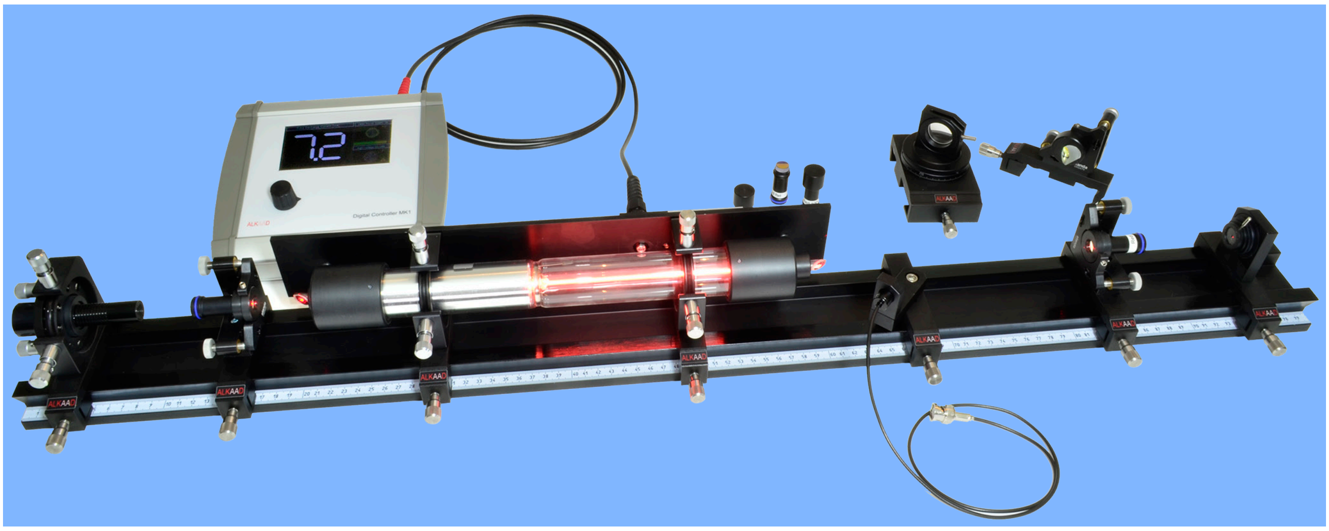
LE-0300 Helium Neon Laser



Keywords

HeNe Energy Level Diagram
Optical Stability Criteria
Gaussian Beams
Birefringent Filter
Free Spectral Range
ABCD Law & Resonator
Cavity Alignment
Line & Mode Selection
Single Mode Etalon
Lamb Dip
Optical Gain
Output Power, Discharge Current
Crystal Optics
Spectrum Analyser
Longitudinal and Transverse Modes

Introduction

The humble Helium Neon (HeNe) laser still has many applications, due to its superior beam quality and coherence. In all physics text books this laser represents the class of the gas laser and was the first gas laser invented by Ali Javan in 1960 right after Theodore Maiman demonstrated the first operation of the ruby laser. Since the HeNe laser was continuously operating and easy to build in a laboratory, it served as specimen for a lot of scientific work and proof for theoretical predictions. It starts with the theory of optical resonator, Doppler broadened laser active material in a cavity, spectral hole burning (Lamb dip), single mode operation, coherence and intra-cavity absorption (inverse Lamb dip) just to name a few. For technical applications the HeNe laser is still in use due to its outstanding beam quality and coherence as secondary meter standard and is present in each air plane or ship as laser gyroscope for navigation. This experiment is designed as an open frame setup in such a way that all components can be arranged freely on a stable optical rail. A Helium Neon tube with Brewster windows on both ends is used to perform a variety of fundamental experiments. Verification of mode selection properties, the optical stability range and the ABCD matrix formalism of the cavity used are discussed. A birefringent filter as well as a Littrow prism is used for the wavelength selection and the effect of an etalon used inside the cavity are investigated. A photo detector for measuring the relative output power and an alignment laser are supplied with a 1 metre long optical rail, along with all necessary mounts and adjusters.
For the visualisation of the mode structure a „Fabry Perot“ extension is available or an electronic spectrum analyser is used to measure the modes beat frequency. The optical resonator is formed by two precision adjustment holders for common 1/2 “ exchangeable mirrors having different radii of curvature. For ease of adjustment, at the beginning a “green” pilot laser is attached as an alignment aid. The laser tube is mounted into XY-adjustments to align the tube with respect to the pilot laser.

