

Raman Spectroscopy of Two-Dimensional Sample Systems

Experiment: 2.11

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1 Prerequisites for the Experiment

For this experiment you should already be familiar with solid-state physics concepts such as the band model and phonon dispersion relations, as well as with optics and the interaction of light with matter.

2 Introduction

Raman spectroscopy is a valuable, non-destructive measurement technique in many areas of surface physics. In particular, for two-dimensional (2D) materials it is an essential tool to investigate properties such as layer number, defect density and mechanical strain. In this experiment we will therefore fabricate 2D sample systems and analyze them by Raman spectroscopy.

3 Experimental Procedure

As first demonstrated by K. S. Novoselov and A. K. Geim [1], graphene can be produced by exfoliating a graphite block. The work in this part of the experiment is divided into the following steps.

Schritt 1: Exfoliation of the Samples

First, suitable substrates ($\approx 5 \times 5$ mm) are cut out of a silicon wafer. A diamond scribe is used to create a predefined break line on the matte Si side, and the wafer is snapped along this line (see Fig. 1).

A strip of Tesafilm is used to lift layers from a graphite block and to transfer them onto the prepared substrates. In the same way, hexagonal boron nitride (hBN) is exfoliated with a strip of Scotch Tape.

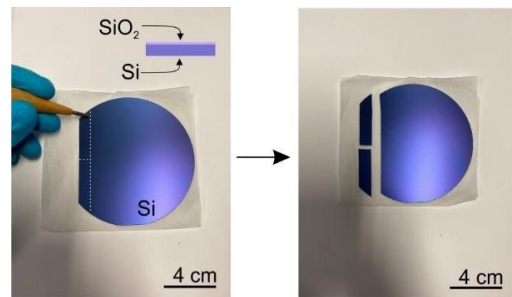


Figure 1: Preparation of the substrates

Schritt 2: Location of Graphene Monolayers

Using an optical microscope, the supervisor and the student search the substrate surface for graphene flakes. Photographs that contain distinctive reference marks are taken so that the same locations can be found later during processing. **Two** graphene flakes will be needed for the remainder of the experiment.

The same procedure is applied to the hBN flakes. Suitable hBN regions are identified together with the supervisor and documented with images. **One** hBN flake will be required later.

Schritt 3: Fabrication of a Heterostructure

A so-called *stacker* (Fig. 2) enables the transfer of exfoliated 2D structures from one substrate to another. By stacking two different 2D layers a heterostructure can be built. The stacker consists of an optical microscope, a holder for the stamp, and a sample holder. Micrometer screws allow precise positioning of both stamp and sample.

