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Growth of 3C-SiC on Si(100) by LPCVD and Patterning of the Grown Layers

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Abstract. A low-cost approach to 3C-SiC low pressure chemical vapour deposition (LPCVD) growth and patterning have been developed and is described. LPCVD with ultra violet (UV) stimulation is used as a technique for the low-temperature growth of SiC on Si with a patterned SiO_2 or silicon nitride mask. Examples of surface micromachined structures patterned by the described lift-off approach with an excellent etching selectivity of Si to SiC are presented. The approach to growth and patterning of SiC on Si can be employed for further pendeo-epitaxial growth or fabrication of micromechanical devices, gas sensors, or biomedical applications.

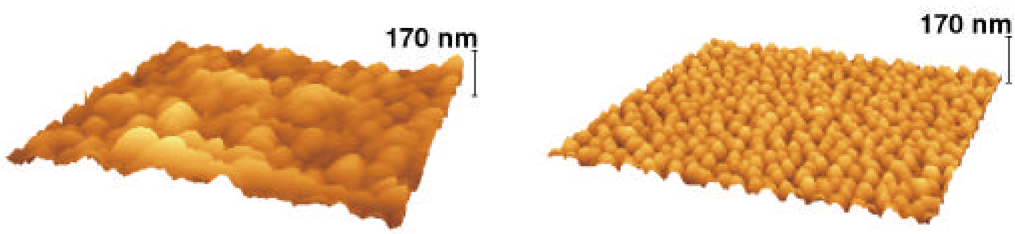
Introduction

Cubic silicon carbide (3C-SiC) is at present a topic of considerable interest due to its great promise as a material for electronic device applications and microelectromechanical systems (MEMS) in harsh environments or for biomedical applications [1-5]. Semiconductor materials grown directly on silicon profit by the availability of low-cost large area substrates, their superior thermal conductivity and the possibility to realize a new generation of devices monolithically integrated with silicon microelectronics. However, large lattice mismatch and the difference in thermal expansion coefficients cause high residual stress and substrate bending. Especially the thermal stress cannot be completely relaxed by the formation of misfit dislocations. Therefore it is important to employ lower growth temperatures in order to improve the quality of the heterostructure and to improve further processing. SiC replaces silicon in MEMS devices and gas-sensors for harsh environments due to its high chemical stability. On the other hand this advantage makes it difficult to employ standard patterning approaches – wet and even dry etching because of low etching rates and poor mask selectivity. New growth and patterning approaches should be developed to sustain flexibility of the device design. A novel alternative processing approach to bulk micromachining of polycrystalline SiC using Si molds was recently reported [6]. The aim of the present paper is to investigate low-temperature low-pressure chemical vapour deposition (LPCVD) growth of SiC on clean Si(100) and on Si(100) patterned with a SiO_2 mask for selective growth of SiC on Si in order to avoid the etching of SiC itself.

Results and discussion

The SiC growth was performed in a standard horizontal infrared-heated LPCVD machine AIX-200 designed by AIXTRON and operated at low pressure (20 to 100 hPa) utilizing the precursors carbon tetrabromide (CBr_4) and monosilane (SiH_4, 2% in H_2) as sources of C and Si, respectively. For more stable operation at high temperatures the heating system has been modified. A 150 W mercury-xenon lamp as an ultra violet (UV) radiation source has been added to the set-up [7]. The growth rate of SiC at 940°C was about 0.25 µm/h. Exactly (100) oriented Si substrates with and without patterned SiO_2 masks were employed. Our samples were grown with or without UV stimulation. Experiments with varied CBr_4/SiH_4 flow ratios were carried out. A short Si substrate-carbonisation step [1] was added in the experiments at the beginning of the SiC growth process.

The samples obtained were investigated by atomic-force microscopy (AFM), scanning electron microscopy (SEM), photoluminescence (PL), optical microscopy, transmission electron microscopy (TEM) and mechanical load-deflection measurements. In this work we concentrated our attention on the fabrication of patterned SiC on Si substrates. SEM and AFM investigations (Fig. 1) showed that the UV stimulation increased the uniformity of the grown surfaces and in most cases decreased their roughness [7].



a b

Fig. 1. AFM images (2×2μm^2) of the surfaces after SiC growth on Si (100) substrates for the same growth conditions (in particular duration 5 min): a – without UV stimulation; b – with UV stimulation.

Optical microscopy and SEM investigations showed mirror-like surfaces of the grown layers. TEM investigations of these samples revealed the transition from amorphous to fine polycrystalline and then to textured 3C-SiC films with variation of the Si/C ratio in the gas phase. We found broad PL peaks around 2.4 eV with full width at half-maximum (FWHM) of about 0.44 eV.

