V64 Interferometry

Abstract

Interferometry is an inportant technique allowing among others the precise measurement of length changes or material properties. The required theoretical and practical knowledge is obtained by using the Sagnac Interfrometer as an example.
The focus of the experiment is on the one hand the achievements of optical alignment skills and on the other hand the use of interference effects to determine material-specific properties (as e.g. the reflection index) with high accuracy.

References

[1] E. Hecht *Optics*, De Gruyter 2018

[2] A. M. Gretarsson *A first Course in Laboratory Optics*, Cambridge University Press 2021

Preparation

For succesful understanding of the experiment, familiarisation with the elementary principles of interferometry is necessary. Therefore, prepare yourself for the following questions.

- What does coherence mean? Familiarise yourself with the terms on degree of coherence, temporal coherence and spatial coherence?(reference [1], chapter 12.4.1)
- What are the different polarisation properties of light? How must two light beams be polarised in relation to each other so that interference effects can be observed? (reference [1], chapter 9.1)
- What are the basic characteristics of a Mach-Zehnder-interferometer, a Michelson Interferometer and a Sagnac Interferometer. With which of the three interferometer types do you expect a particularly high stability of the interference signal against external disturbances? (reference [1], chapter 9.4.2, p.813ff)
- How can the contrast (also visibility) of an interferometer be defined? (reference [1], chapter 12.3 and 12.4)
- How does a **p**olarising **b**eam-**s**plitter **c**ube (PBSC) work? Which orientation has the polarisation of the outcoming light beam of the PBSC, if the polarisation of the incoming light beam lies in the vertical and the PBSC is tilted at 45° away from the vertical. (reference [1], chapter 8.6)
- Show that the maximum intensity I_{max} in case of constructive interference respectively the minimal intensity I_{min} in case of destructive interference, detected by a diode is given by

$$I_{max/min} \propto I_{Laser}\ (1 \pm 2\ \cos(\phi)\ \sin(\phi)) \tag{1}$$

Here I_{Laser} is the average output intensity of the laser and ϕ is the polarisation orientation of the first polarizer.
Assume

$$I \propto \left\langle \; |E_1 \; \cos(\omega \; t) + E_1 \; \cos(\omega \; t + \delta)|^2 \; \right\rangle \tag{2}$$

to calculate $I_{max/min}$. E_i are the electric-field components of the two counter-propagating beams and $\langle ... \rangle$ is the average over one period.
Explain why this assumption about the detected diode signal is justified. What is the significance of the variable δ ? What is the relationship between I_{Laser}, φ and the electric field components E_i ?

- How does the contrast depend on the polarisation angle?
- Which kind of measurement uses one and which two diodes? What is the advantage of measuring the differential voltage of both diodes (differential voltage method)?
- How can you determine the refraction index n from the number of interference maxima and minima?
- How does the refraction index n depend on temperature T and the pressure p of a gas (Lorentz-Lorenz-law)?

Experimental setup and Alignment

Figure 1 shows the topology of the Sagnac interferometer in use. The light source is a HeNe laser with a wavelength of 632.990 nm.

The HeNe laser emits linearly polarised light whereby the polarisation direction is ideally tilted by 45^o with respect to the vertical. The laser beam reaches the interferometer via the two mirrors M_1 and M_2. The laser should hit the two mirrors M_1 and M_2 as centrally as possible. The incident angle should be 45^o at both mirrors. For further adjustment, use the 2 adjustment plates which fit into the provided holes on the base plates of the PBSC and the mirrors M_i.

- Use the mirrors M_1 and M_2 to align through the PBSC to the center of mirror Ma. Use the adjustment plates in position 2 and 3. **First block the beam deflected by the PBSC!**
- Repeat the previous alignment for the deflected beam using the adjustment plates in positions 8 and 9. Adjust the beam this time by moving the base plate of the PBSC itself. The vertical axis can be adjusted by placing metal plates of different thickness under the base plate of the PBSC.
- Now adjust both beams coming from the mirrors Ma and Mc through the adjustment plates at point 5 and 6 by first moving the back plates to the two mirrors. For finer adjustment, there are fine adjustment screws on the back of the mirrors. You should now see a dot on mirror Mb.

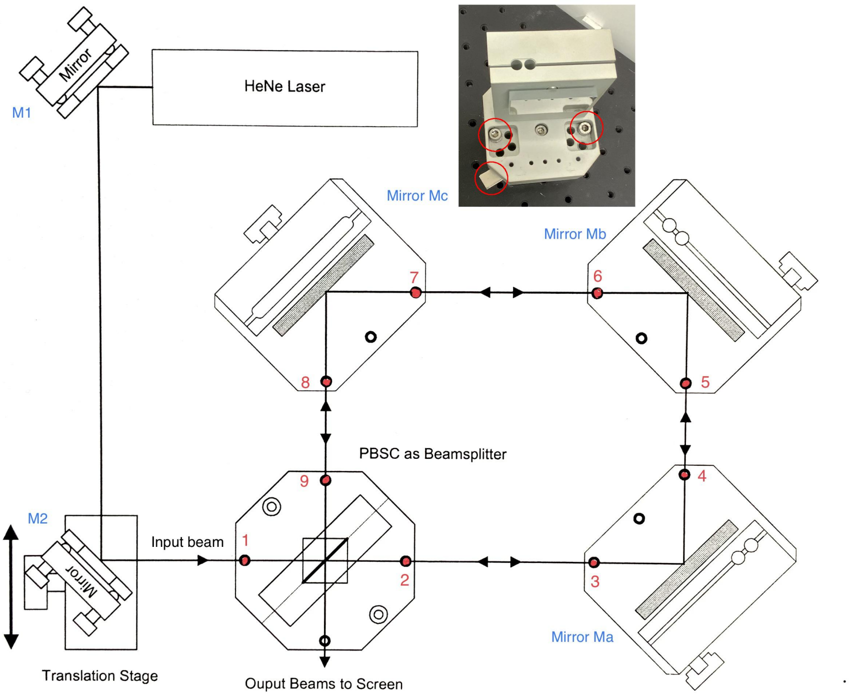

Figure 1: Topology of the Sagnac-Interferometer. Inset: Using shim stock to evelate one corner.

