LASER SCIENCE

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Laser science is a branch of optics that describes the theory and practice of lasers.

Laser science is principally concerned with quantum electronics, laser construction, optical cavity design, the physics of producing a population inversion in laser media, and the temporal evolution of the light field in the laser. It is also concerned with the physics of laser beam propagation, particularly the physics of Gaussian beams, with laser applications, and with associated fields such as nonlinear optics and quantum optics.

History

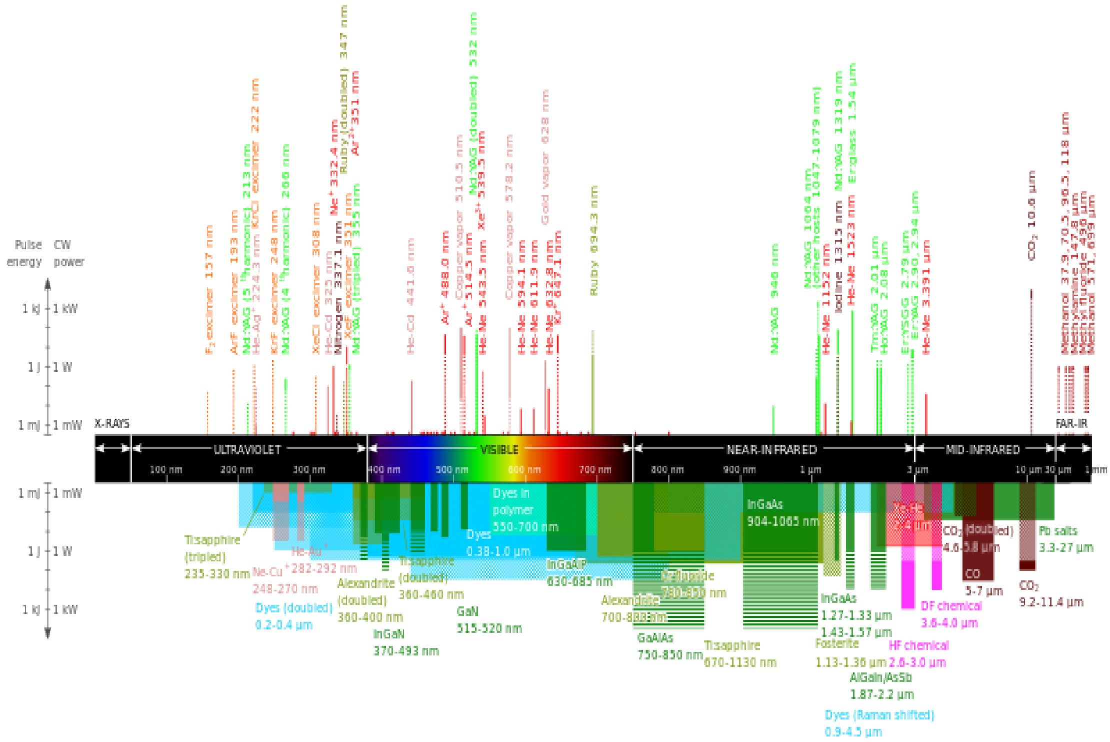
Laser science predates the invention of the laser itself. Albert Einstein created the foundations for the laser and maser in 1917, via a paper in which he re-derived Max Planck's law of radiation using a formalism based on probability coefficients (Einstein coefficients) for the absorption, spontaneous emission, and stimulated emission of electromagnetic radiation. The existence of stimulated emission was confirmed in 1928 by Rudolf W. Ladenburg. In 1939, Valentin A. Fabrikant predicted the use of stimulated emission to amplify "short" waves; In 1947, Willis E. Lamb and R. C. Retherford found apparent stimulated emission in hydrogen spectra and effected the first demonstration of stimulated emission;[2] in 1950, Alfred Kastler (Nobel Prize for Physics 1966) proposed the method of optical pumping, experimentally confirmed, two years later, by Brossel, Kastler, and Winter.

The theoretical principles describing the operation of a microwave laser (a maser) were first described by Nikolay Basov and Alexander Prokhorov at the All-Union Conference on Radio Spectroscopy in May 1952. The first maser was built by Charles H. Townes, James P. Gordon, and H. J. Zeiger in 1953. Townes, Basov and Prokhorov were awarded the Nobel Prize in Physics in 1964 for their research in the field of stimulated emission,.

The first working laser (a pulsed ruby laser) was demonstrated on May 16, 1960, by Theodore Maiman at the Hughes Research Laboratories.

Laser types

This is a list of laser types, their operational wavelengths, and their applications. Thousands of kinds of laser are known, but most of them are used only for specialised research.



Gas lasers

Following the invention of the HeNe gas laser, many other gas discharges have been found to amplify light coherently. Gas lasers using many different gases have been built and used for many purposes. The helium-neon laser (HeNe) is able to operate at a number of different wavelengths, however the vast majority are engineered to lase at 633 nm; these relatively low cost but highly coherent lasers are extremely common in optical research and educational laboratories. Commercial carbon dioxide (CO2) lasers can emit many hundreds of watts in a single spatial mode which can be concentrated into a tiny spot. This emission is in the thermal infrared at 10.6 µm; such lasers are regularly used in industry for cutting and welding.