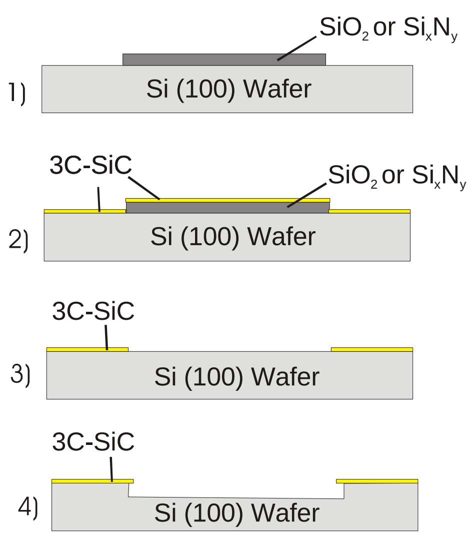


Fig. 2. Patterning of 3C-SiC on Si

The 40-90 nm thick SiC layers were patterned employing a novel lift-off approach [8] with SiO_2 or silicon nitride as sacrificial layer. The latter was sputter deposited on the Si surface up to a thickness of about 70 nm and patterned in HF. The SiO_2 mask was produced employing thermal oxidation at 1200°C up to a thickness of about 1 μm and also patterned in HF. The remaining stripes of the masks were [001] and [011] oriented and served as sacrificial layer for the following lift-off process (widely used in silicon technology and described schematically in Fig. 2) which was carried out in buffered HF (to lift-off SiC on SiO_2 or Si_xN_y). Finally, the Si was patterned employing etching in 30% KOH using the SiC as mask [8]. In both cases SiC was deposited as well on the free as on the masked areas of the surface. However with the silicon nitride mask the formation of significantly thicker SiC is observable near the edges of the silicon nitride mask (Fig. 3 a, b) for both stripe

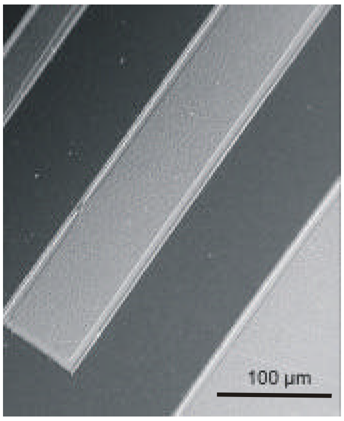
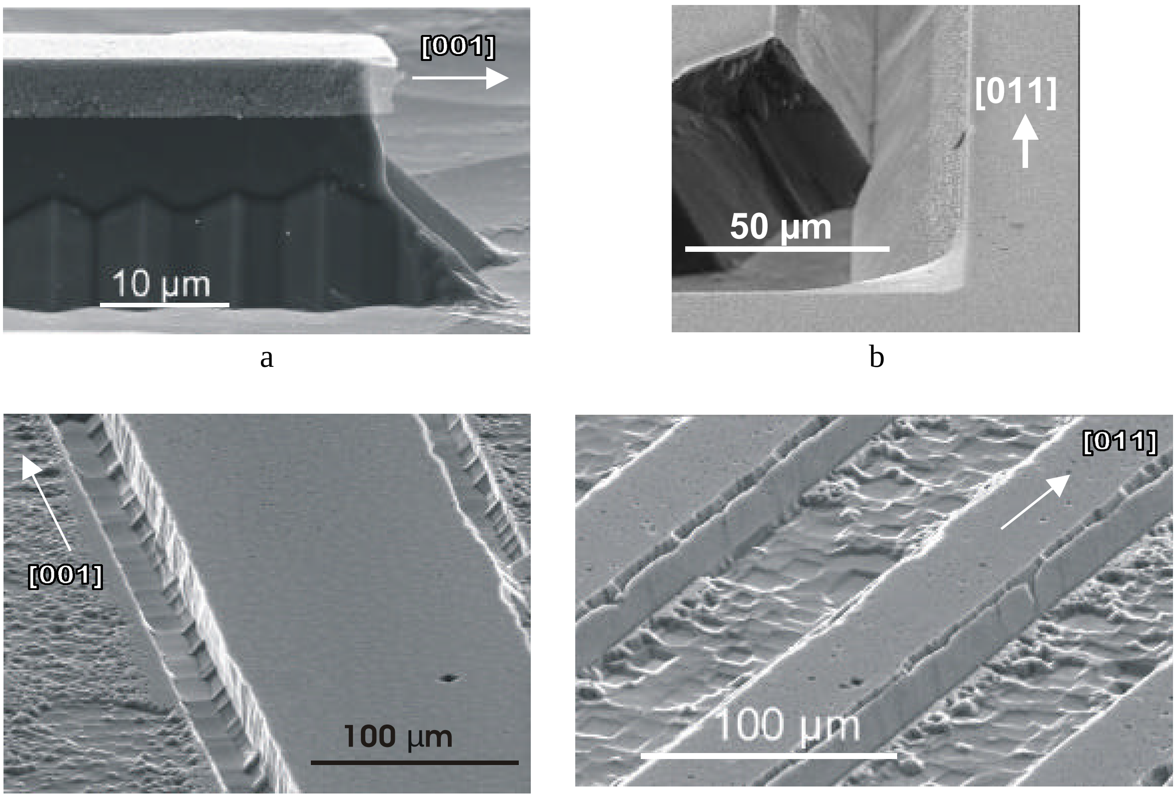


