

Raman and near infrared spectroscopy of crystalline and amorphous silicon

C. Schwarz, P. Seidel, Institute of Solid State Physics, Jena, Germany (November 2011)



Abstract

Silicon plays an important role in electrical and optical applications. We present Raman and NIR spectroscopy comparing amorphous and crystalline samples. The analysis of the Raman spectrum is used to probe the crystallinity of the samples. The near-infrared spectroscopy measures the energy of the fundamental absorption and gives information about the energy gap of the sample. Both measuring techniques are carried out in a wide temperature range from 2 to 300 K.

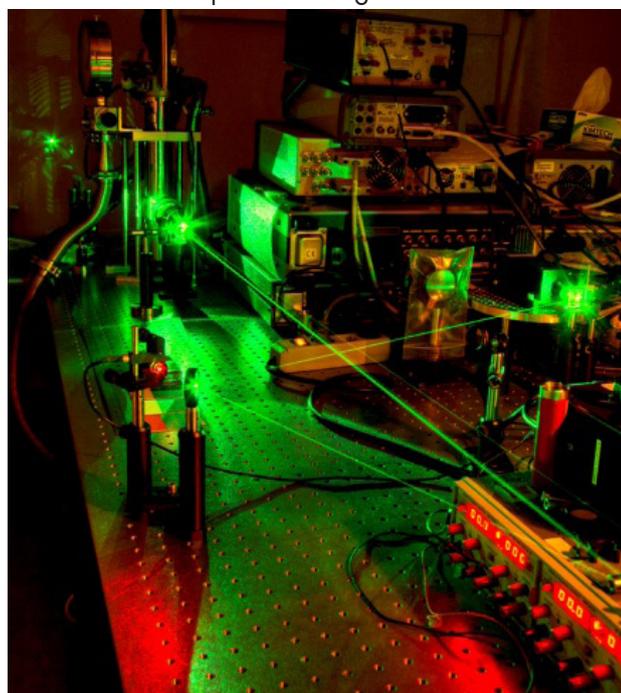


Fig. 1: Photograph of the setup used for Raman spectroscopy.

Introduction

Silicon plays an important role in electrical [1] as well as optical [2] applications. The optical and electrical parameters of silicon samples are strongly dependent on the fabrication process, the concentration of impurities or internal stress [3,4]. Raman spectroscopy as well as infrared spectroscopy is a commonly used tool to identify the crystal orientation, level of impurities or crystallinity. Raman and infrared spectroscopy are based on the same crystal or molecule vibrations but their spectra look different. Due to the rule of mutual exclusion both spectra complement each other. So the combination of both spectra gives an almost complete picture of the vibrational states within the solid.

Application Note

Setup

The experimental setups for Raman spectroscopy as well as the near infrared spectroscopy is based on the Andor Shamrock spectrometer SR500I-B1 and the iVac camera DR324B-FI. The simplified sketches of the setups are given in fig. 2. In both cases the sample is mounted inside a flow cryostat providing the variable operational temperature from about 2 to 300 K. The sapphire windows of the cryostat allow an operation within a wavelength range from 0.2 to 5.5 μm [6]. The sample is mounted on a manipulator that allows fine alignment of the sample inside the cryostat. In the case of the Raman spectroscopy a 532 nm laser is operated at low powers of about 25 mW due to the high sensitivity of the iVac camera that is used for read-out. The infrared transmission spectroscopy uses the Shamrock 500 spectrometer as a monochromator thanks to its second output port. Using the supplied LabView drivers it is easy to set up a custom made measurement software that controls the spectrometer as well as the temperature control of the cryostat. The infrared spectroscopy setup uses a pyroelectric detector for measuring the transmitted light behind the sample.

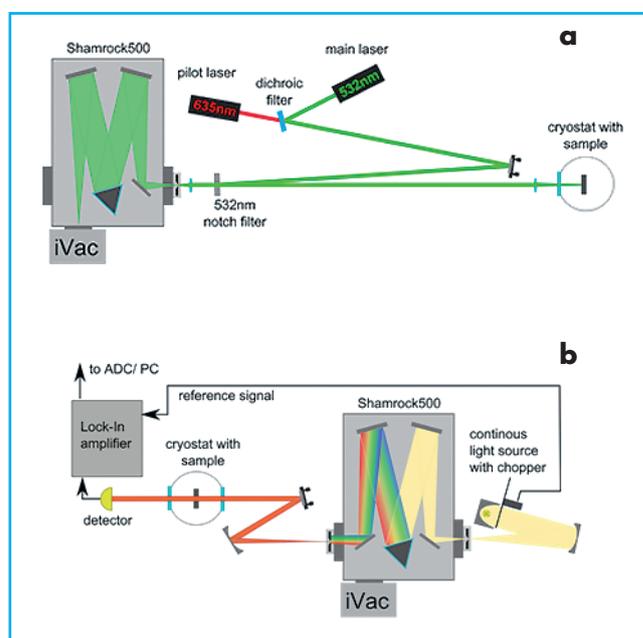


Fig. 2: Sketch of the setup used for Raman spectroscopy (a) and the near infrared spectroscopy (b) in a wide temperature range based on the Shamrock 500 spectrometer and the iVac camera.

Raman and near infrared spectroscopy of crystalline and amorphous silicon

C. Schwarz, P. Seidel, Institute of Solid State Physics, Jena, Germany (November 2011)

Application Note

Results

Fig. 3(a) shows the results of a Raman spectroscopy using a crystalline sample. Stokes and Anti-Stokes lines are clearly visible. Cooling the sample results in a reduction of the intensity of the Anti-Stokes line. The Raman-Shift of the Stokes/Anti-Stokes line was determined to be 522 cm^{-1} which corresponds to the commonly observed Raman active mode T_{2g} given in literature [5]. The comparison of a crystalline and an amorphous sample at room temperature is given in fig. 3(b). The amorphous sample shows a strong broadening of the Raman mode which corresponds to the disordered state of the sample.

