, David Payne and colleagues from Southampton University in the UK developed the first single-mode continuous-wave erbium-doped fibre laser operating at room temperature and the all-important telecommunications wavelength of 1.55 μm. They believed that their laser would find immediate applications in tunable backscatter and chromatic dispersion measurements of optical fibre, with important long-term roles as sources and amplifiers for telecommunications. The laser was tunable over 25 nm and produced powers in excess of 2 W in a *Q*-switched mode.

Previous work involved doping the fibre laser with Nd^{3+}, but this new work used Er^{3+}. The researchers claimed that their results were particularly important as the laser operated in continuous-wave mode, despite erbium being a three-level laser system and thus normally operating in pulsed mode.

The quantum cascade laser

Science **264,** 553–556 (1994)

Just when the laser community thought that no more fundamentally new designs of laser could be invented, a team from Bell Labs described the first quantum cascade laser. Jerome Faist and his colleagues explained that quantum cascade lasers are fundamentally different from diode lasers. The wavelength, which is entirely determined by quantum confinement, can be tailored from the mid-infrared to submillimetre wavelengths in the same heterostructure material. Quantum cascade lasers can also be made using relatively wide bandgap materials without having to rely on temperature-sensitive and difficult-to-process small bandgap semiconductors. The idea of the quantum cascade laser was first proposed by researchers in the early 1970s, but until the work of Faist and his colleagues, no-one had managed to successfully realize one. The group's laser operated at 4.2 μm with peak powers in excess of 8 mW in pulsed mode.

The blue laser diode

Jpn J. Appl. Phys. **35,** 74–76 (1996)

In 1996, Shuji Nakamura, then at Nichia Chemical Industries in Japan, reported the first electrically pumped blue InGaN semiconductor laser diode. His multi-quantum-well laser diodes were fabricated from III–V nitride materials and grown by metalorganic chemical vapour deposition on sapphire substrates. Optically pumped stimulated emission from GaN had been observed more than 20 years beforehand, but stimulated emission by current injection had yet to be demonstrated and so was an important breakthrough. The diodes produced 215 mW of power at a forward current of 2.3 A. A sharp peak in light output at 417 nm was demonstrated, with a full-width at half-maximum of 1.6 nm under pulsed current injection at room temperature. Although other researchers at the time had produced lasers from II–VI materials such as ZnSe, Nakamura believed that his III–V system had significant potential because of its longer lifetime.