Published in Materials Science Forum (MSF) 483-485, 433-436, 2005
which should be used for any reference to this work

Infrared Gratings Based on SiC/Si-heterostructures

C. Rockstuhl[1,a], H.P. Herzig[1,b], Ch. Förster[2,c], A. Leycuras[3,d], O. Ambacher[2,e], and J. Pezoldt[2,f]

[1]Institute of Microtechnology, University of Neuchâtel, Rue A.-L. Breguet 2, CH-2000 Neuchâtel, Switzerland

[2]FG Nanotechnologie, Zentrum für Mikro- und Nanotechnologien, TU Ilmenau, Postfach 100565, 98684 Ilmenau, Germany

[3]CRHEA, CNRS, Parc de Sophia Antipolis, Rue Bernard Gregory, 06560 Valbonne, France

[a]carsten.rockstuhl@unine.ch, [b]HansPeter.Herzig@unine.ch, [c]christian.forester@tu-ilmenau.de, [d]Andre.Leycuras@crhea.cnrs.fr, [e]oliver.ambacher@tu-ilmenau.de, [f]joerg.pezoldt@tu-ilmenau.de

Keywords: infrared, optical properties, optical device, 3C- SiC, Si.

Abstract. The fabrication process and the spectral properties of gratings for the infrared wavelength region on the basis of 3C-SiC layers grown by CVD on (100) oriented Si substrates are demonstrated. The formed 3C-SiC gratings on Si support two phonon polaritons as a function of the geometrical properties excited between 10.3 and 11.4 µm. They appear as a dip in the transmission spectrum. A third minimum in the transmission spectrum is caused by the substrate – grating interaction. The obtained resonances were polarization sensitive, i.e. they appeared only under TM-polarized illumination.

Introduction

The classical application for a material such as SiC is in the field of devices for high temperatures, sensors and high frequencies as well as high power electronics. Beside those primary applications, which exploit the electronic qualities of the material, other properties of SiC attracted the interest of researchers. One of them is its dielectric constant in the infrared region of the spectrum between 10 µm and 12 µm (1000 cm^{-1} and 833 cm^{-1}). In this spectral region independent of the polytype the real part of the dielectric constant takes a negative value between –1 and –10 and the imaginary part is small [1, 2]. This behaviour is caused by the phonon frequencies of SiC. If the frequency of the illuminating wave field matches the eigen frequencies of the SiC lattice, a phonon polariton is excited in resonance. Due to the small remaining imaginary part of the dielectric constant of SiC, the phonon experiences only slight damping. This leads to a large near-field amplitude in the vicinity of the particle and a strong scattering cross section at the resonance frequency. Due to this singular property, SiC can be used as a coherent, directed emitter in the corresponding spectral region. Such a device can be realised by heating a well designed grating made of SiC, which will excite a vibrational state in the SiC lattice. By choosing appropriate geometrical parameters for the morphology of the grating, the phonon mode can be coupled into a radiative mode that propagates into the far-field. Furthermore, it was shown, that the design of the surface morphology allows the modification of the radiation direction and the value of the emission of the structure for a given wavelength [3].

The aim of the presentation is to report on the fabrication and spectral characterisation of SiC based gratings in the infrared wavelength region.

Experimental

The gratings were fabricated by using (100) oriented ß-SiC grown on (100)Si substrates. The thicknesses of the 3C-SiC layers were 1.9, 2.4 and 2.7 µm. On the basis of the grown heterostructures, different gratings were fabricated. The binary gratings consist of SiC bars located on the Si substrate having different periods. The height of the SiC bars equals the SiC layer thickness. The SiC material between the neighboring SiC bars was removed completely in the fabrication process. The periods of the gratings were chosen to be 6, 8, 10 and 14 µm. For each period eight different widths of the SiC bars were designed leading to different grating fill-factors. The fill-factor is defined as the ratio between the width of the SiC bar and the period of the grating. The process sequence of the grating fabrication was as follows: (a) 3C-SiC epitaxial growth, (b) formation of the metall mask by lift-off processing with i-line photolithography, (c) anisotropic dry etching of SiC by an ECR-plasma etch process, (d) removal of the metal mask by selective wet etching (Fig.1).

