Available online at www.sciencedirect.com

SCIENCE DIRECT®

Microelectronic Engineering 83 (2006) 30–33

MICROELECTRONIC ENGINEERING

www.elsevier.com/locate/mee

# Analysis of minority carrier diffusion length in SiC toward high quality epitaxial growth

T. Hatayama *, H. Yano, Y. Uraoka, T. Fuyuki

*Graduate School of Materials Science, Nara Institute of Science and Technology, 8916-5 Takayama, Ikoma, Nara 630-0192, Japan*

---

**Abstract**

Homoepitaxy of 4H-SiC grown by a horizontal hot-wall chemical vapor deposition and the minority carrier diffusion length were studied. With the addition of HCl during the etching and the epitaxy, an optimum growth window on the $(000\bar{1})$ C face became wide. Minority carrier diffusion length in SiC epilayers was evaluated by a line-scanning electron-beam-induced current method.

*Keywords:* SiC; CVD; Minority carrier diffusion length; EBIC

---

## 1. Introduction

Silicon carbide (SiC) has superior electrical properties such as a breakdown field at 2.5 MV/cm and electron mobility over 1000 $cm^2/V$ s. High-performance SiC diodes and transistors had been demonstrated. However, reliability of SiC devices is not as good as that of Si devices owing to the existence of high-density defects over $10^4\ cm^{-2}$ in the commercially available SiC wafers [1].

To realize high power bipolar devices, high-purity and thick epilayers are desired. Recently, the residual donor concentration below $10^{13}\ cm^{-3}$ has been grown by the horizontal hot-wall chemical vapor deposition (CVD) method on the 4H-SiC (0001) Si face [2]. A high growth rate over 50 μm/h has been achieved by the addition of hydrogen chloride (HCl) during the growth [3]. However, few reports are available on behavior of minority carriers in SiC epilayers. The minority carrier diffusion length is one of the important physical parameter, which affects especially the electrical properties of bipolar devices.

In this study, homoepitaxy of 4H-SiC and the analysis of minority carrier diffusion length in the epilayers are reported. We describe additional effects of HCl and doping properties of phosphine ($PH_3$) in the hot-wall CVD system. Epitaxial quality and minority carrier diffusion length in SiC are analyzed nondestructively by an EBIC system.

## 2. Experiments

Commercially available 4H-SiC {0001} 8° and $(11\bar{2}0)$ substrates were used. Epitaxial growth was carried out by a horizontal hot-wall CVD reactor. Propane ($C_3H_8$) and silane ($SiH_4$) were used as source gases. The typical growth temperature, pressure, and C/Si ratio were 1550–1600 °C, 10–30 kPa, and 0.8–2.0, respectively, which yielded a growth rate of 5–10 μm/h. Nitrogen ($N_2$) or $PH_3$ (1% in $H_2$) were used for the n-type dopant sources. Surface structures and electrical properties of epilayers with thickness over 10 μm were characterized. The donor concentration of epilayers was estimated from capacitance–voltage measurements.

Quality of epilayers was evaluated by a scanning electron microscope with a conventional EBIC system [4]. To measure a minority carrier diffusion length by a line-scanning EBIC technique, Schottky contacts were formed on the epitaxial surface. The typical accelerating voltage and primary electron beam current in the EBIC system were 30 kV and 200 pA, respectively. A diameter of the primary electron beam was focused to less than 100 nm. EBIC analyses were carried out at the zero bias condition and at room temperature.

---

* Corresponding author. Tel.: +81 743 72 6072; fax: +81 743 72 6079.
*E-mail addresses:* hatayama@ms.naist.jp, hatayama@ms.aist.-nara.ac.jp (T. Hatayama).

0167-9317/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.mee.2005.10.019

## 3. Results and discussion

A smooth surface without defects such as pits on $\{0001\}$ faces and hillocks on the $(11\bar{2}0)$ face can be obtained by the use of HCl during the etching and the initial stage growth. Reduction of defects with the addition of HCl was remarkably observed on the $(000\bar{1})$ C face. Without the use of HCl, triangular shape defects with the density of 350 $\mathrm{cm}^{-2}$ were formed as shown in Fig. 1(a). The C/Si ratio and thickness of epilayer were 1.7 and 27 μm/h, respectively. On the other hand, with the addition of HCl (1 sccm), the density of the defect could be reduced reproducibly below 50 $\mathrm{cm}^{-2}$ in Fig. 1(b). Though the growth window of the C/Si ratio on the $(000\bar{1})$ C face was narrower than that on the $(0001)$ Si face [5], the smooth surface could be obtained by the use of HCl at the C-rich condition on the $(000\bar{1})$ C face. Surface defects in a substrate and unusual nuclei on the growing surface will be removed by the chemical reactions between HCl and SiC.