How it works

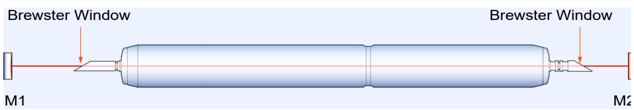


Fig. 2.12: Open frame Helium Neon laser

A glass tube terminated on both sides with Brewster windows contains an optimised mixture of Helium and Neon gas. The mirror M1 and M2 form the optical cavity or resonator. The Brewster windows prevent reflection losses and force the laser to oscillate in linear polarisation. The cavity can be setup as hemispherical, spherical and concentric.

Fig. 2.13: Adjustable etalon for single mode operation

The gain profile of gas laser are Doppler broadened resulting in general in multimode oscillation. An uncoated cylindric glass body with precisely parallel ground surfaces forms a Fabry Perot etalon. Its length is chosen in such a way, that the superimposition of the laser modes and the etalon modes allows only one mode to oscillate

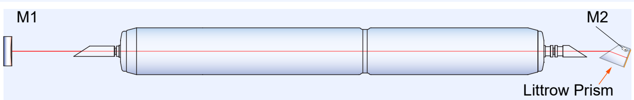


Fig. 2.14: Line selection with a Littrow prism

A Littrow prism is a combination of a prism and a mirror and is shaped such that the laser beam enters the prism under the Brewster angle and hits the mirror (M2) at the rear side exactly under 90°. This is fulfilled for one wavelength only. For another one, the prism needs to be tilted accordingly.

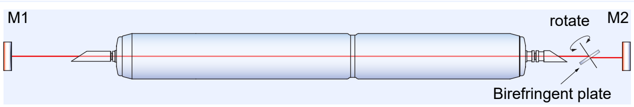
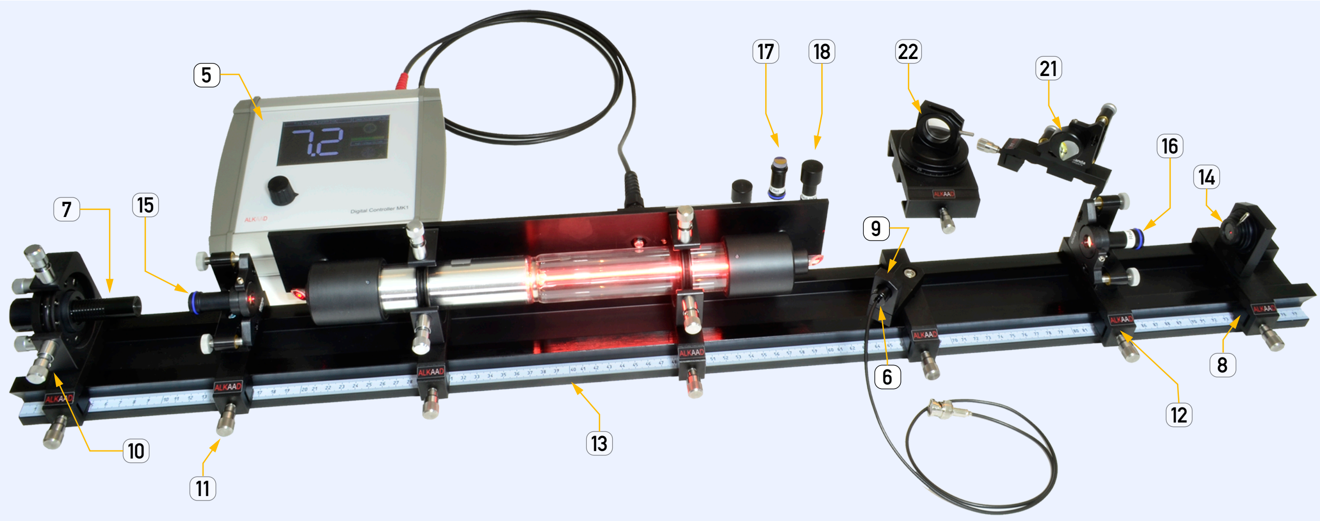


Fig. 2.15: Line selection with a birefringent plate

By rotating the birefringent plate, its optical retardation δ is changed. If the retardation of two passes is a multiple integer of the wavelength λ, this wavelength undergoes no losses at the Brewster window and will oscillate. All other possible lines will be elliptically or circular polarised and the losses at the Brewster prevents their laser oscillation.



