V61

He-Ne Laser

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Contents

1 Objective

To understand the characteristics of a He-Ne laser, several different configurations are adjusted and their radiation properties measured. This includes the wavelength, intensity distribution, polarization, mode spectrum, as well as the influence of mirror type and resonator length.

2 Background [1]

Lasers are ubiquitous tools of modern physics due to their useful properties, characterized by the emission of coherent light with narrow spectral linewidth, low divergence and high power density. They are named after the acronym for light amplification by stimulated emission of radiation, describing the fundamental mechanism for the production of laser radiation. This will be explored in the following, both in the general as well as the special case of the He-Ne laser.

2.1 Components of a laser

The basic setup of a typical laser consists of three main components, namely an active medium, a pumping mechanism and the resonator cavity.

Inside the active medium, realized using materials such as semiconductors or gas mixtures, photons are emitted from atomic transitions to energetically lower states. The energy difference $\varDelta E$ between the involved electron levels is therefore the main determinant of wavelength λ and frequency f via $\varDelta E = hf$.

To excite electrons in the active medium to higher levels, an energy source is required. This is the role of the pumping mechanism, which can be implemented using electrons or photons. The latter case is called optical pumping, as another separate light source tuned to the respective $\varDelta E$ value is used to induce transitions to excited states.

Amplification of the emitted radiation is achieved in the active medium. Instead of using superradiant lasers, which have high gain factors and divergence, or impractically long constructions, mirrors can be used to create a resonator cavity. The resulting standing waves correspond to multiple passes through the material and can generate a stable beam with low divergence, which can exit through a semitransparent window. The mirror geometry can be adapted to the desired function with flat or concave designs.

2.2 Processes in the active medium

There are three main processes shown in Figure 2 occuring inside the active medium to facilitate the operation of a laser.

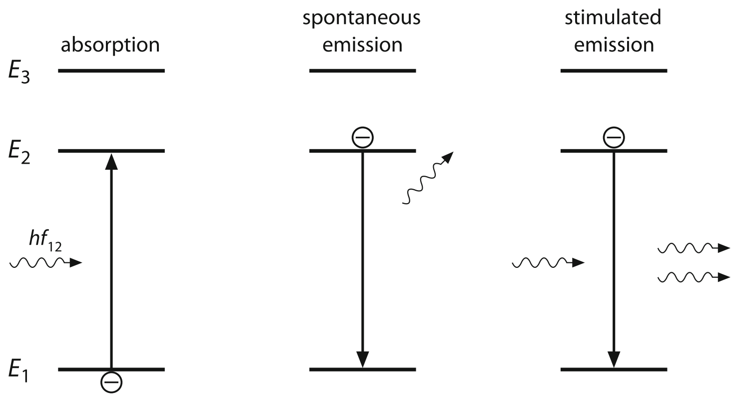

Figure 1: Schematic depiction of relevant processes inside the active medium. [1]

Raising the energy of an electron by $\Delta E = E_2 - E_1$ requires the annihilation of an incident photon that fulfills the condition

$$\Delta E = hf_{12} \, ,$$

where h is the Planck constant. This process is referred to as absorption. The number of transitions per time and volume is proportional to the density of ground state electrons N_1 as well as the photon flux or number per area and time φ via

$$\left.\frac{dN_1}{dt}\right|_{\mathrm{ab}} = -\sigma_{12} N_1 \varphi \, ,$$

with σ_{12} denoting the effective cross section for absorbing a photon. From this also follows the typical exponential intensity reduction

$$\left.\frac{dI}{dx}\right|_{\mathrm{ab}} = -\sigma_{12} N_1 I \, ,$$

where $\alpha = -\sigma_{12} N_1$ gives the absorption coefficient.

When an atom is in an excited state, it returns to the ground state after a time interval, the duration of which follows some random distribution with mean lifetime τ. Due to its stochastic nature, this process is called spontaneous emission. The density in the higher level then follows

$$\left.\frac{dN_2}{dt}\right|_{\mathrm{sp}} = -\tau^{-1} N_2 \, .$$

Besides this, emission can also be initiated by an incoming photon of appropriate frequency. This is calles stimulated emission and results in the production of radiation with the same energy, direction and phase as the inducing quantum. As the inverse process to absorption,

$$\left.\frac{dN_2}{dt}\right|_{\mathrm{st}} = -\sigma_{21} N_2 \varphi \, ,$$

describes the time derivative and

$$\left.\frac{dI}{dx}\right|_{\mathrm{st}} = \sigma_{21} N_2 I \, ,$$

the corresponding intensity relation.