- Then adjust mirror Mb so that the beam coming from mirror Ma (respectively Mc) also passes through the centre of the adjustment plate at position 7 (respectively 4). Both opposing beams should now meet at one point on the PBSC. If this is not the case, you can now readjust the mirrors Ma and Mc using the fine adjustment screws.

- Now look at the two overlapping beams behind the interferometer on a screen. They do not interfere there because they are polarised perpendicular to each other. In order to be able to observe interference here, you will need a polarisation filter that is rotated by 45°. Behind this you should now see a pattern of interference fringes, see Fig 2. The aim is to **eliminate these fringes** by aligning both beams perfectly parallel to each other along their entire length.

- Now use an essential feature of the sagnac interferometer: Move mirror M_2 to shift the incoming beam parallel to the first surface of the PBSC. This separates the two previously overlapping beams into two horizontally offset beams. Use the outer holes of the adjustment plates. which you place at position 2 and 3. You should study the interference pattern for interference fringes as above, and readjust if necessary. It is now possible to manipulate one of these beams while the second remains unaffected.

- Now install the rotation holder together with the two tilted thin glass plates in the beam path. The plates have a thickness of T = 1 mm. Fine adjustment may be necessary here as well. Observe the interfringe pattern as a function of the rotation angle.

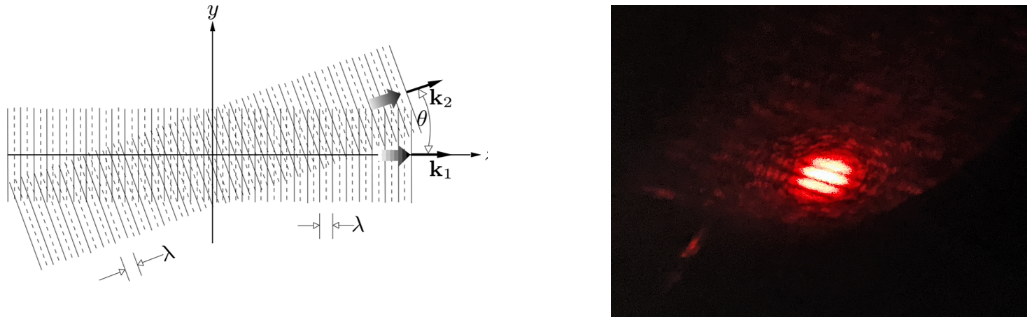

Figure 2: Left: Sketch of the superposition of the wave fronts of two plane waves that propagate in different directions [1]. Right: Resulting pattern of interference fringes behind the interferometer, such as it can be observed in the experiment if the two beams are not parallel.

- For further detection the polarisation filter is now **replaced** by the PBSC rotated by 45°. You should now be able to observe interference in each output beam of the PBSC. How do the two spots relate to each other? Check your expectations by detecting the two spots with photodiodes and displaying them on an oszilloscope as a function of time.
- Now connect both diodes via the Modern Interferometry Controller so that you can measure the difference. What are the advantages of this method?
- Finally, you can minimise variations in air density by placing the plexiglass hood on the interferometer.

Measurements and analysis

- Determine the **contrast of the interferometer** as a function of the polarisation direction Θ of the laser beam. For this purpose, the diode voltage is to be measured for the interference maximum **and** minimum (adjustable by the double glass holder in the interferometer) as a function of the orientation of a linear polarisation filter in front of the first beam splitter cube. Perform this measurement for the angle range of 0°-180°, in 15° steps.
  Compare the measured values with the previously calculated theory curve (calculated in the preparation)!
- Now adjust the polariser so that the contrast is at a maximum and carryout the following measurements using the difference voltage method.

  Refraction index of glass
  Determine the refractive index of the glass from the double glass holder by measuring the number of interference maxima or minima $M = \Delta\Phi/(2\,\pi)$ as a function of the rotation angle Θ of the glass plates (10 repetitions).

  A **single** plane-parallel plate with refraction index n generates for small angles of rotation

Θ approximately a phase shift

$$\Delta\Phi(\Theta) = \frac{2\,\pi}{\lambda_{vac}}\,T\left(\frac{n-1}{2\,n}\,\Theta^2\,+\,\mathcal{O}(\Theta^4)\right) \tag{3}$$

Here λ_{vac} is the wavelength of the light in vacuum and T the thickness of the glassplate.

Consider that 2 glass plates are installed in the holder used, which are already tilted by $\Theta_0 = \pm\, 10°$. Modify equation 2 accordenly!

Refraction index of gases

Now install the gas cell in one of the two beams. The double glass holder can remain in the beam path. Determine the refraction index n of air and another gas by introducing the corresponding gas into the previously evacuated gas cell and measuring the number M of interference maxima or minima as a funtion of pressure (50 mbar steps). At least 3 series of measurements per gas should be recorded. The gas cell has a length of (100.0 ± 0.1) mm. The light beam that passes through the gas cell undergoes a phase shift.

$$\Delta\Phi = \frac{2\,\pi}{\lambda_{vac}}\,\Delta n\,L \tag{4}$$

in relation to the free laser beam.

In addition, determine the refraction index of the two gases at standard atmosphere (15°C, 1013 hPa) using the Lorentz-Lorenz law. Also note the room temperature!