Excitation of Different Transverse Modes

Experiment Objective

- Exciting and observing different transverse laser TEM_{nm} modes

Principles

Different modes may arise in the optical resonator of a laser, i.e. modes of oscillation separated from each other (natural modes).

Different resonator lengths create different longitudinal (axial) modes. If a whole number of oscillations fits in the resonator, a stationary wave is produced. The possible modes' wavelengths differ based on pm-range-magnitudes. Only the line width of the atomic transition determines on which of the many possible resonator modes the laser is able to emit effective light.

In addition to the longitudinal modes, transverse modes can develop in a variety of manners in the laser beam cross-section. A highly symmetrical laser emits a beam with a circular (Gaussian) intensity profile. If symmetry is distorted, complex intensity distributions are developed with ranges of anti-phase oscillations and are separated by dark zones. These transverse modes (TEM = Transverse Electromagnetic Mode) appear in the resonator but can be observed over the whole length of the beam.

The mode designation TEM_{nm} refers to the horizontal and vertical structure of the beam profile. Indices n and m indicate the number of dark bands.

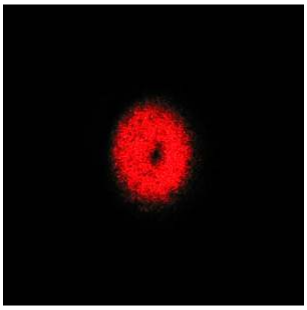
In the beam profile's intensity distribution, a point (x,y), which is vertical in relation to the direction of propagation of the laser beam with Gaussian radius *r*, can be determined by the following equation:

$$I_{nm}(x,y) = I_0 \left[H_n\left(\frac{\sqrt{2}x}{r}\right) e^{-\frac{x^2}{r^2}} \right]^2 \left[H_m\left(\frac{\sqrt{2}y}{r}\right) e^{-\frac{y^2}{r^2}} \right]^2$$

In the equation above, $H_n(x)$ is the n-th degree Hermit polynomial:

$$H_n(x) = (-1)^n e^{x^2} \frac{d^n}{dx^n} e^{-x^2}$$

Symmetry distortion and thus transverse modes often occur even when both resonator mirrors are not oriented precisely. In addition, the so-called "Doughnut mode" TEM_{01^*} is often observed in the present arrangement. It is formed by overlapping and rotation of different higher modes:



TEM_{01^*}

According to the symmetry distortion in the resonator, radially symmetric structures or structures in two orthogonal directions are produced (orthogonal symmetry). Even with the Brewster window, ideal cylindrical rotation symmetry is distorted.

In experiment P5.8.1.6, different transverse modes of the laser resonator are excited. In order to do that, the fundamental mode, $TEM_{00,}$ is arranged first and losses of this mode are intentionally increased by introducing a thin absorber (e.g. a hair). Higher transverse modes, whose intensity distribution shows a minimum at the absorber point, can now be excited and their intensity distribution can be observed.

Kem-0810

Apparatus

1 Basic Set "He-Ne Laser" 471 810
1 Optical bench, 2 m, standard cross section 460 33
1 Holder for laser mirror 471 020
1 Laser mirror, HR, R = -1,000 mm....................... 470 103
1 Sliding rider 90/50 .... 460 383
1 Holder with spring clips 460 22
1 Lens in holder, f = 50 mm................................... 460 02
1 Screen.. 441 531

Additionally recommended:
Adjustment goggles for He-Ne laser 471 828

Safety Notes

Important: Make sure you follow the instructions provided with the equipment!

The installed He-Ne laser complies with the Class 3B regulations according to DIN 60825-1 "Safety of Laser Products". Lasers belonging to Class 3B are potentially dangerous if a direct or mirror-reflected beam reaches the unprotected eye (directly looking at the beam).

- Do not look at the direct or reflected laser beam!
- Avoid unintentional mirror-reflections (e.g. through watches, jewellery, tools with metallic surfaces)!
- Block all laser beams by placing an absorbing or diffuse scattering material at the end of the purpose-related beam path.
- Wear laser adjustment goggles (471 828) if necessary.

Laser tubes require voltages >12 kV to ignite the gas discharge and contact-hazardous voltages of up to 2.5 kV for operation.

- The connection to the supply device should only be established through the high voltage plugs.
- Wiring and changes in the experiment setup should only be carried out when the supply device is switched off.
- The supply device should only be switched on when the circuit is completed.

Preliminary remarks

The experiment only really succeeds when the setup is thoroughly adjusted and all optical surfaces are free of impurities. Cleaning a precision optics system always represents a risk for the surface. In order to reduce the need to clean the optics as much as possible, they should be preserved in their original packing or they should be covered with a protective cover and placed in their support when they are not in use.

