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50 Years of the Laser

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1. Introduction

This laser was originally called the optical maser, since both maser and laser devices are based on a same principle. The maser is an acronym for microwave amplification by stimulated emission of radiation, and the laser is an achronym for light amplification by stimulated emission of radiation.

The process of stimulated emission was incubated by Albert Einstein in 1917. Stimulated emission of radiation from an upper level to a lower level is normally overwhelmed by stimulated absorption from the lower level to the upper level. In order to observe stimulated emission, therefore, population of the two levels must be inverted so that it may be effectively at a negative temperature.

Until 1940's population inversion at a negative temperature could only be observed in a transient condition. Besides, coherent properties of stimulated emission were not interested at all.

The advent of the maser in 1954 and the laser in 1960 revolutionalized optics and electronics. Many variety of lasers have been developed and engineered since. The laser is now indispensable to every branch of science and technology.

Development of the laser and the laser application during the last 50 years cannot be reviewed in short. Therefore, this paper outlines activities of the laser research around 1960.

2. Invention of the Maser

The idea of ammonia maser was conceived by Charles Townes of Columbia University in 1951, And the first maser oscillation at 24GHz was achieved by Gordon, Zeiger and Townes in 1954 [1].

A strong beam of ammonia molecules runs in vacuum towards the cavity resonator through the focusser, where molecules in the upper level are focused and those in the lower level are defocused. Then a larger number of molecules in the upper level than in the lower level can be obtained in the cavity so as to produce self-sustained oscillation at the resonant frequency.

There were controversies whether the maser output is phase coherent or incoherent. Most theoreticians such as Bohr, von Neumann and others believed that the maser radiation was equivalent to the amplified spontaneous emission or thermal noise which are random in phase.

We did not think so, however, from our theoretical consideration. I was confident that the output of a maser is similar to that of an electronic oscillator rather than an amplified thermal noise.

In order to investigate the quantum coherence of the maser we built the second maser in the fall of 1954. Output frequencies of the two masers were not identical, but slightly different. The observed beat was not a narrow-band Gaussian noise but a sinusoidal wave with a small fluctuation as we expected.

At first the ammonia maser was demonstrated to be an high-resolution microwave spectrometer [2]. Secondly it would be a precise frequency standard. In particular, maser action on other molecules was expected to generate higher frequencies than that could be obtained by electronic devices.

Possibilities for generating infrared and optical radiations by using the principle of the maser were substantially discussed by Arthur Schawlow and Charles Townes in 1958 [3]. They proposed optically pumped alkali vapor as a promising material for an infrared maser. Then the quest for realization of optical masers became more and more active and competitive.

3. Atomic Radio-Light from Rudy

At the first International Quantum Electronics Conference held in September 1959 Theodore Maiman of Hughes Research Laboratory gave a paper on ruby masers for amplification of millimeter waves. He became interested in the work of Schawlow and Townes. Then he studied ruby for an optical maser instead of alkali vapor. He found that continuous operation of optically pumped ruby laser was very difficult and decided to make a pulsed laser.

On May 16, 1960 he observed stimulated emission at 694nm from a piece of ruby which was excited by an intense light of a flash lamp. At the press release on July 7,1960 he announced that he observed “atomic radio-light”. Short publication of this experiment, entitled “Stimulated Optical Radiation in Ruby”, appeared on August 6, 1960 in Nature [4].

Regrettably directivity of the emission was not reported. Neither maser action nor laser was mentioned in this paper. But later experiments in Hughes Research Laboratory [5] and in Bell Telephone Laboratory [6] confirmed that he did achieve laser action in ruby for the first time.

Output of the ruby laser was usually made of a number of spikes whose intensities and frequencies were quite irregular. The duration of each spike was less than one microsecond and the peak power was no less than 5kW.

4. Continuous Optical Maser Oscillation in Gas

Ali Javan started to build a laser using gas discharge at Bell Telephone Laboratories in 1958. He observed small gain in a gas discharge of a mixture of helium and neon in 1959. Then he constructed a He-Ne laser with a Fabry-Perot resonator inside.

The first He-Ne laser worked well on Dec.12,1960. Optical communication with the gas laser was demonstrated in the following week. Detailed report of this laser entitled “Population Inversion and Continuous Optical Maser Oscillation in a Gas Discharge Containing a He-Ne Mixture” was received on December 30, 1960 [7].

The cw output of the first gas laser at a wavelength of 1.153 micrometer was 15 mW, and the measured linewidth was in the range of 10 to 80 kHz. The angular spread of the beam was less than one minute of arc.

Intrinsic coherence of the laser was demonstrated in 1963 by using two single-mode lasers with frequency stabilization in 1963 [8].

People were excited with these remarkable properties of the ruby laser and the He-Ne laser. Then the research for new materials of solid-state lasers and gas lasers as well as new types of lasers became a boom.

5. Semiconductor and a Variety of Lasers

Robert Hall at the General Electric R & D Center conceived a way to obtain laser emission from a semiconductor p-n junction in 1962. He assembled a team at GE that demonstrated the first GaAs injection lasers within a few months [9]. Almost simultaneously a group at the IBM Watson Research Center reported stimulated emission at a wavelength in near infrared from similar devices [10]. Then another group at MIT Lincoln Laboratory also reported injection lasers of GsAs [11].

Fabrication of semiconductor devices had been well-developed from diode rectifiers of Ge and Si to transisters. At the time Hall was working to make tunnel diodes with heavily doped GaAs following Leo Esaki. Thus he was familiar to the process for making injection diodes.

Diode lasers are useful for many applications because of their small size and high efficiency. However, diode lasers in the 1960s were operated at cryogenic temperatures. Introduction of double heterojunction by I.Hayashi and M.B.Panish in 1970 demonstrated room temperature operation at room temperature [12]. It was the breakthrough which enabled thriving application of lasers.

In the mean time a wide variety of solid-state lasers, gas lasers and other devices on the one hand and X-ray free electron lasers on the other hand are under active investigation.

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