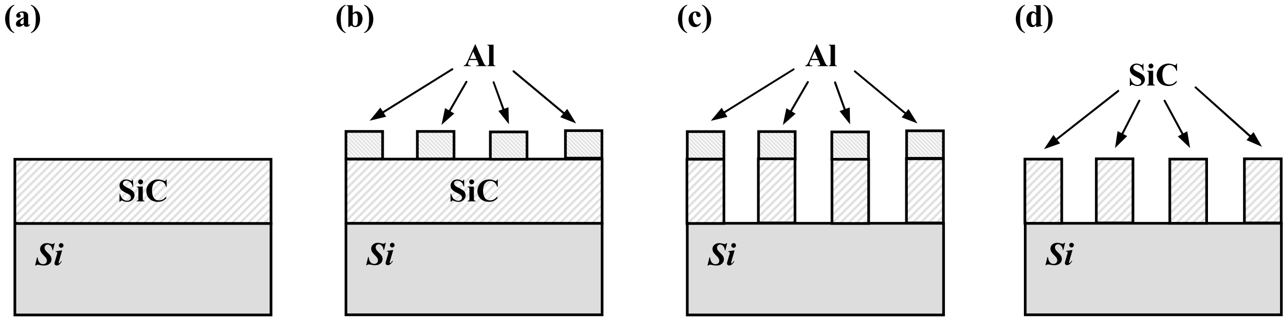
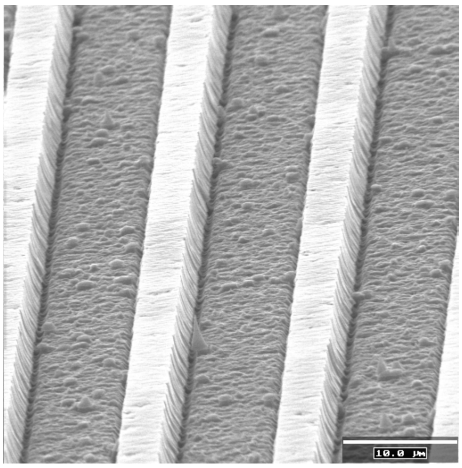


Fig.1: Process Steps of the gratings: (a) heteroepitaxy, (b) metal mask formation, (c) anisotropic dry etching, (d) selective wet metal etching.

The metal mask consists of a 100 nm thick Al layer deposited by magnetron sputtering. Subsequently to the Al lift-off process, the SiC in the unmasked region was completely removed by using an ECR-plasma etch system described in [4]. A 8:4:1 mixture of Ar, SF_6 and O_2 at a process pressure of $1.8x10^{-3}$ mbar was used to etch the silicon carbide layer, with a pronounced anisotropic etch behaviour. The etch process was carried out at 720 W. A low DC bias voltage of 70 V on the substrate was applied to obtain a smooth and straight step profile as well as low etching damage on the bottom trenches and the side walls. To remove the etch mask a high selective mixture of H_3PO_4, HNO_3 and H_2O was used.

The geometry of the fabricated gratings was evaluated by scanning electron microscopy (SEM) and profilometry. The smallest achieved SiC bar width was 0.8 µm. The largest bar width was 1 µm below the grating periodicity. SEM pictures of fabricated SiC gratings on Si (100) are shown in Fig. 2a and 2b.

(a)



(b)

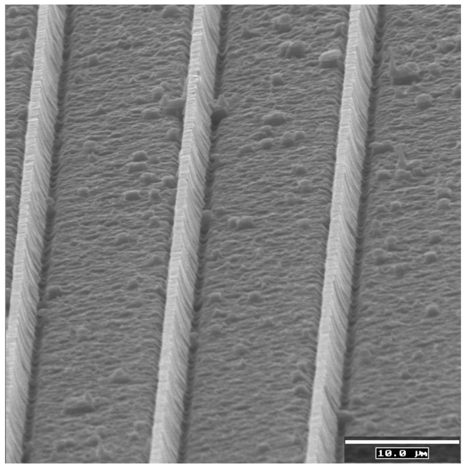


Fig. 2: ß-SiC gratings fabricated on (100)Si: (a) 2.7 µm (height) x 3.0 µm (width) x 2 mm (length) and 14 µm periodicity, (b) 2.7 µm (height) x 0.8 µm (width) x 2 mm (length) and 14 µm periodicity

