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THE HISTORY OF LASER DEVELOPMENT. GAS LASERS

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Annotatsiya: This article explores the historical development of laser technology, with a particular focus on gas lasers. It traces the evolution from early theoretical foundations in quantum electronics to the realization of the first operational lasers. Special attention is given to gas lasers, such as helium-neon and carbon dioxide lasers, which played a crucial role in advancing laser applications due to their high monochromaticity and beam quality. The paper also highlights the contributions of pioneering scientists, key milestones, and the wide-ranging uses of gas lasers in industry, medicine, and scientific research. The significance of gas lasers in shaping modern photonics and optical technologies is emphasized throughout the discussion.

Keywords: Laser development, gas lasers, helium-neon laser, carbon dioxide laser, quantum electronics, monochromaticity, laser history, photonics, optical technology, scientific applications, industrial lasers. Laser Physics and Its Interconnection with Other Branches of Physics. The science of laser physics is closely interconnected with other branches of physics, as the history of laser development is the result of progress in optics, thermodynamics, and radiophysics. As we know, lasers are based on three fundamental ideas:

1. The concept of stimulated emission, proposed by Einstein, which is related to optics.

2. The concept of a non-thermodynamic equilibrium state, introduced by Fabrikant, which is connected to thermodynamics.

3. The concept of a system with positive feedback, which belongs to radiophysics. Studying laser physics in depth is very beneficial for our society because, nowadays, lasers are widely used in all areas of production — in both light and heavy industries, in geology, and essentially in every field. This can be clearly seen in the topic of laser technology. Radiation from light sources operating in the optical part of the spectrum is generally incoherent. For instance, the total radiation of such a source is composed of emission from its microscopic elements like atoms, molecules, ions, or free electrons, and these emissions are not mutually coherent. Examples of incoherent radiation include the glow of gas discharges, thermal radiation from artificial and natural sources, and luminescence stimulated by various methods.

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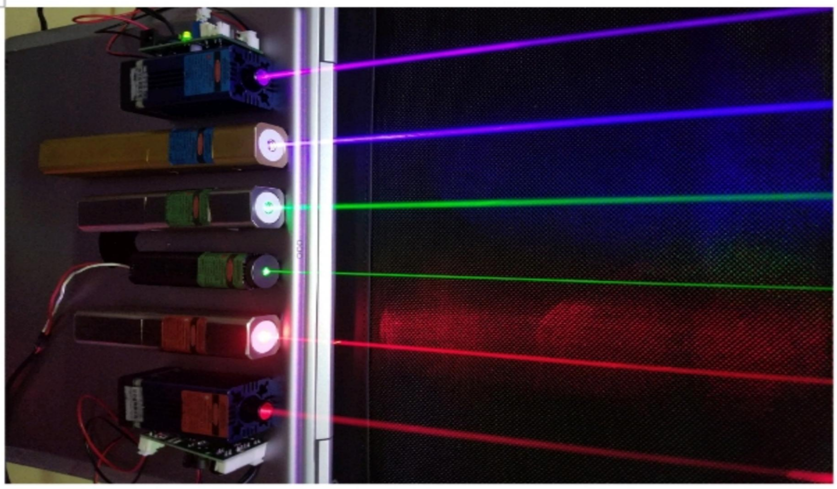