LE-0300 HeNe-Laser, description of the components

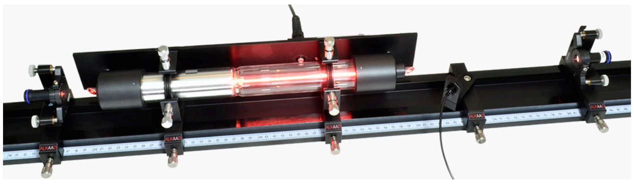


Fig. 2.16: Fundamental setup

The basic experiments like

1. Cavity alignment
2. Power measurement
3. Stability criteria of a hemispherical cavity
4. Gaussian beam diameter distribution

are performed with the basic setup. A green pilot laser (7) is mounted into a 4 axes adjustment holder (10) and in combination with the adjustable iris (14) the optical axis is aligned with respect to the mechanical centre line.

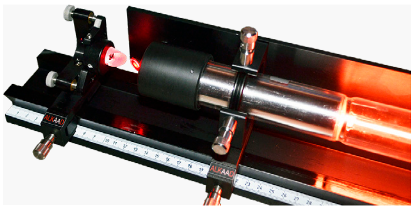


Fig. 2.17: Line tuning with Littrow prism

A way to select different lines of a laser is to use a Littrow prism. Within this experiment we are using such a module to tune the lines of the Helium Neon laser. The Littrow prism is made from fused silica which is the required substrate for IBS (Ion Beam Sputter) coating. The spectral range of the IBS coating covers 580..720 nm with a reflectivity of >99.98 %. The prism is mounted into a precise adjustment holder where it can be smoothly tilted in vertical or horizontal direction.
The prism is used instead of the left mirror (11,15). Before the setup is modified for the Littrow prism experiments, the Littrow prism is adjusted by using the output beam of the still running HeNe laser. After that, the left mirror with its adjustment holder (11,15) is removed and the laser continues to oscillate with the Littrow prism as mirror M1 (see the principle as shown in Fig. 2.14.

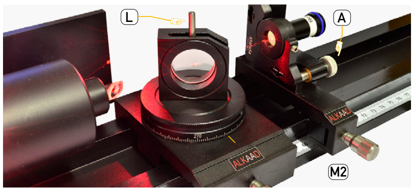


Fig. 2.18: Line tuning with birefringent tuner (BFT)

Another way to select different lines is done by using a birefringent optical plate inside the cavity. The birefringent plate is set to the Brewster angle (57°) and placed in front of mirror M2. When rotating the birefringent plate by tilting the lever (L) laser emission should occur. If not lift the lever up and down while adjusting the knob A to compensate the beam deviation caused by the quartz plate. Then gently tune to the maximum of performance and optimise the alignment of the mirror M2. By tilting the lever some other wavelength should show up. In total 5 different lines will be observed.
It will be noted that the line selection with a BFT requires no change of the geometrical path of the laser cavity as it is the case with the Littrow prism.

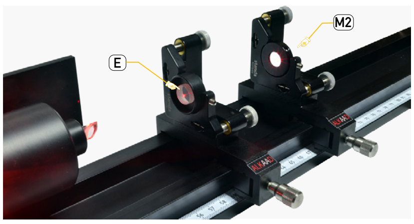


Fig. 2.19: Single mode etalon

Commonly, gas laser oscillate due to the Doppler broadening of the laser transitions on many longitudinal modes. To force the operation on only one longitudinal mode an etalon (E) is inserted into the cavity. It consists of a quartz cylinder with its end faces ground precisely parallel within a few arc seconds. The length is designed so that the convolution of its free spectral range with the Helium Neon laser cavity favours only one mode. The alignment is quite simple, before the etalon is placed into the cavity, it is aligned out side the cavity (behind M2) by using the laser output as alignment beam. The etalon is aligned perpendicular to the laser beam. Once inserted inside the cavity laser oscillation should continue. If not, small alignments of the fine pitch screws lets the laser flash up and further alignment comes to a stable oscillation again. The etalon is then tilted by turning let's say the screw for vertical tilt. The laser oscillation ceases, but turning further the laser starts to oscillate again and the etalon is tilted to its first order.

