

Experiment 2.12

Light-Semiconductor-Interaction

Introduction

Light-semiconductor interaction has become an integral part of our modern day technology. The CCD-chip of a digital camera, screens of TVs and PCs, as well as nightvision- and movement sensors are just a few examples of optoelectronic principles in our daily lives. In this experiment, you are supposed to get an understanding of the basic aspects of light-semiconductor interaction and have the opportunity to confirm fundamental concepts of solid state physics. Furthermore you shall be able to collect first hand experience in the handling of optical setups.

To accomplish these goals, you will be experimenting on a supercontinuum laser, whose broadband spectrum can be filtered with the help of acoustooptic modulators (AOMs). The setup thus allows for wavelength dependent measurements in either transmission or absorption mode.

A special focus is put on the independent development of an experiment, which is why you will get the opportunity to develop and realise your own measurements from the second part of the experiment onwards.



laser radiation:

In the experiment a supercontinuum laser of the class 3B is used. This means that direct exposure of the eyes can lead to severe visual impairment. Because of this you should wear the available laser protection goggles for the entire duration of the experiment.

Requirements

At the start of the experiment you should be familiar with the following concepts:

band structures, Fermi-level, semiconductors, electron-photon- and electron-photon-phonon interaction in solid state materials, PN-junctions, photodiodes, optoelectronic measurements of light, lasers, self-phase modulation, acoustooptic modulators, parabolic mirrors.

Literature

Information about the concepts highlighted above can be found in the following resources:

- Supplemental material for the experiment (overview of all aspects of the experiment)

- Ashcroft, Mermin: solid state physics (band structure, semiconductor, p-n junction)
- Corner: introduction to laser physics (laser)
- Boyd: Nonlinear Optics (self-phase modulation)

Experimental procedure

The experiment can be partitioned into three parts:

1. Construction of the beam line and measurement of Si

In the first part of the experiment, you should record a transmission spectrum (e.g. the transmission for a number of different wavelengths) of a silicon sample. To do this, you must use the available optical components (mirrors, flip-mirrors, parabolic mirrors), to create a beam line, which directs the laser beam from the outputs of the AOMs, through the silicon sample and onto the InGaAs-detector. You can copy the setup in Im. 1 or come up with one yourself. To measure the transmission spectrum, you have to record one spectrum with and one spectrum without the Si-sample. The actual transmission spectrum can be derived from these, by dividing the spectrum of the Si-sample by the reference spectrum:

$$T(\lambda) = \frac{I_{\text{Si}}(\lambda)}{I_{\text{Ref}}(\lambda)}.$$

2. Construction and characterization of a photodetector:

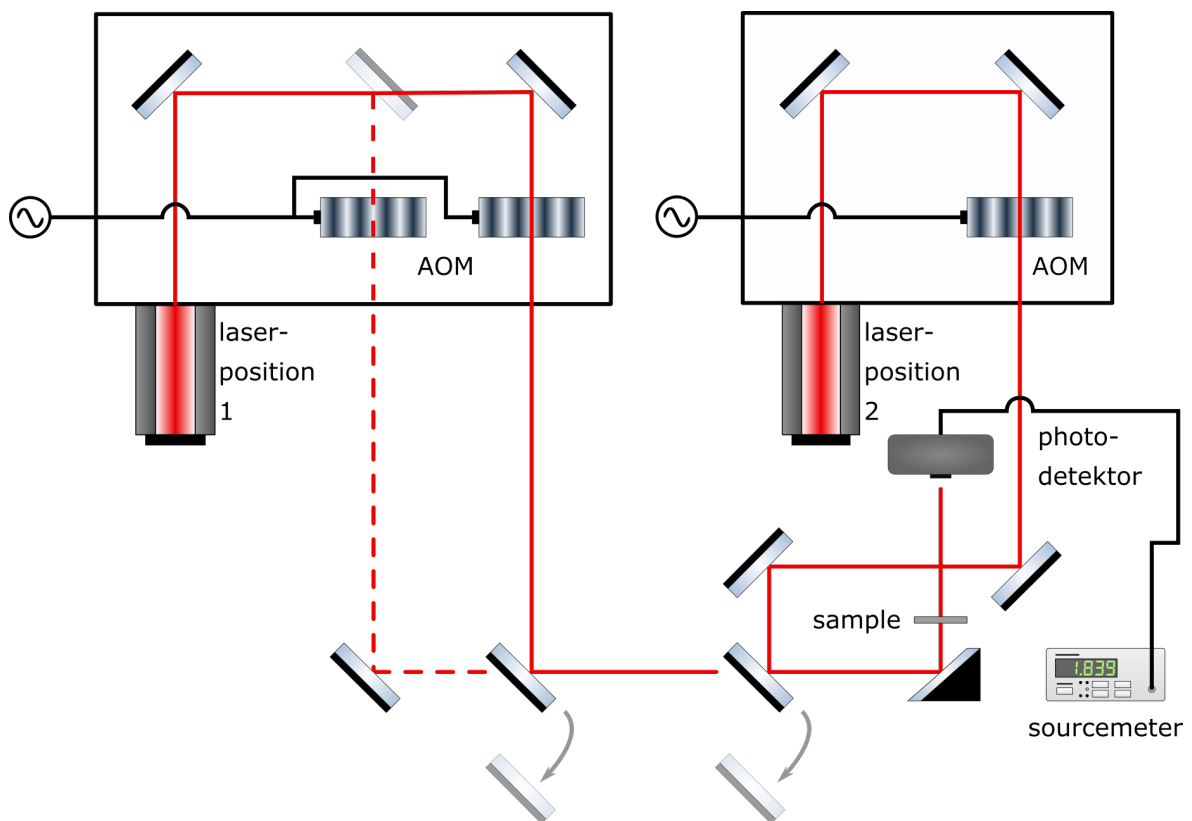
In the second part of the experiment, you are supposed to build your own photodetector from a simple photodiode. For this, think about how a photodiode can be used as a detector and which types of measurement are possible with such a photodiode. Next to photodiodes with different wavelengths and the sourcemeter of the first part of the experiment, you will also have access to a source-measurement-unit (SMU), with which a voltage or a current can be send through the photodiode, while the other variable is being measured. Additionally a few delay-stages will be available, with which you can move your photodiode with an accuracy in the μm -range.

In this task you can decide for yourself which measurements you consider sensible and in which way you want to characterize your photodiode. It is only important, that you can explain the meaningfulness of your recorded measurements and that you are able to properly analyze the data. To make sure that this is the case, discuss with your supervisor before the experiment, to set a realistic and useful goal.

You can spend as much time with this task as you like, as long as you can come up with sensible measurements. It is not a requirement for the successful completion of the experiment to have worked on all the tasks, instead you are supposed to develop and train your abilities to independently plan, execute and analyze a physics experiment

3. Free part:

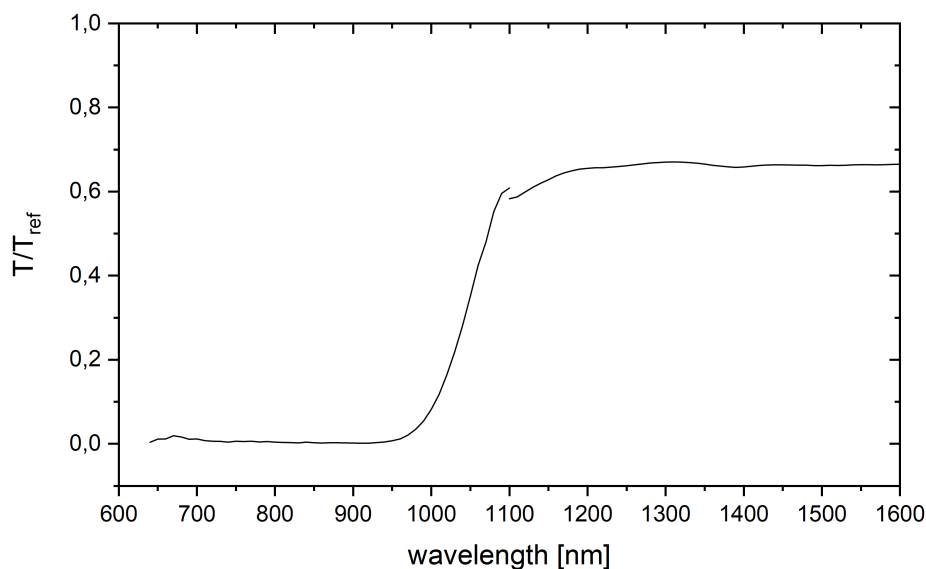
Once you are content with the collected data of the former task and still have time left, you are now free to decide for yourself which further measurements you want to take, using the given setup. As an example you could measure other samples or try to record a reflection measurement. Again, there are no limitations on the type of measurements you are allowed to implement. Provided you can explain the usefulness of your suggested measurement to your supervisor, you can carry it out.