Solid-state lasers

Solid-state lasers use a crystalline or glass rod which is "doped" with ions that provide the required energy states. For example, the first working laser was a ruby laser, made from ruby (chromium-doped corundum). The population inversion is actually maintained in the "dopant", such as chromium or neodymium. These materials are pumped optically using a shorter wavelength than the lasing wavelength, often from a flashtube or from another laser.

Neodymium is a common "dopant" in various solid-state laser crystals, including yttrium orthovanadate (Nd:YVO4), yttrium lithium fluoride (Nd:YLF) and yttrium aluminium garnet (Nd:YAG). All these lasers can produce high powers in the infrared spectrum at 1064 nm. They are used for cutting, welding and marking of metals and other materials, and also in spectroscopy and for pumping dye lasers.

These lasers are also commonly frequency doubled, tripled or quadrupled, in so-called "diode pumped solid state" or DPSS lasers. Under second, third, or fourth harmonic generation these produce 532 nm (green, visible), 355 nm and 266 nm

(UV) beams. This is the technology behind the bright laser pointers particularly at green (532 nm) and other short visible wavelengths.

Thermal limitations in solid-state lasers arise from unconverted pump power that manifests itself as heat. This heat, when coupled with a high thermo-optic coefficient (dn/dT) can give rise to thermal lensing as well as reduced quantum efficiency. These types of issues can be overcome by another novel diode-pumped solid-state laser, the diode-pumped thin disk laser. The thermal limitations in this laser type are mitigated by using a laser medium geometry in which the thickness is much smaller than the diameter of the pump beam. This allows for a more even thermal gradient in the material. Thin disk lasers have been shown to produce up to kilowatt levels of power.

Fiber lasers

Solid-state lasers or laser amplifiers where the light is guided due to the total internal reflection in a single mode optical fiber are instead called fiber lasers. Guiding of light allows extremely long gain regions providing good cooling conditions; fibers have high surface area to volume ratio which allows efficient cooling. In addition, the fiber's waveguiding properties tend to reduce thermal distortion of the beam. Erbium and ytterbium ions are common active species in such lasers.

Quite often, the fiber laser is designed as a double-clad fiber. This type of fiber consists of a fiber core, an inner cladding and an outer cladding. The index of the three concentric layers is chosen so that the fiber core acts as a single-mode fiber for the laser emission while the outer cladding acts as a highly multimode core for the pump laser. This lets the pump propagate a large amount of power into and through the active inner core region, while still having a high numerical aperture (NA) to have easy launching conditions.

Pump light can be used more efficiently by creating a fiber disk laser, or a stack of such lasers.

Fiber lasers have a fundamental limit in that the intensity of the light in the fiber cannot be so high that optical nonlinearities induced by the local electric field strength can become dominant and prevent laser operation and/or lead to the material destruction of the fiber. This effect is called photodarkening. In bulk laser materials, the cooling is not so efficient, and it is difficult to separate the effects of photodarkening from the thermal effects, but the experiments in fibers show that the photodarkening can be attributed to the formation of long-living color centers.

Besides, there are still Chemical lasers, Excimer lasers, Photonic crystal lasers, Semiconductor lasers, Dye lasers, Free-electron lasers, Exotic media and so on.

Uses

Lasers range in size from microscopic diode lasers (top) with numerous applications, to football field sized neodymium glass lasers (bottom) used for inertial confinement fusion, nuclear weaponsresearch and other high energy density physics experiments.

When lasers were invented in 1960, they were called "a solution looking for a problem". Since then, they have become ubiquitous, finding utility in thousands of highly varied applications in every section of modern society, including consumer electronics, information technology, science, medicine, industry, law enforcement, entertainment, and the military.

The first use of lasers in the daily lives of the general population was the supermarket barcode scanner, introduced in 1974. Thelaserdisc player, introduced in 1978, was the first successful consumer product to include a laser but the compact disc player was the first laser-equipped device to become common, beginning in 1982 followed shortly by laser printers.

Some other uses are:

– Medicine: Bloodless surgery, laser healing, surgical treatment, kidney stone treatment, eye treatment, dentistry
– Industry: Cutting, welding, material heat treatment, marking parts, non-contact measurement of parts
– Military: Marking targets, guiding munitions, missile defence, electro-optical countermeasures (EOCM), alternative to radar, blinding troops.
– Law enforcement: used for latent fingerprint detection in the forensic identification field
– Research: Spectroscopy, laser ablation, laser annealing, laser scattering, laser interferometry, LIDAR, laser capture microdissection, fluorescence microscopy
– Product development/commercial: laser printers, optical discs (e.g. CDs and the like), barcode scanners, thermometers, laser pointers, holograms, bubblegrams.
– Laser lighting displays: Laser light shows
– Cosmetic skin treatments: acne treatment, cellulite and striae reduction, and hair removal.

In 2004, excluding diode lasers, approximately 131,000 lasers were sold with a value of US$2.19 billion. In the same year, approximately 733 million diode lasers, valued at $3.20 billion, were sold.

References

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