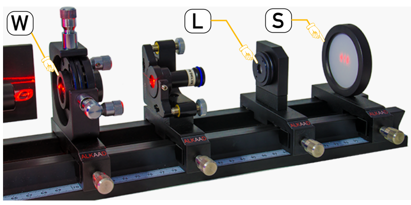


Fig. 2.20: Excitation of transverse modes

Setting up a nearly concentric cavity by using two mirrors with radii of curvature of 700 mm (16) and positioning the laser tube in the centre of both mirrors one can observe a multitude on non-axial, or transverse modes. For better viewing the laser beam is expanded by the lens (L) and imaged on a translucent screen (S). To get a better mode separation and a clearer image a wire (W) is inserted into the cavity which can be rotated and adjusted in X and Y direction. Depending on the adjustment state, position of the tube and of the wire a great variety of transverse modes can be observed, even the famous doughnut mode.

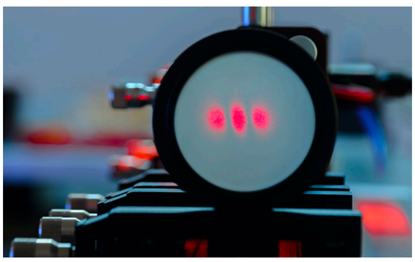


Fig. 2.21: Photographed transverse modes

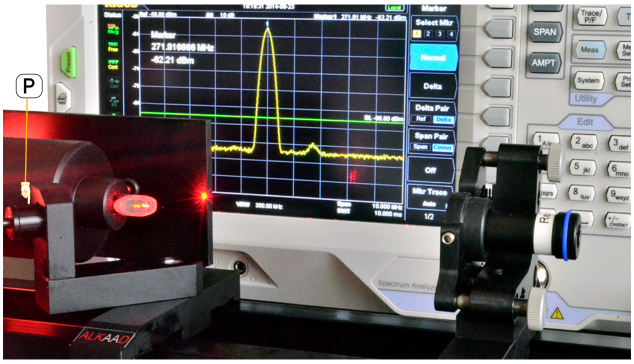
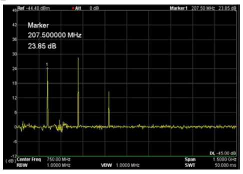


Fig. 2.22: Mode beat frequency measurement

Multimode emission consists of a number of simultaneously oscillating longitudinal modes with a frequency difference δν to each other, which depends on the cavity length L as δν=c/2L. For a length L of 0.75 m and the speed of light c, this frequency difference will be 200 MHz. The experiment comes with a fast photodetector (P). Connecting the photodetector to an electronic spectrum analyser this beat frequency



appears as a strong peak on the analyser. Depending on the number of oscillating longitudinal modes, multiples of the beat frequency will be observed. The number of harmonics tells us on how many modes the laser is oscillating. The gain bandwidth of the Helium Neon laser is 1.5 GHz. Under ideal conditions a cavity with a free spectral range of 200 MHz can have 7 to 8 modes. Since modern spectrum analysers with a range of 1 GHz are economically available, this method of measuring the beat frequency is very attractive

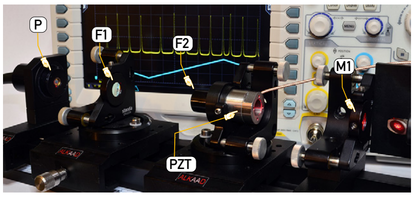


Fig. 2.23: Measuring the mode spectrum with the Fabry Perot Extension LE-0350

The classical way to measure the mode spectrum of a laser is to use a Fabry Perot. Such a Fabry Perot (FP) consists of two curved mirrors (F1 and F2) and are operated in the confocal configuration. One of the mirrors (F2) is mounted to a piezoelectric transducer (PZT). A triangular voltage applied to the PZT moves the mirror periodically forth and back. Each time the wavelength fits to the free spectral range of the FP it becomes transparent and the photodetector detects the change of intensities. Each peak of the oscilloscope represents a mode of the laser. The FP is placed behind the flat mirror (M1) of the Helium Neon laser cavity. For this experiment a mirror with a output coupling of 3% is used to increase the intensity for the FP. Otherwise the signal behind the FP is too close to the noise figure.