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The Active Element and Operation Principles of Lasers. The ions included in the active element are called “active centers”, and laser light is generated as a result of these centers (ions) emitting radiation parallel to the optical axis of the laser. In semiconductor lasers, the role of active centers is played by electron-hole pairs. The pumping system is used to excite the active centers. The method of excitation can vary depending on the type of active medium. In gas lasers, an electric current is passed through a gas (or gas mixture), forming a gas plasma, and the active centers are excited through collisions between particles. In solid-state lasers, where the active element is a solid material, the element is illuminated using a high-power light-emitting lamp (such as a flash lamp). In semiconductor lasers, current is passed through a p-n junction, resulting in injection of electron-hole pairs. Sometimes, chemical reactions or electron beams are used to excite the active element.The optical resonator can consist of two flat mirrors, one flat and one spherical mirror, or two spherical mirrors. Typically, one of the mirrors has a reflectivity of 100%, while the other is partially transmitting. In lasers with a high gain coefficient, the second mirror may simply be a transparent flat-parallel glass plate. There are many types of lasers, and they are used for various purposes. Most commonly, lasers are used in industry. Lasers can also emit different colors of light, depending on their construction and materials. Laser Technology and Its Applications.Laser technology processes can be conditionally divided into two main types. In the first type, the highly precise focusing of laser beams and the ability to accurately dose energy in both pulsed and continuous modes are utilized. In such technological processes, lasers with moderate average power are used, such as pulsed-periodic gas lasers and neodymium-doped yttrium aluminum garnet (Nd:YAG) crystal lasers. Using these lasers, technologies have been developed for: Drilling tiny holes (with diameters of 1–10 microns and depths of up to 10–100 microns) in rubies and diamonds for the watchmaking industry. Producing dies for drawing fine wires. The main field of application for low-power pulsed lasers is in microelectronics and the electrovacuum industry, where they are used for cutting and welding miniature components, and engraving marks on small parts. In the printing industry, lasers are used to automatically burn numbers, letters, and images onto various materials. As previously mentioned, the optical resonator of a laser ensures the collimation (directionality) of the emitted radiation. When using ruby rods, even though it is difficult to reach the diffraction limit for the beam divergence angle of the emitted light cone, the laser beam remains narrowly focused, typically within a few arc minutes. Solid-State Lasers.Examples of solid-state lasers include ruby, yttrium aluminum garnet (YAG), and glass lasers. The active ions are introduced into the crystalline or amorphous lattice structures as dopants. The active media in solid-state lasers typically have three or four energy levels. Solid-state lasers are convenient and easy to use, and they are capable of producing very high power. The overall development of laser technology originally began with solid-state lasers. In solid-state lasers, if electroactive dopant atoms are present, their ions undergo population inversion at certain energy levels via optical (light) excitation. For these lasers to operate efficiently, their active elements must meet several criteria:

Have a high gain coefficient;

Be optically homogeneous;

Be mechanically strong and thermally resistant;

Be technologically processable;

Allow the fabrication of large-sized active components;

Have high thermal conductivity.

Since the number of active materials meeting these requirements is limited, the types of solid-state lasers are also limited. In practice, rubies, glass, and yttrium aluminum garnet (YAG) are the most commonly used materials. Neodymium-doped glass lasers operate using four energy levels. One advantage of glass-matrix-based lasers is the ability to manufacture large active elements — up to 5–10 cm in diameter and up to 2 meters in length. This allows the generation of high-energy radiation pulses. These lasers surpass others, such as ruby lasers, due to their wide energy range and lower cost. If the gain of a wave traveling along the laser path exceeds the total energy losses from reflection and transmission at the mirrors, the amplitude of the wave increases with each pass. The wave continues to grow in intensity until the gain is reduced by the saturation effect, at which point the energy density reaches a steady state. This stationary condition corresponds to the point where the gain exactly compensates for all losses in the medium. Thus, in laser radiation generation, the saturation effect plays a fundamental role. One of the most important characteristics of a laser is the spectral width of the emitted radiation, i.e., monochromaticity. Gas lasers possess extremely high monochromaticity—around 10^{-10}—which is significantly higher than that of gas discharge lamps previously used as frequency standards. Solid-state lasers and especially semiconductor lasers, on the other hand, have a noticeable frequency range in their radiation, meaning they are not highly monochromatic. A very important feature of lasers is efficiency. In solid-state lasers, efficiency ranges from 1 to 3.5%, in gas lasers from 1 to 15%, and in semiconductor lasers from 40 to 60%. Despite this, every effort is made to improve laser efficiency, because low efficiency can require cooling the laser to temperatures as low as 4–77 K, which significantly complicates equipment design. Today, the laser is one of the most powerful tools in science. It is impossible to list all fields of application, as new tasks for lasers are discovered every day. In this work, we have reviewed the main types of lasers and their operating principles. The main areas of application have also been covered, including: industry, medicine, information technology, and science. Thanks to their unique properties, lasers can perform a wide variety of tasks. Coherence, monochromaticity, and high energy density allow for the execution of complex technological operations. The laser is a tool of the future that has already firmly entered our daily lives. In the process of developing advanced state-of-the-art lasers, it is effective to search for new active media that are tunable to new and useful wavelengths, to improve conversion efficiency, increase output power, improve beam quality, adjust pulse duration, enhance reliability, and extend operational lifetime.

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