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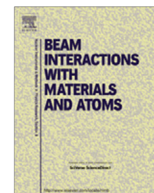

An XPS study to investigate the dependence of carbon ion fluences in the formation of buried SiC

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ABSTRACT

A detailed XPS analysis has been performed to observe the effect of carbon ion fluences in the formation of β-SiC by ion implantation. Carbon ion fluences of 1×10^{17}, 2×10^{17}, 5×10^{17}, and 8×10^{17} atoms/cm^2 at an ion energy of 65 keV have been used to implant Si at room temperature. The implanted samples were annealed at 1100 °C for 1 h in a mixture of Ar 96% and H_2 4%. The compositional depth profile along with the change in the chemical state of the implanted carbon and silicon in the annealed samples has been measured. The effect of ion fluences in the formation of SiC has been discussed in reference to binding energy shifts and integrated peak intensities of C 1s and Si 2p signals. It has been observed that the implanted carbon is totally consumed to make Si–C bonds for samples implanted at fluences of 1×10^{17}, 2×10^{17}, and 5×10^{17} atoms/cm^2. However, for the sample at a fluence of 8×10^{17} atoms/cm^2, a portion of the implanted carbon is found to be in the form of C–C bonds in the compositional depth profile peak position.

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1. Introduction

Due to its remarkable properties such as wide band gap, high thermal conductivity, and high breakdown fields [1], crystalline SiC materials are useful for high power, high frequency, and high temperature electronic device applications [2]. High quality SiC materials have also been employed to fabricate light emitting diodes [3–4] and UV sensors [5]. Several researchers have found promising applications of SiC in Micro-Electro-Mechanical Systems (MEMS) [6], field emission arrays [7], and selective etch stop layers [8]. In the current study, we are interested in synthesizing buried SiC layers by the implantation of C ions into Si. By controlling the energy and fluence of carbon implanted into Si by ion implantation, one has precise and predictable control over the depth and thickness of buried SiC structures [9]. Ion implantation has become a widely accepted tool to fabricate the buried SiC structures in Si.

With the first report of ion beam synthesis (IBS) of SiC in 1971 [10], large numbers of research works [11–14] have been published on IBS of SiC. According to previous studies, post implantation thermal annealing is required to form crystalline β-SiC if the implantation is performed at room temperatures. Previous published studies in the synthesis of SiC reported (a) the effects of post implantation annealing conditions [15] and (b) the effects of implanted carbon ion energy and ion fluences [16]. Various characterization techniques such as Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), and transmission electron microscopy (TEM) have been utilized to observe the phase formation of SiC for Si implanted with C ions [9]. However, there is still a very limited amount of research that uses the in-depth capability of any particular characterization tools to study the ion beam synthesis of SiC. In this paper, a more extensive use of the X-ray photoelectron spectroscopy (XPS) technique to study the effect of carbon ion fluence in the SiC formation process has been presented.

2. Experiment

Si(1 0 0) wafers (Boron doped p-type, resistivity of 10–20 Ω cm) were used in the present experiments. The silicon wafers were implanted with 65 keV carbon ions (C^-) at fluences of 1×10^{17}, 2×10^{17}, 5×10^{17}, and 8×10^{17} atoms/cm^2 by using the ion implantation facility in the Ion Beam Modification and Analysis Laboratory (IBMAL) at the University of North Texas. A National Electrostatics Corporation Source of Negative Ions by Cesium Sputter (SNICS-II) was used to produce the ions for the implantation [17–18]. The low current densities were maintained in order to avoid sample heating during ion implantation. The typical raster

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beam current densities were 1 μA/cm^2 and the implantation fluences were determined by current integration. The implantation profile of the carbon ions was simulated using a Monte Carlo simulation code (The Stopping and Range of Ions in Matter, SRIM-2008) [19]. For the 65 keV C^- implantation, the projected range (Rp) and straggling of the ions was simulated to be 192 and ±59 nm, respectively. The as-implanted samples were annealed in a gas mixture of argon and hydrogen (Ar 96% + H_2 4%) at a temperature of 1100 °C for 1 h to allow for the growth of crystalline SiC. XPS measurements on samples were performed with a XPS-phi Versa Probe model 5000 equipped with a sputter depth profiling system at the Center for Advanced Research and Technology (CART), University of North Texas, USA. In the XPS measurement, the Al monochromatic radiation (1486.6 eV) was used as source of x-rays, which was focused to a spot size of about 200 μm. The argon sputtering was performed at a chamber pressure of about 7.5×10^{-10} torr and at a typical beam voltage of 1 kV. The sputtering rate was determined to be about 80 Å/min.

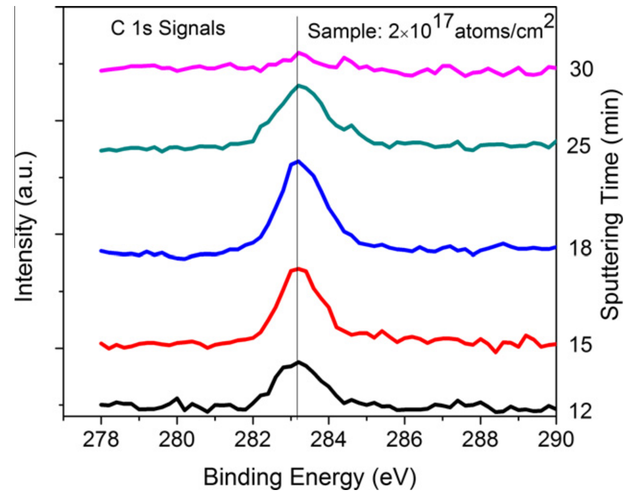

Fig. 2. XPS C 1s spectra of the sample implanted at a fluence of 2×10^{17} atoms/cm^2.

