Alpha-Irradiation-Induced Doping of Si

Eun Je Lee, Young Bae Kong, Min Goo Hur*
Radiation Instrumentation Research Division, Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute, 29 Geumgu-gil, Jeongeup-si, Jeollabuk-do 580-185, Republic of Korea
**Corresponding author: hur09@kaeri.re.kr*

1. Introduction

It has been revealed that semiconducting materials can be doped by nuclear reactions. Those reactions can be induced by thermal neutrons, high energy charged particles and photons. Among them, researches on neutron transmutation doping have been intensively performed [1]. Furthermore, this method has been widely used for the production of P-doped Si in semiconductor industries. However, researches on nuclear doping induced by charged particles were rarely carried out relatively [2]. In this study, we present a doping method based on the alpha irradiation of pure Si. The alpha-irradiated Si sheets were characterized using a field emission scanning electron microscopy (FESEM) and X-ray photoelectron spectroscopy (XPS).

2. Methods and Results

2.1 Materials, Alpha Irradiation Experiments, and Characterization

Si sheets with no doping (size: 10 mm x 10 mm x 0.5 mm, purity: 99.999%, SI003077, Goodfellow) were used as irradiation targets.

Main nuclear transmutations induced by the alpha irradiation of Si (^{28}Si: 92.223%, ^{29}Si: 4.685%, ^{30}Si: 3.092%) are ^{28}Si(α, p)^{31}P and ^{28}Si(α, n)^{31}S. Phosphorus donor impurities can be produced in two ways: (a) directly by the former reaction and (b) by the latter reaction followed by β+ decay with a half-life of 2.58 s. To determine the alpha particle beam energy for the production of P by the nuclear transmutation, experimental cross-section data were obtained from EXFOR database [3]. According to EXFOR database, experimental cross-section data of ^{28}Si(α, p) ^{31}P reaction is provided only up to ~12 MeV and shows the maximum value of ~0.3 barns around 10.7 MeV. In the case of ^{28}Si(α, n)^{31}S reaction, the cross-section shows the maximum value of ~ 0.5 barns around 29 MeV. Considering cross-sections of above nuclear reactions and circumstances of the cyclotron, the energy of the alpha particle beam was determined to be ~29 MeV.

Si sheets were irradiated with an alpha particle beam generated from a cyclotron (MC-50, Scanditronix, Sweden) at Korea Institute of Radiological and Medical Sciences (KIRAMS). The irradiation process was carried out at room temperature in a vacuum chamber. The current density of the beam was ~320 μA/cm^2. Fluences of the alpha particle beam irradiating the samples were changed from 3.58 x 10^{15} to 2.86 x 10^{16} cm^{-2}.

The morphologies of pristine and alpha-irradiated Si sheets were characterized with FESEM (Hitachi S-4800). The chemical compositions of pristine and alpha-irradiated Si sheets were investigated with XPS using a Mg and Al Kα X-ray source in a SIGMA PROBE (Thermo VG) spectrometer. All the XPS spectra were charge-compensated to C 1s at 285.0 eV [4].

2.2 Surface Morphology

Fig. 1 displays low magnification FESEM images of the pristine and the alpha-irradiated Si sheets. Because the pristine Si sheet was naturally unpolished, it showed rough surface structures. Comparing FESEM images of the pristine and the alpha-irradiated Si sheets, no significant change in the morphology was observed. Even in magnified FESEM images (Fig. 2), there was no apparent change. This result indicated that the surface morphology of Si sheets was hardly influenced by the alpha irradiation.

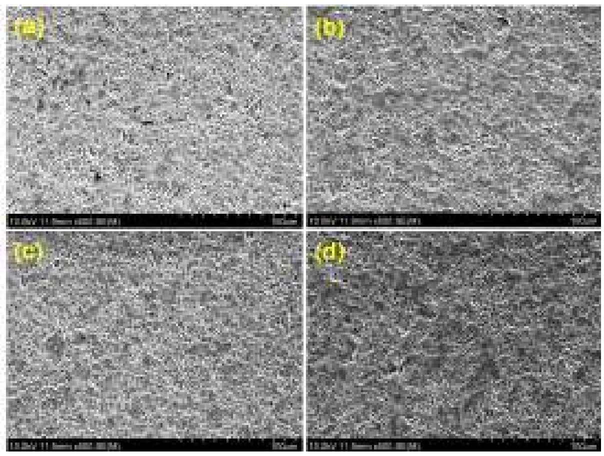

Fig. 1. Low magnification FESEM images of pristine (a) and alpha-irradiated Si sheets with fluences of 3.58 x 10^{15} (b), 1.43 x 10^{16} (c), and 2.86 x 10^{16} cm^{-2}, respectively.

