

# Low-temperature epitaxial growth of $\beta$ -SiC by multiple-energy ion implantation

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A cubic silicon carbide ( $\beta$ -SiC) buried layer was synthesized in Si(111) using a combination of multienergy carbon ion implantation at room temperature and post-thermal annealing. The crystal structure and the crystalline quality of the  $\beta$ -SiC layer was identified by x-ray diffraction in the  $\theta$ - $2\theta$  mode and was examined by pole figure measurement of x-ray diffraction. Interestingly, by using the multienergy implantation technique, the  $\beta$ -SiC buried layer showed epitaxial growth at annealing temperatures as low as 400 °C. At an annealing temperature of 800 °C, the x-ray pole figures show that the  $\beta$ -SiC buried layer has a near-perfect epitaxial relationship with the silicon substrate. [S0163-1829(98)02843-4]

Silicon carbide is a promising candidate material for device applications due to its outstanding properties such as wide band gap, high-temperature stability and high thermal conductivity, radiation hardness and chemical inertness, etc.<sup>1,2</sup> Considerable effort has been devoted to developing and improving methods to produce silicon carbide with high purity and good crystalline quality. Among these methods, high-dose carbon implantation into silicon in combination with subsequent or *in situ* thermal annealing, namely, ion beam synthesis (IBS), has been proven a powerful means of synthesizing polycrystalline or epitaxial  $\beta$ -SiC in silicon.<sup>3,4</sup> In accordance with the previous studies, the key factor that determines the crystalline quality of the  $\beta$ -SiC layer by IBS is the annealing temperature.<sup>5</sup> It seems to be clear from the published results to date that annealing temperatures between ~850 and 900 °C are needed to crystallize the implanted Si-C layer and transform the disordered Si-C bonds into the ordered  $\beta$ -SiC structure.<sup>6,7</sup> However, other authors demonstrate that much higher annealing temperatures, e.g., 1000,<sup>8</sup> 1250,<sup>9</sup> and 1405 °C (Ref. 10) are demanded to achieve crystalline silicon carbide layer in silicon. It has been reported also that other conditions like the implantation temperature<sup>11</sup> and the implanted carbon dose<sup>9</sup> might have some influence on the growth of the buried silicon carbide layer. Therefore, more systematic work is required for successful application of IBS to synthesize SiC.<sup>5</sup>

Recently, a multienergy ion implantation approach has been proposed to produce thick silicon carbide layer in silicon, and to modify its composition profile.<sup>12</sup> By selecting carefully the implantation energy and dose of carbon ions, a rectangular carbon concentration profile can be achieved for the buried  $\beta$ -SiC layer using this approach.<sup>12</sup> It is therefore applicable in device fabrications now that the  $\beta$ -SiC layer is able to grow epitaxially at low annealing temperatures.

We report, in this paper, the epitaxial growth of the  $\beta$ -SiC buried layer in silicon at low annealing temperatures by using this multienergy ion implantation technique.

A silicon wafer of (111) orientation was used as a substrate for multienergy carbon ion implantation. Using TRIM simulation, three different energies, i.e., 160, 100, and 60 keV, and three corresponding doses, i.e.,  $1 \times 10^{18}$ ,  $9 \times 10^{17}$ , and  $5.3 \times 10^{17}$  C<sup>+</sup>/cm<sup>2</sup>, were selected for the implantation. The beam current density of the carbon ions was controlled in the range of 9–12  $\mu$ A/cm<sup>2</sup>, which results in a target temperature of about 335–365 °C due to the beam heating effect. The implanted samples were then annealed in argon flux at temperatures from 400–1200 °C for 10 h to allow the growth of crystalline silicon carbide. After annealing, all samples were analyzed by x-ray diffraction in the  $\theta$ - $2\theta$  mode to identify the structure and by the pole figure measurement of the x-ray diffraction to examine the crystalline quality of the SiC buried layer.

X-ray diffraction analysis in the  $\theta$ - $2\theta$  configuration was carried out using a precise x-ray diffractometer with a resolution of 0.002°. The x-ray-diffraction pattern was obtained using a step of 0.02° with Cu K $\alpha$ 1. The Cu K $\alpha$ 2 was filtered by a monochromator. Figure 1 shows the diffraction pattern

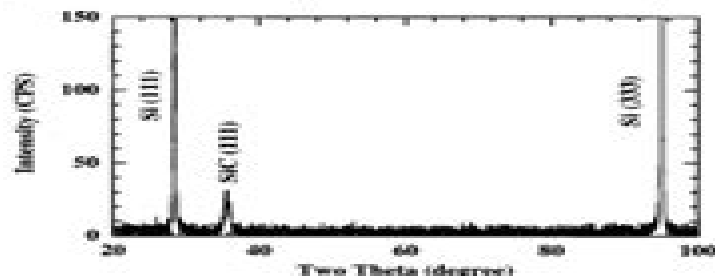


FIG. 1. The x-ray-diffraction pattern of the  $\beta$ -SiC buried layer formed after 10 h annealing at 800 °C, showing clearly the  $\beta$ -SiC (111) peak.