3. Results and discussion

Fig. 1 shows the compositional depth profiles of 65 keV carbon ions implanted into Si at fluences of (a) 1×10^{17} atoms/cm^2, (b) 2×10^{17} atoms/cm^2, (c) 5×10^{17} atoms/cm^2, and (d) 8×10^{17} atoms/cm^2, respectively. The carbon compositional depth profiles are for the samples annealed at 1100 °C for 1 h. The composition profile was deduced from the integrated peak intensity of C 1s and Si 2p XPS signals. A small amount of oxygen was also detected in the near surface region due to the air exposure and furnace annealing of the samples. The oxygen count was found to decay rapidly to below the detection limit within a depth of 20 nm. The carbon profile peak position for the sample implanted at higher fluences (5×10^{17} and 8×10^{17} atoms/cm^2) and lower fluences (1×10^{17} and 2×10^{17} atoms/cm^2) is observed to be different and attributed to the different surface sputtering effect during the ion implantation process. The XPS signals from the sample surface and the first few Ar sputtering cycles are not included in the depth profile of Fig. 1. An intense surface C 1s peak due to carbon contamination was observed in the sample surface. The presence of such surface carbon peaks was also observed in crystalline Si implanted with a high fluence of carbon at room temperature [9]. In order to monitor the formation of SiC, the shift in the binding energy as well as the change in the peak area in the XPS spectra of C 1s and Si 2p signal has been utilized. For example, Fig. 2 shows the XPS profile of the C 1s signal measured at different depths of the sample implanted at a fluence of 2×10^{17} atoms/cm^2. Similar features have been observed for samples implanted at higher fluences of 5×10^{17} and 8×10^{17} atoms/cm^2, respectively. The C 1s signals for samples implanted at fluences of (a) 5×10^{17} atoms/cm^2 and (b) 8×10^{17} atoms/cm^2 are shown in Fig. 3. As seen in Fig. 3, the intensity of the peak increases with depth up to the profile peak position (at around the 30th measuring cycle) and then starts to decrease after the peak profile position. From Fig. 3, it can be clearly seen that the binding energy (BE) is shifted to higher values from the surface to the profile peak position. The BE is shifted to lower values from profile peak towards the deeper layers in the Si substrate. In the case of the sample implanted at a fluence of 8×10^{17} atoms/cm^2, the BE shift to about 284 eV around the profile peak position can be seen in Fig. 3b. However for sample implanted at a fluence of 5×10^{17} atoms/cm^2 (Fig. 3a), the BE is not close to 284 eV at any depths from the surface. In order to study the nature of carbon related chemical bonds at different depths of implanted samples in more detail, the BE positions and full width at half maximum (FWHM) of the C 1s and Si 2p signals measured at different

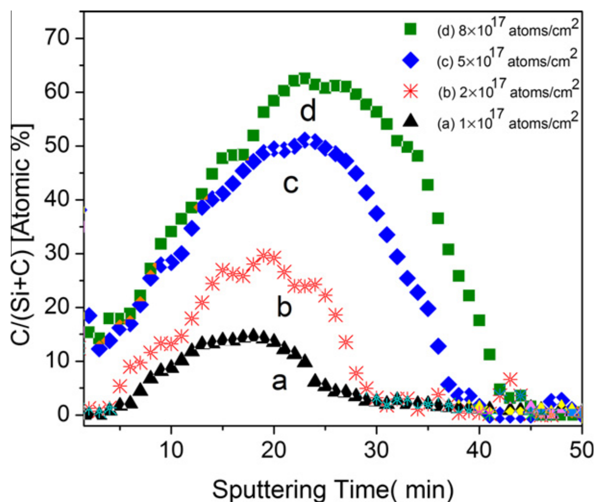

Fig. 1. Carbon atomic concentration profiles determined from the integrated intensity of C 1s and Si 2p signals.

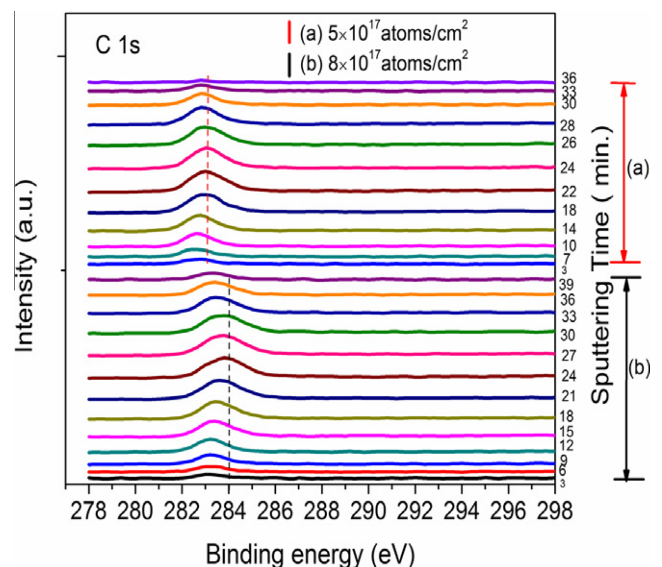

Fig. 3. XPS C 1s spectra of the sample implanted at a fluence of (a) 5×10^{17} and (b) 8×10^{17} atoms/cm^2 at various depths.

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