By the use of the site-competition effect, unintentionally doped epilayers showed the n-type conduction at $5\times10^{13}\ \mathrm{cm}^{-3}$ on the $(0001)$ Si and $8\times10^{14}\ \mathrm{cm}^{-3}$ on the $(000\bar{1})$ C face, respectively. In the case of $N_2$ doping, the donor concentration from $2\times10^{15}\ \mathrm{cm}^{-3}$ to $2\times10^{18}\ \mathrm{cm}^{-3}$ on the $(0001)$ Si face was changed by the control of flow rate from 0.1 to 100 sccm. In the case of $PH_3$ doping, n-type epilayers were grown reproducibly. Memory effects cased by residual phosphorus related species in the reactor were not observed even in the hot-wall CVD reactor. With the increase of $PH_3$ flow rate from 0.03 to 0.12 sccm, the donor concentration in $(11\bar{2}0)$ face proportionally increased from $8\times10^{15}\ \mathrm{cm}^{-3}$ to $4\times10^{16}\ \mathrm{cm}^{-3}$. Fig. 2 shows the C/Si ratio dependence of donor concentration for 4H-SiC epilayers on $(0001)$ and $(11\bar{2}0)$ faces. The $PH_3$ and $SiH_4$ flow rates were kept at 0.1 and 3 sccm, and the $C_3H_8$ flow rate was changed. The phosphor incorporation is gradually decreased with the increase of C/Si ratio, following the site-competition effect. The donor concentration for the $(11\bar{2}0)$ face was about ten times higher than that for the $(0001)$ Si face. The difference between $(0001)$ Si and $(11\bar{2}0)$ face will cause the bond configuration on the growing surfaces: the number of adsorption sites for phosphorus on the $(11\bar{2}0)$ face is larger than that on $(0001)$ Si face.

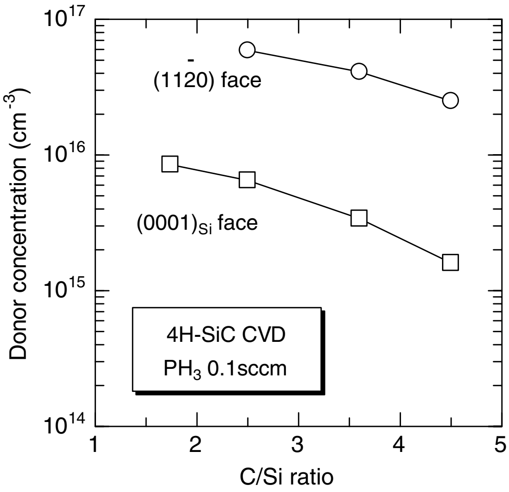

Fig. 2. C/Si ratio dependence of donor concentration.

With the addition of HCl during the etching and growth, a featureless EBIC image for an epilayer was observed. On the other hand, without the addition of HCl, many dark areas were observed as shown in Fig. 3. A dark area indicated the decrease of EBIC signal in our system. After an observation of EBIC image, a sample was etched by a conventional KOH method to identify the kinds of defects. Dark areas corresponded to defects, which are recombination centers for the minority carriers generated by the primary electron beam in the EBIC system. Small dark spots in the magnified EBIC image were edge and screw dislocations. Triangular-like and streamer EBIC images correspond to the triangular shape defects and basal plane dislocations, respectively, which has a gradation at the upper stream of the $(11\bar{2}0)$ off direction in

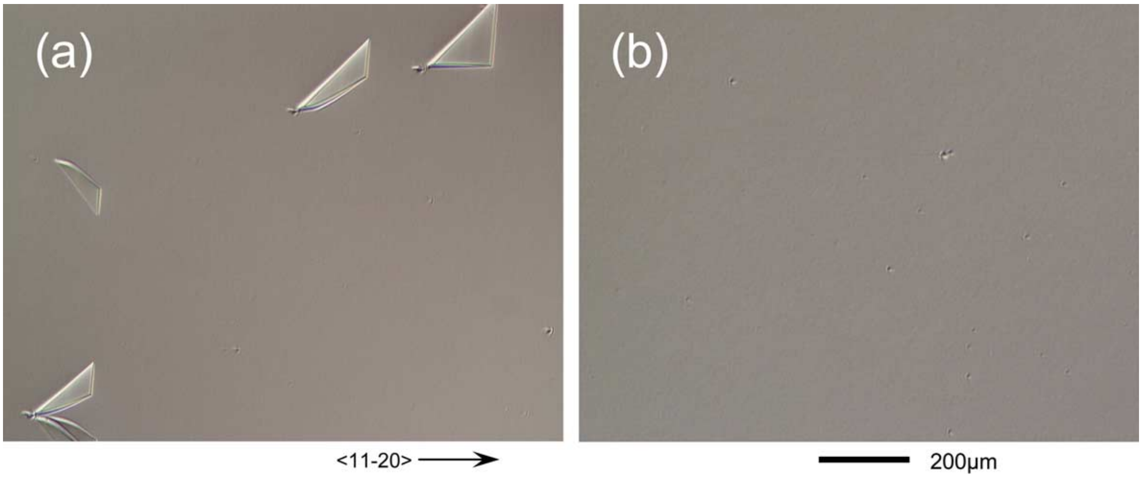

Fig. 1. Surface morphology of a 4H-SiC $(000\bar{1})$ C face epilayer: (a) without and (b) with an addition of HCl.