During the experiment, make sure to avoid the damaging any mirror surfaces (including the rear side of the output mirror) and the Brewster window of the laser tube. Do not touch them with your bare hands. Immediately remove fingerprints, oil or water stains, because the skin acids attack the coating on the glass and permanent stains can be left behind.

If cleaning is necessary, it is advisable to use one of the methods recommended in the instruction sheets.

Setup

Setup and calibration of the He-Ne laser are described in experiment P5.8.1.1. L = 60 cm is used as the mirror spacing. Figure 1 shows the setup for the present experiment. The left edge position of the optics riders is given, in cm, for each element respectively.

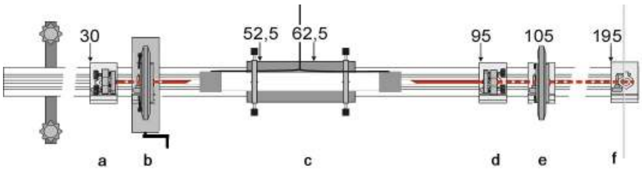


Fig. 1: Experiment setup

a Highly reflecting mirror HR, R = -1000 mm
b Holder with a cross hair, for example, in sliding rider
c Laser tube in laser support
d Output mirror OC, R = -1000 mm
e Lens in holder, f = 50 mm
f Screen

Method

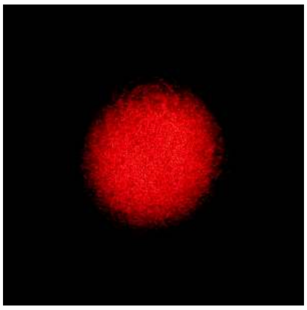
Important: Once the laser process has started, optimise the output power by observing the brightness and form of the laser beam on the screen. To do this, carefully turn the fine adjustment screw on the mirror. Ideally, TEM_{00}, the fundamental mode, appears.

- Slowly move the vertically-attached hair in the laser beam inside the resonator by turning the driving mechanism of the sliding rider. While doing so, observe the laser beam on the screen. When the hair is in the middle of the resonator, the TEM_{10} mode is formed; if an off-centre position is reached, it is possible to form other modes such as TEM_{20}.
- Vertically move the holder with the attached cross hair so as to position the horizontal hair in the laser beam.
- Slowly move the attached cross hair in the laser beam inside the resonator by turning the driving mechanism of the sliding rider. (Since the hair is not absolutely horizontally aligned, the relevant modes are also formed.)

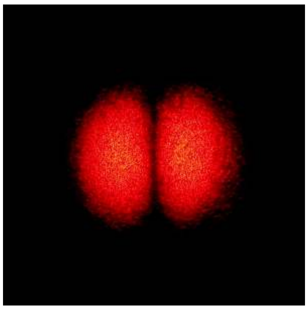
While moving the attached hairs, the laser process stops in between the formations of the different modes. Particularly, the height adjustment should be very precise to be able to achieve the TEM_{11} mode with the cross.

Hint: As soon as a mode is achieved, other higher modes can be reached, if necessary, by carefully shifting the mirror. In addition, tiny impurities on the glass surfaces lead to disturbances inside the resonator and give rise to other modes.

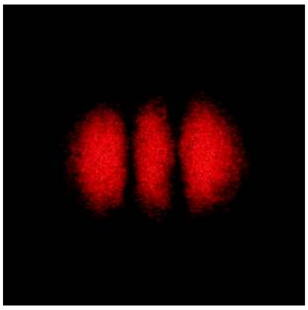
Observation example



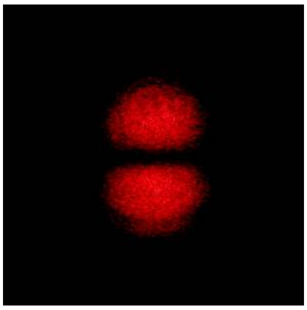
TEM_{00}



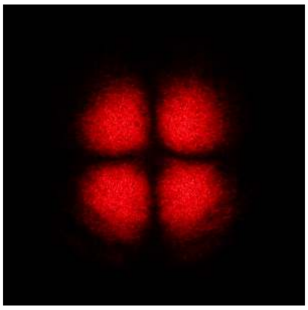
TEM_{10}



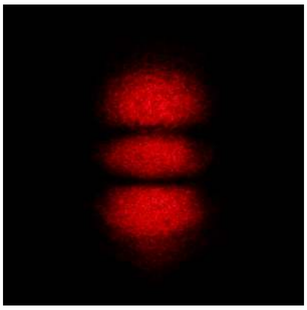
TEM_{20}



TEM_{01}



TEM_{11}



TEM_{02}

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