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β-SiC GROWTH ON Si BY REACTIVE-ION MOLECULAR BEAM EPITAXY*

J. Kuzmík [1]

Institute of Electrical Engineering, Slovak Academy of Sciences,
Dúbravska cesta 9, 842 39 Bratislava, Slovakia

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A novel technique of reactive-ion molecular beam epitaxy for the Si carbonisation is demonstrated. For a suggested temperature regime and technological recipe, stoichiometric β-SiC was obtained. This was proved by an in-situ diffraction patterns observation and after process X-ray photoelectron spectroscopy and atomic-force microscopy investigation.

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1 Introduction

Like diamond, SiC has long been recognised as a semiconductor material with outstanding physical and chemical characteristics. Compared to Si, SiC exhibits a larger bandgap, a higher breakdown field, a higher thermal conductivity and a high saturation velocity. These properties make SiC interesting for high-temperature, high-power and high frequency electronic devices. SiC has many crystalline forms with the same chemical composition. Among the many polytypes, β-SiC (or 3C-SiC) has a cubic structure and only this SiC polytype can be grown on Si.

The difference between the lattice constant of Si and that of β-SiC (20%) requires special attention to be focused on the Si/SiC interface. Therefore the heteroepitaxial growth of β-SiC on Si is performed in two steps. The first step is the carbonisation of Si. A thin strained layer of β-SiC may be formed when a bare Si surface is exposed to highly reactive carbon-containing radicals. After successful carbonisation, a co-deposition of Si and C-containing species can lead to epitaxial growth of SiC. The goal of our experimental work was to develop carbonisation technique on Si substrate using molecular beam epitaxy (MBE).

Till now, MBE growth of β-SiC heteroepilayers were reported by several combinations of sources for Si and C, e.g., solid Si source/C^+ ion beam [1], reactive ion beam SiH_4/CH_4 [2], $SiHCl_3$/C_2H_4 [3], solid Si source/C_2H_2 [4,5], Si_2H_6/C_2H_4 [6], and reactive ion beam C_3H_8/Si_2H_6 [7], respectively. In our work, for the first time, a carbonisation of Si substrate with propane cracked by dc electrostatic discharge is reported.

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[1] E-mail address: elekkuzm@savba.sk

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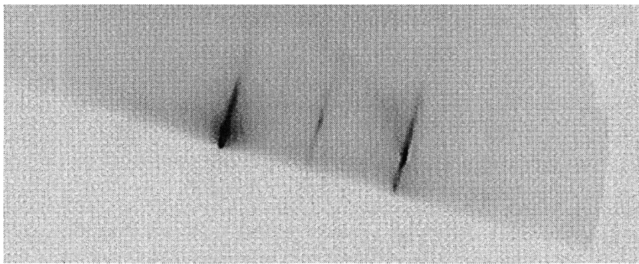

Fig. 1. Si RHEED pattern before carbonisation.

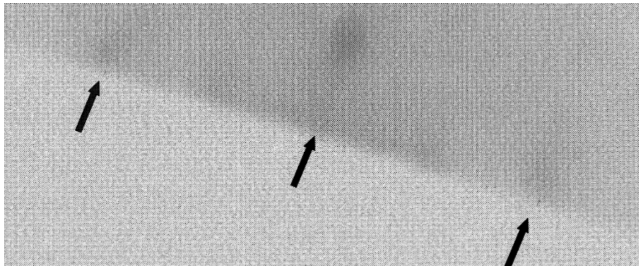

Fig. 2. β-SiC RHEED pattern after carbonisation.

2 Experiment

Growth of SiC was carried out in MBE system that consisted of a growth chamber and a loading chamber. The growth chamber is equipped with a sputter ion pump to achieve an ultrahigh vacuum prior to growth, and a turbo molecular pump for evacuation during source gas supply. We used e-gun for Si solid-source MBE growth and a cracker cell for gas-source supply of C radicals. The growth chamber is equipped with a reflection high-energy electron diffraction (RHEED) system for in-situ observation of the surface. Diffraction patterns on a RHEED screen were monitored and recorded with a CCD camera.