# Low Temperature Epitaxial Growth Of Semiconductors

**Donald T. Hawkins**



## **Low Temperature Epitaxial Growth Of Semiconductors:**

*Low Temperature Epitaxial Growth of Semiconductors* Takashi Hariu, 1991 Low temperature processes for semiconductors have been recently under intensive development to fabricate controlled device structures with minute dimensions in order to achieve the highest device performance and new device functions as well as high integration density. Comprising reviews by experts long involved in the respective pioneering work, this volume makes a useful contribution toward maturing the process of low temperature epitaxy as a whole. **Silicon Molecular Beam Epitaxy** E. Kasper, 2018-05-04 This subject is divided into two volumes. Volume I is on homoepitaxy with the necessary systems, techniques, and models for growth and dopant incorporation. Three chapters on homoepitaxy are followed by two chapters describing the different ways in which MBE may be applied to create insulator/Si stackings which may be used for three-dimensional circuits. The two remaining chapters in Volume I are devoted to device applications. The first three chapters of Volume II treat all aspects of heteroepitaxy with the exception of the epitaxial insulator/Si structures already treated in volume I. *State-of-the-Art Program on Compound Semiconductors : (SOTAPOCS XLII) and Processes at the Compound-Semiconductor/Solution Interface* P. C. Chang, 2005 *Semiconductor Physics And Devices* Donald Neamen, 2012 Provides a basis for understanding the characteristics, operation, and limitations of semiconductor devices. This title deals with the electrical properties and characteristics of semiconductor materials and devices. It intends to bring together quantum mechanics, the quantum theory of solids, and semiconductor material physics. **Low Temperature Epitaxial Growth of III-Nitride Semiconductors on Silicon Carbide Templates by Remote Plasma Metal-organic Chemical Vapor Deposition** Robert Dubreuil, 2017 Group III Nitride III-N semiconductors are of high interest due to their thermal and electrical properties. Opposed to other III-V group semiconductors, III-N semiconductors are hexagonal wurtzite structures that have a direct bandgap across the entire composition range. This wide bandgap range covers from the deep ultra violet to the infrared region of the electromagnetic spectrum. This makes the III-N semiconductor group ideal for LEDs, laser diodes, and photodetectors. This thesis presents an in-depth study to the growth of III-Nitrides on Silicon Carbide (SiC) templates. Due to the difficulty in growing bulk crystals for the III-Nitrides, non-native substrates must be used. Because of this, there exists a lattice mismatch between the substrates and thin films grown on top. SiC proves to be an ideal substrate as the lattice mismatch is around 3-5%. Thin films of III-N were grown upon commercially purchased SiC templates using remote plasma-enhanced metal-organic chemical vapor deposition (RP-MOCVD) in the Lakehead University Semiconductor Research Lab. Results were characterized using x-ray diffraction (XRD), atomic force microscope (AFM), energy-dispersive x-ray spectroscopy (EDX), and Raman spectroscopy. **Chemical Vapor Deposition: 1960-1980** Donald T. Hawkins, 1981-11-30 *JJAP*, 2006 *Advanced Processing of Electronic Materials in the United States and Japan* National Research Council (U.S.). Panel on Materials Science, 1986 **Semiconductors**, 1999 **Gallium Arsenide and Related Compounds**

**1990, Proceedings of the 17th INT Symposium on Gallium Arsenide and Related Compounds, Jersey, Channel Islands, September 1990** K. E. Singer, 1991 The 17th International Symposium on Gallium Arsenide and related Compounds was held in Jersey Channel Islands on 24-27 September 1990. This volume contains a total of 112 papers including four invited papers and a number of late news papers. The papers are divided into eight chapters relating to various aspects of the subject. These include bulk and epitaxial growth, characterization, processing, electron transport, and both high speed and optoelectronic devices. Current research and recent developments in these areas are covered. Particularly apparent is the increasing importance of III-V devices. These proceedings will be invaluable to researchers in solid state semiconductor and device physics both in industry and academia as they represent the latest developments in this exciting and rapidly developing field. *Laser Chemical Processing of Semiconductor Devices* Materials Research Society. Meeting Symposium B., 1984. **Semiconductors and Semimetals** Robert K. Willardson, 1998. *An Introductory Guide to EC Competition Law and Practice* Valentine Korah, 1994. Rare-Earth Doped Semiconductors II: Volume 422 S. Coffa, Albert Polman, Robert N. Schwartz, 1996. Rare earth doped semiconductors hold great potential for a variety of optoelectronic applications including lasers, LEDs, and optical amplifiers. In fact, the field has grown rapidly over the past several years with a clear switch in direction. The first book by this name was devoted to rare earth doped II-VI and III-V semiconductors; more than half of the papers in this new volume are devoted to rare earth doped silicon. This indicates that rare earth doping of silicon is now seriously considered as a means to achieve silicon based optoelectronic devices. In addition, new reports on rare earth doped III nitrides are also presented. Researchers from 14 countries come together in the volume to discuss current trends, highlight new developments, and identify potential electronic and optoelectronic applications. Topics include incorporation methods and properties, structural, electrical, and optical properties, excitation mechanisms, and electroluminescence and integration. **Japanese Technical Periodical Index**, 1987. *Gallium Arsenide and Related Compounds*, 1992. *Gallium Arsenide and Related Compounds 1988, Proceedings of the 15th INT Symposium, Atlanta, Georgia, September 1988* J. S. Harris, 1989. These proceedings cover gallium arsenide and related compounds. They provide an overview of research into materials growth and characterization, discrete device physics, and processing technology, epitaxial growth, and ion implantation. For researchers in physics, materials science, electronics, and electrical engineering. Indian Journal of Pure & Applied Physics, 1992. *Advances in Materials, Processing and Devices in III-V Compound Semiconductors: Volume 144* Devendra K. Sadana, Russell Dupuis, 1989-11-20. The MRS Symposium Proceeding series is an internationally recognised reference suitable for researchers and practitioners. *Materials Technologies for IR Detectors* Jean Besson, 1986.

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