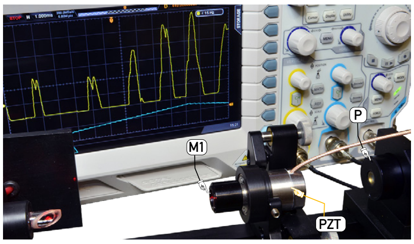


Fig. 2.24: Power intensity profiles, Lamb dip

A great extension to the Helium Neon laser experiments is a PZT to which one of the cavity mirror (M2) is attached. This allows the scanning of the cavity length periodically by some orders. The provided photodiode (P) detects the intensity changes of the HeNe laser during the scanning. Both signals, the PZT voltage and the photodiode signal are shown simultaneously on an oscilloscope whereby the PZT signal is used as trigger signal. Since the PZT movement follows almost linearly the PZT voltage the time axis of the oscilloscope track is equivalent to cavity resonance frequency. In case this frequency equals a multiple integer of half of the laser wavelength the laser starts to oscillate. The signal of the photodiode shows the power profile of such a mode as function of the cavity frequency. In this way the famous Lamb dip can be measured and displayed.
Furthermore this way of scanning the Helium Neon laser cavity provides information of the gain bandwidth as well the number of actual lasing modes. A great idea to scan the Helium Neon laser cavity!

LE-0300 HeNe-Laser, advanced consisting of:

Item	*Code*	*Qty.*	*Description*	*Details page*
1	CA-0080	1	Optics cleaning set	127 (12)
2	CA-0220	1	Multimeter 3 1/2 digits	129 (21)
3	DC-0060	1	High voltage supply 4.0 - 7 mA adjustable	122 (6)
4	DC-0140	1	Mini SiPIN photodetector with connection lead	123 (16)
5	DC-0380	1	Photodetector Junction Box ZB1	125 (30)
6	LQ-0030	1	Green (532) pilot laser25 with USB power supply	118 (2)
7	MM-0020	1	Mounting plate C25 on carrier MG20	93 (1)
8	MM-0230	1	Photodetector mount on rotary arm on MG20	95 (18)
9	MM-0420	1	Four axes kinematic mount on carrier MG20	96 (24)
10	MM-0460	1	Kinematic mirror mount M16, left	96 (28)
11	MM-0462	1	Kinematic mirror mount M16, right	97 (29)
12	MP-0100	1	Optical Bench MG-65, 1000 mm	92 (4)
13	OC-0400	1	Adjustable iris mounted in C25	100 (19)
14	OC-1000	1	Laser mirror M16, flat, T 3% @ 632 nm	104 (57)
15	OC-1005	1	Laser mirror M16, flat, HR @ 632 nm	104 (58)
16	OC-1020	1	Laser mirror M16, ROC 700 mm, HR @ 632 nm	105 (61)
17	OC-1030	1	Laser mirror M16, ROC 1000 mm, HR @ 632 nm	105 (62)
18	OM-0560	1	HeNe laser tube with XY and wobble alignment	113 (25)
19	OM-0570	1	Littrow Prism Tuner	114 (26)
20	OM-0580	1	Birefringent Tuner	113 (24)
21	OM-0590	1	Single Mode Etalon with kinematic mount	114 (28)
22	OM-0596	1	Transverse Mode Enhancer	114 (29)
23	UM-LE03	1	Manual HeNe Laser	
	Option (order separately)			
24	CA-0060	1	Infrared display card 0.8 -1.4 µm	127 (9)
25	CA-0200	1	Oscilloscope 100 MHz digital, two channel	128 (19)
26	CA-0210	1	Spectrum Analyzer 100 kHz - 500 MHz	129 (20)
27	CA-0270	1	Fibre coupled spectrometer 200 - 1200 nm, USB	129 (26)
28	CA-0510	1	Laser safety goggles 632 nm	130 (29)
29	DC-0120	1	Si-PIN Photodetector, BPX61 with connection leads	123 (14)
30	LE-0350	1	HeNe Fabry Perot Mode Analyser	132 (1)
31	OC-1040	2	Laser mirror M16, ROC 700 mm, HR @ 1180 nm	105 (63)
32	UM-LM03	1	Manual Fabry Perot Resonator	

Highlights

Basic, advanced, and top level ★★★ experiments

Outstanding features for a Helium Neon Experimental Laser:

- ★★★ Scanned Laser Cavity
- ★★★ Power Profile
- ★★★ Lamb Dip
- ★★★ Beat Frequency Measurement
- ★★★ Excitation of transverse modes

Intended institutions and users:

- Physics Laboratory
- Engineering department
- Electronic department
- Biophotonics department
- Physics education in Medicine