In our experiment, we used on-axis Si (1,0,0) substrate. A Si substrate was chemically cleaned with an oxidation solution NH_4OH : H_2O_2 : H_2O = 1:1:6. The substrate was immediately loaded into MBE system and heated from the backside by a resistive heating element in ultrahigh vacuum. The SiO_2 layer was removed at 850 ^{o}C and new 100 nm Si layer was grown using e-gun. Crystallinity of Si surface has been checked by RHEED after each processing step. Propane was chosen as the carbon containing gas. It flowed through a cracker cell where plasma was generated by means of dc-electrostatic discharge. The growth chamber is equipped by a liquid nitrogen shroud, by which most of the gas molecules are absorbed giving a high vacuum below 10^{-3} Pa during the growth. The carbonisation was carried out for various temperatures of the Si-substrate and different temperature cycles. The structural changes on the Si surface were in-situ monitored using RHEED diffraction patterns. For a “gradual regime”, the supply of cracked C_3H_8 was started at temperature of 400 ^{o}C (after the substrate was cooled down from 850 ^{o}C), and elevated to 1000 ^{o}C at a rate of 7 ^{o}C/min. The RHEED pattern remained intact up to the temperature of 810 ^{o}C, and for higher temperatures, ring-like RHEED pattern has appeared suggesting polycrystalline SiC surface. For “constant regime”, the bare Si surface was exposed to the C_3H_8-based plasma keeping the substrate at constant temperature. For 800 ^{o}C substrate temperature, Si diffraction pattern (Fig. 1) disappeared upon exposure for several seconds. A faint β-SiC diffraction pattern was observed after exposure in the plasma for 270 sec-

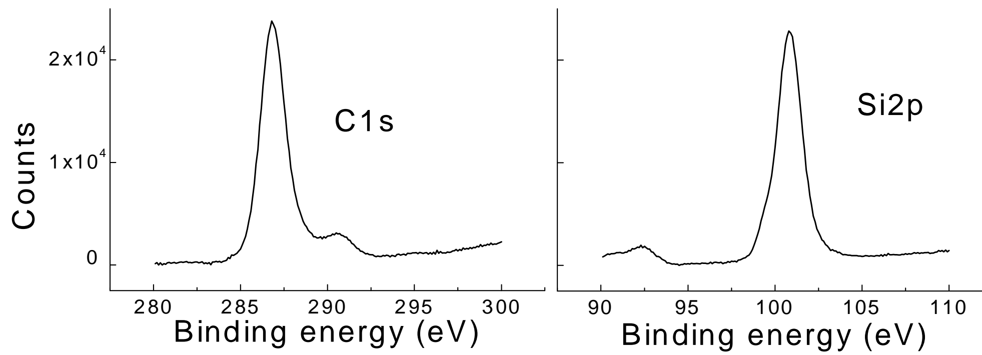

Fig. 3. XPS data for sample carbonised at 800 ^{o}C.

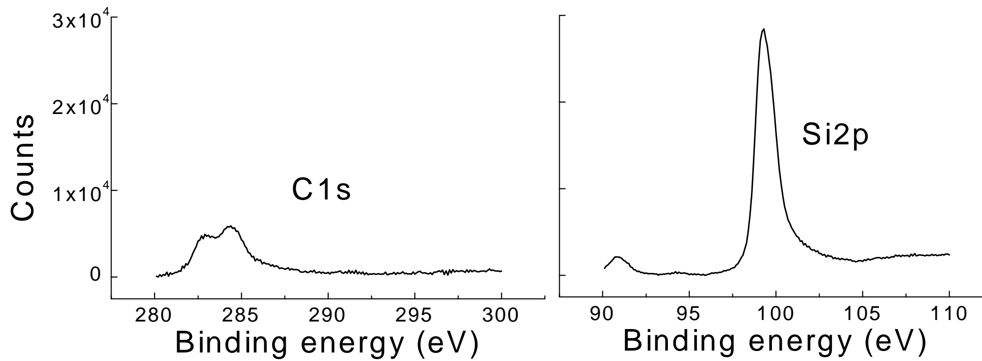

Fig. 4. XPS data for sample carbonised at 750 ^{o}C.