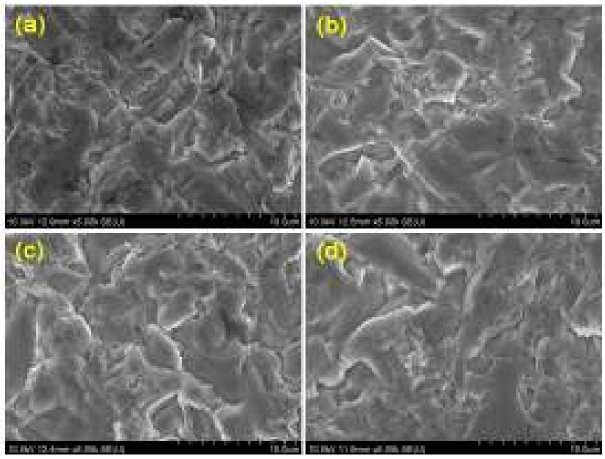

Fig. 2. Magnified FESEM images of pristine (a) and alpha-irradiated Si sheets with fluences of 3.58 x 10^{15} (b), 1.43 x 10^{16} (c), and 2.86 x 10^{16} cm^{-2}, respectively.

2.3 Chemical Composition

Fig. 3 shows XPS spectra of the pristine and the alpha-irradiated Si sheets. The spectrum of the Si sheet irradiated with a fluence of 3.58 x 10^{15} cm^{-2} exhibited no significant peak as well as that of the pristine Si sheet. However, a small peak centered at ~130.6 eV corresponding to P 2p bond appeared when the Si sheet were alpha-irradiated with a fluence of 1.43 x 10^{16} cm^{-2}. In addition, intensity of the peak increased when the fluence was further increased to 2.86 x 10^{16} cm^{-2}. This result revealed that P atom was successfully produced by the alpha irradiation of Si.

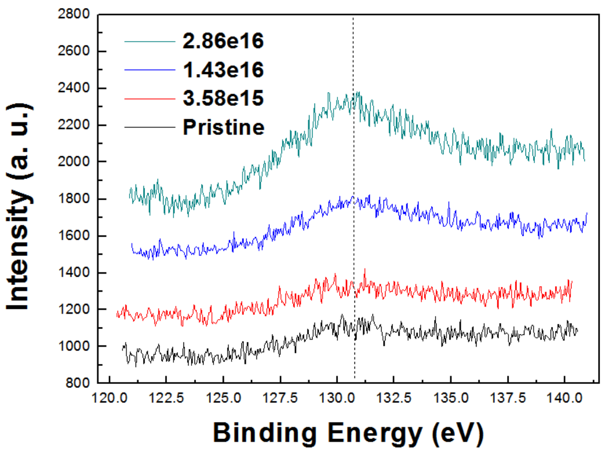

Fig. 3. XPS spectra of pristine (a) and alpha-irradiated Si sheets with fluences of 3.58 x 10^{15} (b), 1.43 x 10^{16} (c), and 2.86 x 10^{16} cm^{-2}, respectively.

3. Conclusions

A method to dope Si was presented on the base of the alpha irradiation. After the alpha irradiation, P atoms were created from Si atoms by nuclear transmutation while the microstructure of Si surfaces was almost unchanged. As the fluence increased, the amount of P atoms on the Si surface was also increased.

The alpha irradiation method can be an alternative method for P-doping of semiconducting materials.

REFERENCES

[1] I. S. Shlimak, Neutron Transmutation Doping in Semiconductors: Science and Applications, Physics of the Solid State, Vol.41, p.716, 1999.

[2] V. V. Kozlovskii and L. F. Zakharenkov, Radiation Doping Methods of Semiconductor Materials: the Nuclear Doping by Charged Particles, Radiation effects and Defects in Solids, Vol.138, p.75, 1994.

[3] <http://www.nndc.bnl.gov/nndc/exfor>.

[4] R. Q. Liang, X. B. Su, Q. C. Wu, and F. Fang, Study of the Surface-Modified Teflon/Ceramics Complex Material Treated by Microwave Plasma with XPS Analysis, Surface and Coatings Technology, Vol.131, p.294, 2000.