2.3 Necessity of multiple level systems

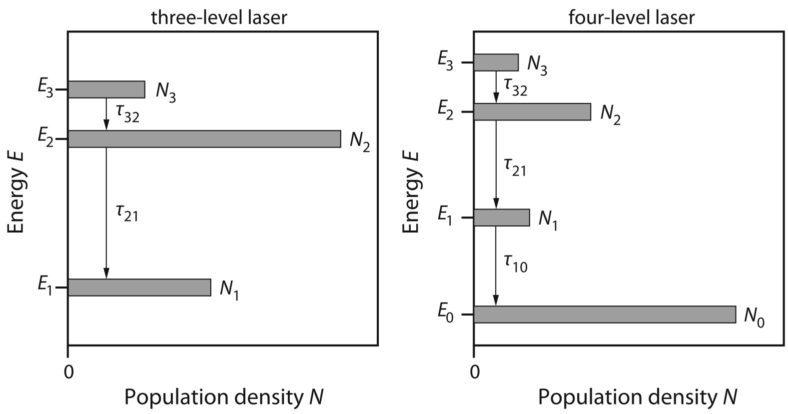

Figure 2: Exemplary energies and population densities for multiple levels. [1]

2.4 Stability for different resonators

2.5 Transverse and longitudinal modes

2.6 Doppler broadening of the transition

2.7 Brewster windows and polarization

3 Procedure

4 Procedure

4.1 Aligning the Laser

The alignment of the He-Ne laser is initiated by positioning an auxiliary alignment laser (wavelength: 532 nm, maximum power: 1 mW, reduced power: 0.2 mW) on the optical bench. A target screen with a cross mark is placed at the end of the optical rail. The alignment laser should be adjusted such that its beam passes through the center of the cross on the target screen. This ensures that the alignment laser coincides with the optical axis of the He-Ne laser.

Next, the He-Ne laser components are positioned in the following order: the laser tube (length: 408 mm, diameter: 1.1 mm), resonator mirrors (diameter: 12.7 mm), and Brewster windows. These components together form the laser resonator, with the Brewster windows ensuring minimal loss while defining the polarization direction. The alignment of these components is critical: the alignment laser's back reflections should be made to hit the target screen's cross at the center, indicating proper alignment along the optical axis.

4.2 Verifying the Stability Condition

Once the laser has been aligned, the stability condition must be verified. The laser is adjusted to its maximum power using a photodiode, and the maximum resonator length is set by gradually increasing the gap between the two resonator mirrors. Throughout the process, the laser power is continuously readjusted. With a well-aligned setup, the system should approach the theoretical value from the stability condition. This step is repeated for different resonator lengths to study the effect on the laser's stability.

4.3 Observing Transverse Modes

To observe transverse electromagnetic (TEM) modes, a thin tungsten wire (diameter: 0.005 mm) is placed between the resonator mirror and the laser tube. This wire stabilizes different modes, which can be observed on an optical screen. A scattering lens may be used to enlarge the laser beam, making it easier to identify the modes. The wire functions to stabilize the laser beam, enabling clearer mode identification. The optical screen is then replaced with a photodiode to measure the intensity distribution for at least two modes. The measured intensity distributions are plotted and compared with theoretical expectations to validate the mode stability.

4.4 Determining the Polarization

The laser's polarization is determined by placing a polarizer behind the outcoupling mirror. The intensity of the laser beam is measured with a photodiode as the polarizer is rotated. The Brewster windows, which minimize reflection losses, ensure a well-defined polarization direction. By comparing the experimental intensity distribution with theoretical calculations, the polarization characteristics of the laser are evaluated, and the influence of the Brewster windows and resonator mirrors on the polarization is examined.

4.5 Analyzing Spectra in Multimode Operation

In the absence of a Fabry-Perot etalon, the laser operates in multimode, meaning several longitudinal modes coexist. This leads to temporal intensity variations due to the beating between modes. To analyze these beat frequencies, a fast photodiode with a bandwidth up to 1 GHz is used, and the Fourier spectra are recorded for various resonator lengths with a spectrum analyzer. The spread of the neon transition is compared with the distance between the longitudinal modes, and the multimode operation is justified. Additionally, the dependence of the beat frequency on the resonator length is investigated.

4.6 Measuring the Wavelength

The wavelength of the He-Ne laser is determined by using diffraction patterns produced by a slit and diffraction grating. The diffraction maxima and minima are measured to accurately determine the wavelength. This method provides a precise measurement of the laser's wavelength and can be used to verify the laser's output characteristics.

5 Results

6 Discussion

References

[1] Hans Joachim Eichler, Jürgen Eichler, and Oliver Lux. *Lasers. Basics, Advances and Applications*. Springer Cham, 2018. ISBN: 978-3-319-99895-4. DOI: `https://doi.org/10.1007/978-3-319-99895-4`.

Appendix