onds, shown in Fig. 2. A similar experiment for a lower temperature of 750 ^{o}C did not produce any change in the Si substrate RHEED pattern and no carbonisation process was observed for this condition. On the other hand, the reactions at 850 ^{o}C proved to be too fast, and the ring-like RHEED pattern suggested polycrystalline SiC surface. These conclusions were also proved by an X-ray photoelectron spectroscopy (XPS) experiment. The results for the 800 ^{o}C sample are shown in Fig. 3. Almost stoichiometric quality is demonstrated. Similar results were obtained for polycrystalline SiC. On the other hand, only 20% atomic percentage of C was obtained for a 750 ^{o}C MBE growth (Fig. 4) and, in addition, a shift in the binding energy was observed. An atomic-force microscopy image (AFM) of the 800 ^{o}C sample is shown in Figs. 5, 6. We suppose that the SiC is represented by 12 nm long triangle-like hillocks.

3 Conclusion

A successful carbonisation of Si substrate using gas source MBE is presented. dc electrostatic discharge in a cracker cell for producing C containing radicals is tested for the first time. It is shown that if Si is kept at a temperature of 800 ^{o}C during the process, stoichiometric β-SiC can be obtained. A decrease or increase in the temperature of Si substrate can lead to suppression of the carbonisation or the SiC surface polycrystallisation, respectively.

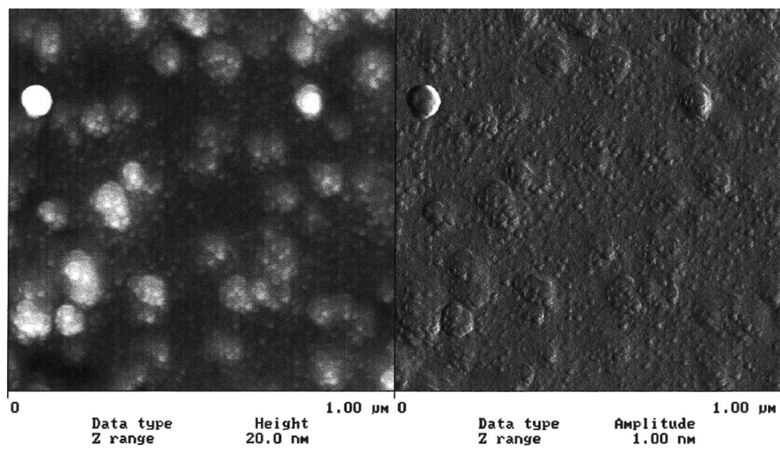

Fig. 5. AFM image of successfully carbonised Si.

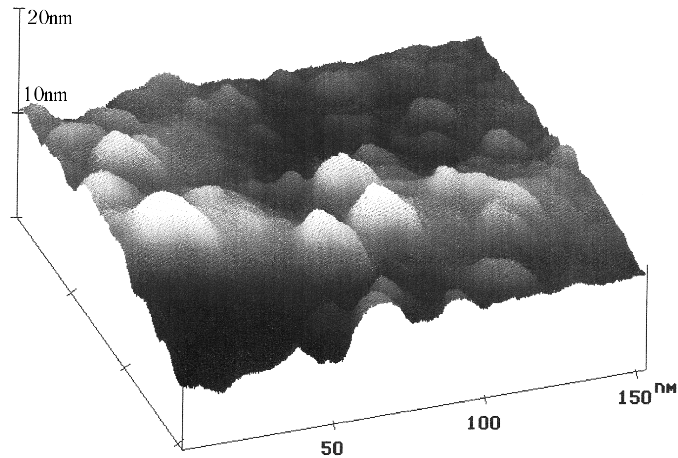

Fig. 6. AFM view angle image of successfully carbonised Si.

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