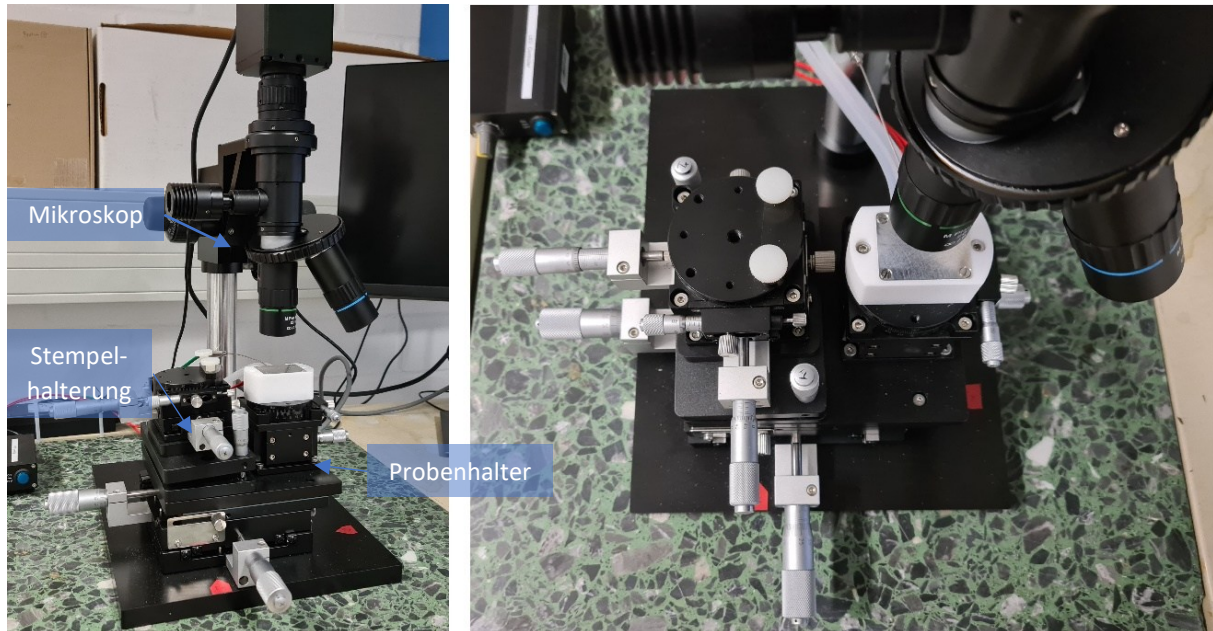


Figure 1: Picture of the stacker used for stacking 2D materials.

First, the graphene sample identified in Step 2 using the optical microscope must be located again using the stacker's optical microscope. Next, a polymer stamp is attached to a glass slide and clamped into the stamp holder. The stamp is positioned over the graphene sample. The graphene sample should not be moved at this point. The stamp and the graphene sample are slowly brought into contact and then heated to 60 °C for 10 minutes. After the sample has cooled back down to 25 °C, the graphene sample can be lifted off the substrate along with the stamp.

The graphene sample's original substrate is replaced with a substrate containing hBN. A suitable area of hBN is positioned beneath the stamp. The hBN and the graphene on the stamp are slowly brought into contact. The entire system is heated to 120 °C for 10 minutes. After cooling to 25 °C, the stamp can be lifted off without the graphene, leaving a heterostructure of graphene and hBN on the substrate.

As a final step, the heterostructure must be cleaned. To do this, the sample is immersed in chloroform twice for 15 minutes each, then rinsed with acetone and dried with nitrogen gas.

Schritt 4: Raman measurements

The samples are now analyzed using Raman spectroscopy. For this purpose, a laser with a wavelength of 532 nm and a grating with 1,800 lines per millimeter are used. Point spectra are obtained from graphene on silicon, graphene on hBN, and a reference sample that is provided.

4 Experiment Analysis

The Raman spectroscopy measurement data are available in ASCII format. We recommend using the Origin software for analysis. The following points should be analyzed:

1. In the spectra of all graphene samples, the mode positions are determined and assigned to the respective Raman modes. Which peaks belong to graphene and which to hBN?
2. The Raman modes are fitted from the spectra of all graphene samples. The **defect densities** of the graphene samples should be compared with one another based on the fits. How can this be measured/compared?
3. Finally, a qualitative comparison of the **nature** and **strength** of strain in graphene on the various substrates (SiO₂, hBN, and a control sample) will be performed. The peak positions of the modes and their half-widths are relevant here. The evaluation will be carried out using the methods presented in the current literature. [2-3]

5 Control questions

- What does “exfoliation” mean? For which materials does this work?
- Why are 2D materials interesting? How does 2D density of states differ from 3D ones? What is unique about graphene?
- What types of scattering between light and matter exist?
- How does Raman spectroscopy work?
- Why must monochromatic light be used for this?
- How can Raman lines be distinguished from photoluminescence lines?
- How do Raman modes arise, and what types of Raman modes exist in graphene? What does a typical Raman spectrum of graphene look like?
- What information can the modes of graphene contain?

6 Literature

[1] K. S. Novoselov, A. K. Geim, **Electric Field Effect in Atomically Thin Carbon Films.** *Science*, 306, 666–669, 2004

[2] L. Banszerus et al. **Identifying suitable substrates for high-quality graphene-based heterostructures.** *2D Materials*, 4(2):025030, 2017.

[3] C. Neumann, et al. **Raman spectroscopy as probe of nanometre-scale strain variations in graphene.** *Nature communications*, 6:8429, 2015.

[4] Kittel, C. (2002). *Einführung in die Festkörperphysik*. Berlin, Boston: De Gruyter.

[5] E. H. Martins Ferreira, et al. **Evolution of the raman spectra from single-, few-, and many-layer graphene with increasing disorder.** *Physical Review B*, 82(12), 2010.

- [6] Demtröder, W. (2013). Laserspektroskopie 2. Berlin, Heidelberg: Springer.
- [7] Schrader, B. (1995). Infrared and Raman Spectroscopy: Methods and Applications. Weinheim: VCH.
- [8] Ting Yu, Zhenhua Ni, et al. **Raman mapping investigation of graphene on transparent flexible substrate: The strain effect.** *The Journal of Physical Chemistry C*, 112(33):12602–12605, 2008