Fig. 3. Optical microscopy image of the sample after SiC growth on Si with a silicon nitride patterned mask (dark area is unmasked)

orientations. The lift-off process was complicated in most cases due to this pronounced growth on the edge of the sacrificial layer. In the case of growth employing SiO_2 masks no pronounced increased edge growth was observed and the lift-off yield approached 100%.

After etching the Si through the SiC mask we found for structures oriented along <100> directions undercut (Fig. 4 a, b). Cracking or fracturing of the overhanging layers was not observed even in the case of a very small radius of bending (Fig. 4a). Investigations of the second SiC layer deposition on an already patterned SiC/Si structure showed that for the [011]-oriented stripes further growth occurred everywhere except the borders between the SiC layer on the stripe and the sidewalls of the patterned Si and also except the narrow area of the planar Si wafer near the lower part of the Si sidewalls (Fig. 4 d). For the [001]-oriented stripes the SiC growth occurred on the first SiC layer including the bended part of the layer covering partly the Si sidewalls and on the Si wafer except an approximately 20 µm wide area near the sidewalls (Fig. 4 a, c). These features were revealed



a b

c d

Fig. 4. Plan-view SEM image of a micro-patterned SiC structure grown on Si (100) substrate: a - [001]-oriented stripe after first SiC layer growth and patterning (layer thickness approx. 40 nm); b – [001] and [011]-oriented surfaces after first SiC growth and patterning (layer thickness approx. 40 nm); c – [001]-oriented stripe after second SiC growth (layer thickness approx. 90 nm); d – [011]-oriented stripe after second SiC growth (layer thickness approx. 90 nm)

employing further Si etching. The presence of the 20 µm area near the sidewalls free of SiC gives a further possibility to promote SiC and Si patterning employing smaller spacings between the stripes.

The difference of patterning employing SiO_2 or Si_xN_y as a mask is caused by the difference of the growth on these different masks and in our case also by the significant difference in the thicknesses of both masks, 1µm and 70 nm respectively.

A plan-view SEM image of a micro-patterned SiC lateralresonant structure is shown in Fig.5. The edges of the patterned structure are sharp. Load-deflection measurements were employed to investigate mechanical properties of the grown layers. Circular and rectangular SiC membranes have been fabricated and measured with a local pressure of 80 and 160 kPa on the loading area using Dektak tracer [8]. The layers obtained reveal exciting mechanical stability.

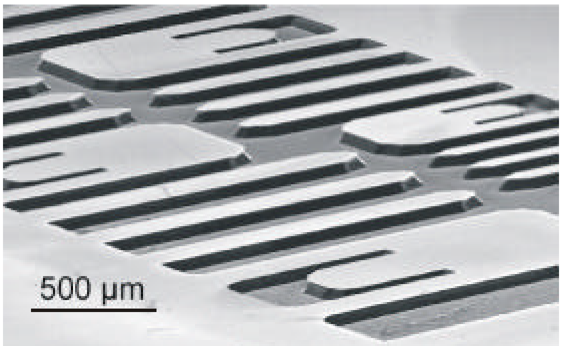


Fig. 5. Plan-view SEM image of a micro-patterned SiC lateral resonant structure on Si (100) substrate.

Summary

We have developed and described a low-cost approach to 3C-SiC LPCVD growth and patterning. LPCVD with UV stimulation has been developed as a technique for the low-temperature (below 950°C) growth of SiC on Si with a patterned SiO_2 or silicon nitride mask. Examples of surface micromachined structures patterned by the described lift-off approach with an excellent etching selectivity between Si and SiC are presented. The approach can be used for further pendeo-epitaxial growth or fabrication of micromechanical devices, gas sensors, or biomedical applications.

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