The measurements of the transmission properties of the gratings in the infrared were carried out using an FTIR spectrometer Magna IR 860 from Nicolet. The structures were illuminated with a slightly focused beam and the wavelength dependent transmission in the 0th order was measured. As the reference spectrum, used for the normalization of the results, the transmission by the bare silicon substrate was applied. The spectral resolution was chosen such that Fabry-Perot oscillations caused by multiple reflections of the light within the substrate were avoided.

Results and discussion

A typical result of a measured transmission spectrum (design values: 2.7 µm height and 4.0 µm width) in comparison with a simulation is shown in Fig. 3. The simulation was carried out by using the Fourier Modal Method [5] and we assumed a slightly different value for the width (3 µm) for a better accordance. The measured width of the bars was 3.3 µm. The scattering signature for single objects without a periodic boundary have been calculated for comparison with the Boundary Element Method[6]. The illuminating wave field was TM-polarized, meaning that the magnetic field vector oscillates parallel to the grating structure. For comparison, the calculated spectral transmissions of nonstructured SiC/Si heterostructures with different SiC thicknesses are shown in Fig. 4.

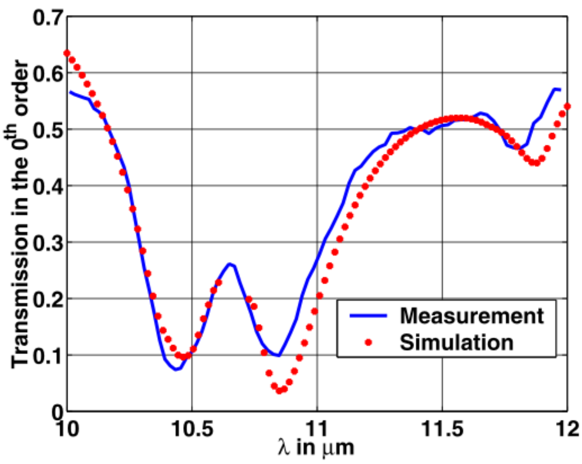


Fig. 3: Comparison between a measured and simulated transmission signal for a ß-SiC grating (2.7 µm height and 4.0 µm width)

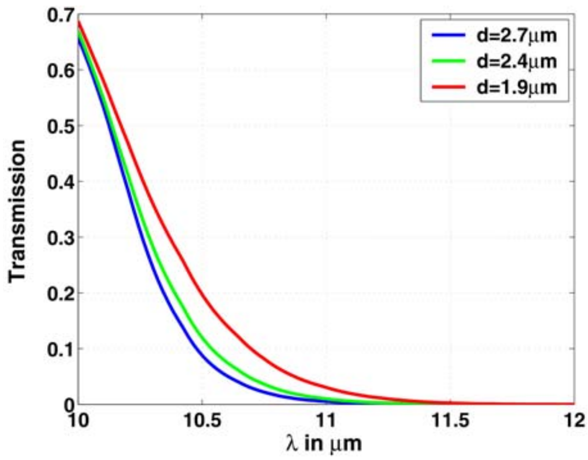


Fig. 4: Spectral transmission of a plane SiC/Si heterostructure at normal incidence calculated for different thicknesses

The measured transmission spectrum in Fig. 3 displays three pronounced minima, which do not appear in the transmission spectrum for the case of the plane heterostructures. These dips in the transmission are due to excited phonon resonances. Two well defined minima at lower wavelengths appear at 10.4 µm and 10.9 µm. They are associated with the rectangular geometrical cross-section of each bar of the SiC grating. The minimum in the transmission at 11.85 µm is attributed to the substrate – object interaction and has no counterpart in the spectrum of the freestanding object (ß-SiC). The difference in the resonance wavelength of the measured and the simulated phonon polaritons is probably due to an incertitude in the assumed dielectric constant for the calculation. The reason for the deviation in the dielectric constants can be mainly caused by the residual stress in the grown SiC layer. This residual tensile stress shifts the TO phonon position to lower wave numbers and therefor lead to changes in the dielectric function in the infrared region of the spectra. Due to the fact that each of the resonances is associated with a specified value of the real part of the dielectric function, a change in this parameter will shift the wavelength for which the phonon is excited. In the case of TE-polarized light no resonances could be measured, in accordance with the theoretical prediction. The wavelengths for which the phonon polaritons are excited depend primarily on the axis ratio of the SiC bar, defined as film thickness divided by the width of the bar [7].