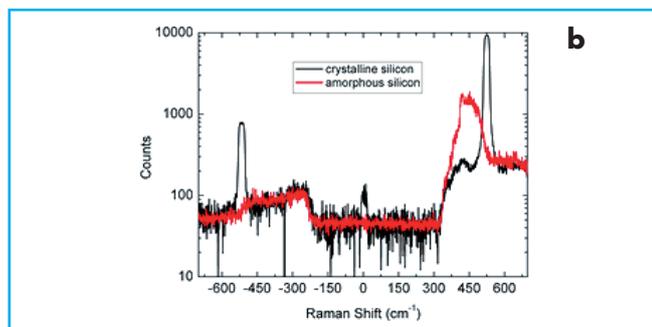
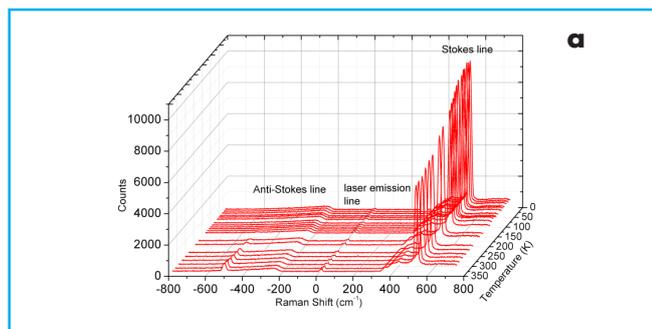


Fig. 3: (a) – Temperature dependence of the Stokes- and Anti-Stokes line of a crystalline silicon sample in a range from 5 to 300 K.

(b) – Comparison of a crystalline and an amorphous silicon sample at room temperature.

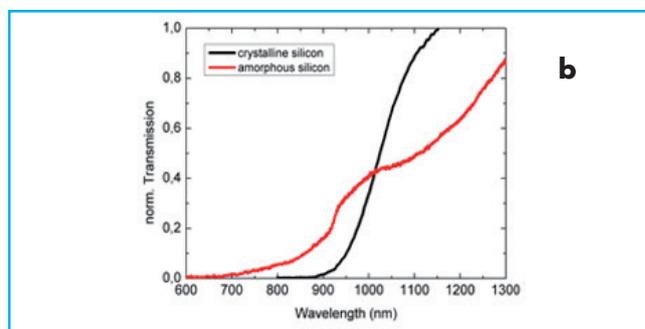
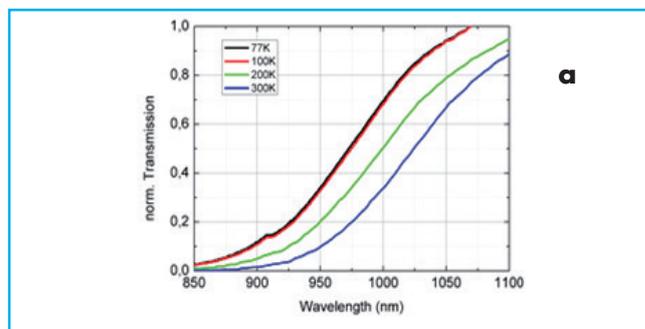


Fig. 4: (a) – Temperature dependence of the fundamental absorption of crystalline silicon.

(b) – Comparison of the fundamental absorption of crystalline and amorphous silicon at room temperature.

Fig. 4(a) compares the fundamental absorption of a crystalline silicon sample between 77 and 300 K. The absorption edge is shifted to lower wavelength while cooling. The total shift between 77 and 300 K corresponds to an energy shift of the band gap of 59 meV. This value corresponds to typical changes of the gap energy between room temperature and low temperatures around 77 K [7]. The fundamental absorption of amorphous silicon was determined to have a broader transition compared to crystalline samples (see fig. 4(b)). The disordered state of the amorphous silicon is again the reason for this difference. Probing the fundamental absorption will thus additionally give information about the crystalline state of the sample.

Acknowledgement

This work is supported by the German Science Foundation under contract SFB Transregio 7.

Raman and near infrared spectroscopy of crystalline and amorphous silicon

C. Schwarz, P. Seidel, Institute of Solid State Physics, Jena, Germany (November 2011)



Application Note

References

- [1] H. Iwai, Silicon integrated circuit technology from past to future, *Microelectronics Reliability* 42 (2002) 465–491
- [2] R. Schnabel, Building blocks for future detectors: Silicon test masses and 1550nm laser light, 8th Edoardo Amaldi Conference on Gravitational Waves, *Journal of Physics: Conference Series* 228 (2010) 012029
- [3] R. S. Jacobsen, Strained silicon as a new electro-optic material, *Nature* 441, 199-202 (11 May 2006)
- [4] I. De Wolf, Micro-Raman spectroscopy to study local mechanical stress in silicon integrated circuits, *Semicond. Sci. Technol.* 11 (1996) 139–154
- [5] H. Kuzmany, *Solid-State Spectroscopy*, Springer 2009.
- [6] Properties of optical materials - <http://www.lot-oriel.com/files/downloads/tips/de/opticalmaterials10.pdf>
- [7] Ch. Kittel, *Introduction to Solid State Physics*, Wiley 2005

Contact

Christian Schwarz
Institute of Solid State Physics
Helmholtzweg 5,
D-07743 Jena,
Germany

Phone: +49 3641 947420

Email: christian.schwarz.1@uni-jena.de

Web http://www.physik.uni-jena.de/exp_phys/