Im. 1: Schematic sketch of a setup used for a transmission setup, containing a supercontinuum laser and several AOMs. For more information, see the supplemental material of the experiment.

Questions

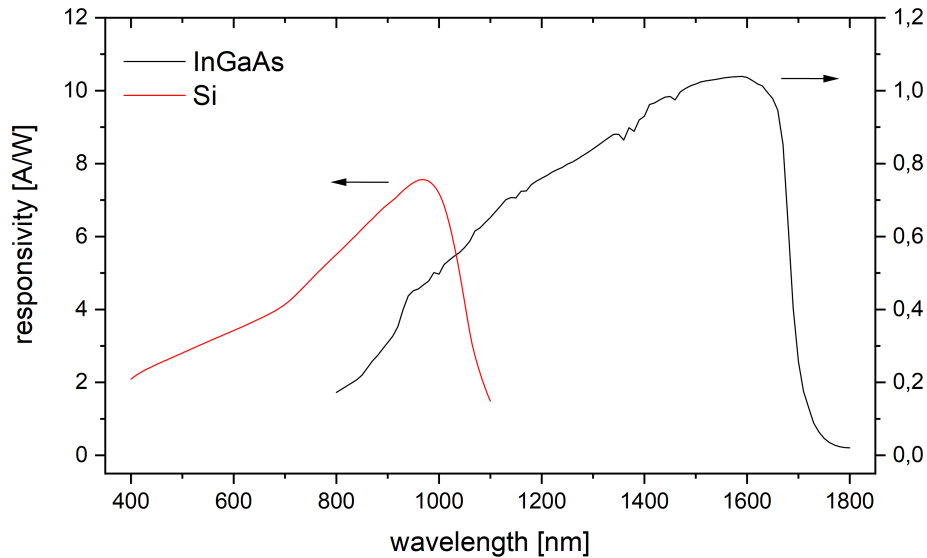
1. What does the band structure of a material describe and how is the band structure connected to physical properties like the conductivity?
2. How is a semiconductor defined? What is the difference between a direct and an indirect semiconductor?
3. Which types of interaction occur between electrons and photons in a semiconductor?
4. Which additional types of interaction occur, when additionally phonons are taken into account?
5. In the lower sketch a transmission spectrum of silicon (indirect semiconductor) is shown. Explain the most important areas of the spectrum. (The discontinuity in the center has no physical meaning.)



Im. 2: Transmission spectrum of silicon.

6. What changes do you expect in the transmission spectrum for a direct semiconductor like GaAs?
7. What does the Fermi-level describe? What influence does it have on the physical properties?
8. How and why does the doping of a semiconductor change its Fermi-level?
9. What are the mechanisms that lead to the creation of a PN-junction?
10. What types of measurements can be used to measure photons with a PN-junction? What are the pros and cons of these methods?
11. Describe the IV-curve of a photodiode. In which areas are photons emitted?
12. In the lower curve, the responsivity of the InGaAs-detector and the Si-detector is shown. Why does the responsivity sink for higher photon energies (smaller wavelengths)?

Hint: Think about how the power is linked to the photon count. How would the curve look like if the responsivity was not plotted in A/W but instead in A/N , where N is the photon count?



Im. 3: Responsivity of the available photodetectors.

13. In practice, PN-junctions are mostly used to measure photons. How could photons be measured with a pure semiconductor instead?
14. What are the main parts of the supercontinuum laser used in this experiment?
15. To change the output power of the supercontinuum laser, the repetition rate of the laser is changed, while the intensity of the single pulses remain constant. Why is the intensity of the Nd:YAG-laser itself not changed, while the repetition rate stays constant (as is usually the case)?
16. What is the working principle of an acoustooptic modulator?