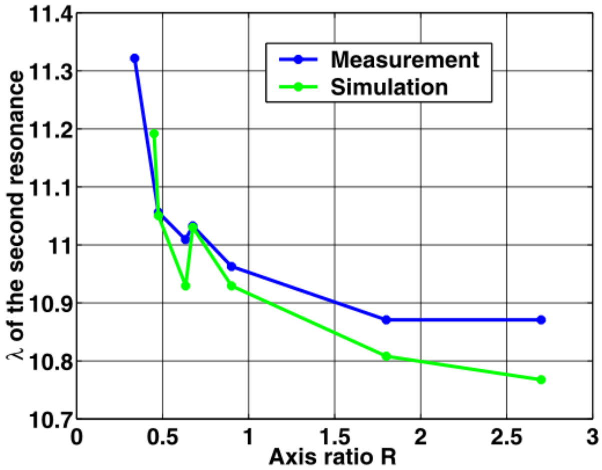


Fig. 5: Measured and simulated wavelength of the second surface phonon polariton resonance versus the axis ratio of the SiC bars.

In Fig. 5 the wavelength of the second surface phonon polariton resonance is shown as a function of the axis ratio and compared with theoretically predicted values. Fig. 5 summarizes the results obtained for gratings with a period of 10 µm prepared on heterostructures based on different SiC layer thicknesses grown by CVD on Si substrates. As can be seen, changing the geometrical properties of the grating allows the possibility to tune the resonance frequency of the grating. If the axis ratio decreases, i.e. if the width of the SiC bars increases for a given layer thickness and a constant period of the grating, a red shift of the resonance wavelength can be obtained. The discontinuity at axis ratios around 0.63/0.67 in the function of the resonance wavelength versus the axis ratio is caused by the fact that different film thicknesses (2.7, 2.4 and 1.9 µm) have been used for the measurements and the absolute size of the structure has an influence on the phonon wavelength. The slight systematic deviation between the simulated and measured phonon wavelengths is attributed to the incertitude in the dielectric constant for the SiC structures in the calculation, as already outlined. Another ambiguity is the precise width of each fabricated grating structure.

Summary

SiC gratings were fabricated by processing SiC/Si heterostructures. These gratings show theoretically predicted surface phonon polariton resonances in the infrared spectra. The resonance frequencies can be tuned by changing the geometrical properties of the SiC grating. The formed gratings are suitable for wavelength and polarization filters in the infrared spectra.

Acknowledgement

This work was supported by the European Union within the framework of the Future and Emerging Technologies-SLAM program under grant No. IST-2000-26479. The authors would like to thank the group of J. Faist at the Institute of Physics from the University of Neuchâtel for providing the equipment for the infrared measurements. C. Rockstuhl thanks the Canon-Foundation Europe for supporting his research.

References

[1] W.J. Choyke, NATO ASI Series E: Applied Sciences Vol. 185 (1990), p. 563.

[2] W.J. Moore, R.T. Holm, M.J. Yang and J.A. Freitas: Jr., J. Appl. Phys. Vol. 78 (1995), p. 7255.

[3] J. LeGall, M. Olivier and J.J. Greffet: Phys. Rev. Vol. B 55 (1997), p. 10105.

[4] Ch. Förster, V. Cimalla, R. Kosiba, G. Ecke, P. Weih, O. Ambacher and J. Pezoldt: Mater. Sci. Forum Vol. 457-460 (2004), p. 821.

[5] J. Turunen in H. P. Herzig: *Micro-Optics* (Taylor & Francis, 1997)

[6] C. Rockstuhl, M. Salt and H.P. Herzig: J. Opt. Soc. Am. Vol. A 20 (2003), p. 1969.