How did the laser come about, and what did it bring to us?

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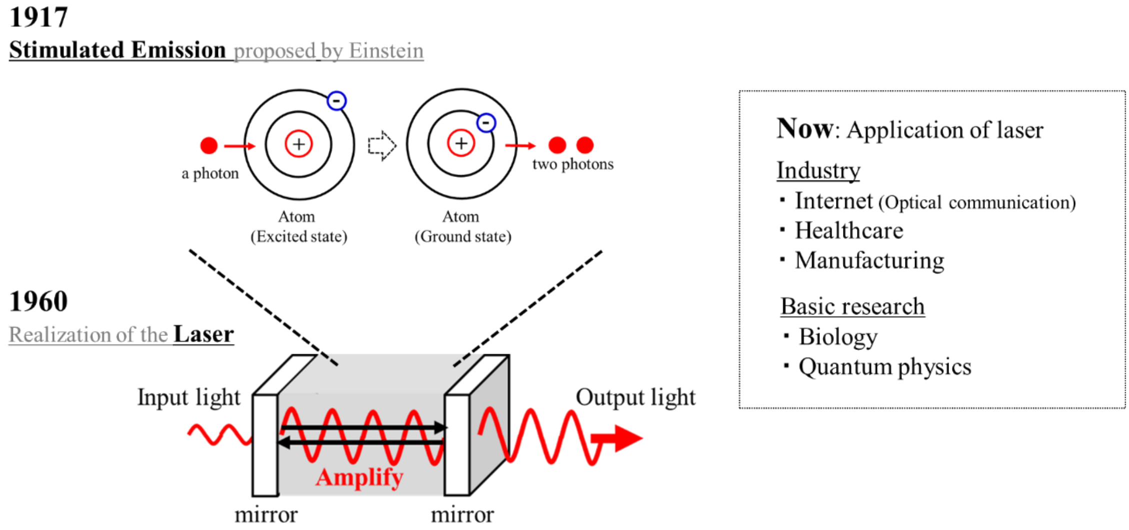

I remember my classmate was scolded by his teacher for playing with a laser pointer when I was in junior high school. Or we know that Ichiro's pitch is often likened to a laser beam. We often hear the word “laser” daily and understand that it means intense light traveling straight ahead. However, when asked to explain the difference between a laser and a flashlight, we are at a loss to answer and are not familiar with the roots of the laser.

In fact, the laser is an acronym for “Light Amplification by Stimulated Emission of Radiation.” However, this acronym sounds too technical. Simply put, it is amplified light with an aligned wavelength and direction of travel. Since the Nobel Prize in Physics was awarded for the discovery of the laser in 1964, this technology has been indispensable to us. The realization of the laser has an exciting history of fundamental research by many physicists. In this essay, I would like to share with you the fascination of basic research through an introduction to the history of the realization and development of the laser.

First, I start to explain what a laser is. Let us consider the situation a light introduces into a pair of mirrors. The light traveling perpendicularly to the mirrors' faces is reflected between the mirrors, creating a standing wave. As you learned in high school physics class, a standing wave has discrete wavelengths. On the other hand, all other directional light is reflected repeatedly and out of the mirrors. Thus, there is only a straight directional light with an aligned wavelength in a pair of mirrors.

Then, how do we amplitude the light? The keyword is "stimulated emission," a phenomenon proposed by Einstein in 1917. As reminding the atom physics class in high school, an atom has discrete energy levels. The situation of the minimal energy level is called the ground state, and the others are the excited states. When an atom in an excited state interacts with a single photon, two photons can be emitted with relaxation from the excited state to the ground state. In other words, two photons emission with a photon reception. This process is called stimulated emission. Therefore, when we introduce the light into a pair of mirrors covered with the appropriate atoms, we can cause the chain reaction of the stimulated emission and get amplified light with an aligned wavelength and direction of travel, that is, laser.

The idea of the laser was first devised in 1952[1] when the theory of quantum mechanics had evolved, and the understanding of stimulated emission had advanced. However, getting the laser sustainably was impossible because we could not cause the stimulated emission semi-permanently due to the finite number of the atoms' excited states. To solve this problem, an innovative method "optical pumping" was devised in

1957.[2] In this method, the number of excited states is kept high by promoting the transition from the ground state to the excited state, which allows us to extract photons sustainably. The first laser was realized in 1960,[3] 43 years after the discovery of stimulated emission. This realization results from much basic research, including the development of quantum theory and the emergence of new technologies such as optical pumping.

The impact of lasers on the industry is enormous. For example, optical communication is one of the most significant innovations by the laser. Laser light, with its uniform wavelength and direction, has low attenuation over long distances and is used as a communication medium through undersea cables connecting countries. Without lasers, today's Internet may not exist. The other examples of the application are laser processing and laser therapy, which utilize the laser's ability to localize intense light in a tiny area. In these applications, we can damage only a local spot in an arbitrary material such as metal, crystal, cornea, or cancer.

On the other hand, do you know that the laser continues to make tremendous contributions to basic research in biology, chemistry, and physics? This essay will finally introduce the relationship between basic research and the laser.

Microscopy has a dramatic advance owing to the establishment of laser light sources. For example, the realization of confocal laser microscopy has strongly promoted progress in biological research. Confocal laser microscopy is a technique that can visualize transparent targets in three dimensions and produce high-contrast images. It is still widely used today as a visualization technique for living cells. Another known example of revolutionizing biophysics is the optical tweezers, which won the 2018

Nobel Prize in Physics. A strong electric field gradient generated near the focus of the laser beam allows us to manipulate the position of a single cell or atom at will. While microscopy technology allows us to "see" cells, optical tweezers let us "touch" cells.

Alternatively, the optical tweezer is also used in the cold atom system, one of the methods of quantum computers. Research using optical tweezers to arrange 256 atoms and perform quantum simulations precisely is truly at the cutting edge of quantum technology.[4] Quantum simulation is achieved by skillfully manipulating the transitions between the ground and excited states of the cold atoms, and the laser is also used for these transitions. Since the laser has a single wavelength, it can induce only the desired transition.

Today, Einstein's stimulated emission theory in 1917 has been transformed into the laser technique, which has never ceased to be essential to human life and development. We can never know precisely what fundamental research will make an irreplaceable technology in the next 100 years. However, the invention and development of the laser have taught us about the universal significance of basic research as well as the fascinating nature of that.

References

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Assistive Technologies

I made my original draft in Japanese and translated it with DeepL and Grammarly.