Research Article

Formation of Silicon Carbide Using Volcanic Ash as Starting Material and Concentrated Sunlight as Energy Resource

Kensuke Nishioka, Junki Komori, Kouji Maeda, Yasuyuki Ota, Hiroshi Kaneko, and Kosei Sato

Faculty of Engineering, University of Miyazaki, 1-1 Gakuen Kibanadai Nishi, Miyazaki 889-2192, Japan

Correspondence should be addressed to Kensuke Nishioka; nishioka@cc.miyazaki-u.ac.jp

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SiC was formed using volcanic ash as starting material and concentrated sunlight as energy resource. The solar furnace was composed of two parts: Fresnel lens and reacting furnace. The reacting furnace was composed of a cylindrical vacuum chamber and quartz glass plate functioning to guide the concentrated sunlight into the furnace and was placed at the focal point of the Fresnel lens. The sample was made from the mixture of silica formed from volcanic ash and graphite and placed in the carbon crucible inside the reacting furnace. The temperature in the carbon crucible reached more than 1500°C. After the reaction using concentrated light, β -SiC was formed. The weight % of formed SiC was 90.5%.

1. Introduction

Growing interest in silicon carbide (SiC) has arisen from the need for electronic devices that are capable of operating at high power levels, high temperatures, and hostile environments. SiC is a wide band-gap semiconductor and ensures high temperature stability and is also characterized by large breakdown fields [1–4]. α - and β -SiC are the major polytypes of SiC. The hexagonal polytypes of 2H-, 4H-, and 6H-SiC are classified as α -SiC. The cubic type of 3C-SiC is categorized as β -SiC. These crystal structures have an important role in application of SiC to own different physical properties [1, 2]. The reaction of α -SiC production by silica with carbon is shown by the following equation:

Regarding the reaction of β -SiC, production is given by the following equations:

In industry, α - and β -SiC powders are mainly produced by a carbothermic reaction of silica and carbon at temperatures greater than 2200°C and 1500°C, respectively [5–8]. It is an energy intensive process. In this process, the high purity silicon dioxide (SiO_2) and infinite energy for high temperature are needed.

In order to prepare the high purity SiO_2 from unexplored feedstock, we used volcanic ash as a starting material. A kind of volcanic ashes called “Shirasu,” abundantly deposited due to a big pyroclastic flow in Southern Kyushu, Japan, is one of the unused natural resources. In our previous work, we have successfully formed high purity SiO_2 from Shirasu with a simple process [9, 10].

In order to generate the high temperature, we used concentrated sunlight as an energy source for the formation of SiC. The solar furnace can produce high temperature in a short period of time by utilizing optical systems as a sunlight concentrator. Through this method, a new production process to create materials that require to be produced under high temperature condition with regard to the shortage of energy resources has been significantly provided [11–14].

There is no report which forms the semiconductor material of high value like SiC by using environment-friendly

FIGURE 1: Solar furnace system. As shown in (a), the solar furnace was composed of two parts: Fresnel lens and reacting furnace. The carbon crucible was covered with heat insulators to keep the crucible's high temperature, as shown in (b).

concentrated sunlight. In this study, we prepared a SiC using the solar furnace that produces an ultrahigh temperature condition by utilizing a Fresnel lens as a sunlight concentrator.

2. Experimental

Figure 1 shows the solar furnace used in this study. As shown in Figure 1(a), the solar furnace was composed of two parts: Fresnel lens and reacting furnace. The material of the Fresnel lens used in this study was polymethyl methacrylate (PMMA), and it had the area of $1.40 \text{ m} \times 1.05 \text{ m}$. The reacting furnace was composed of a cylindrical vacuum chamber (diameter: 20.45 cm and depth: 14.3 cm) and quartz glass plate functioning to guide the concentrated sunlight into the furnace and was placed at the focal point of the Fresnel lens. The carbon crucible was covered with heat insulators to keep the crucible's high temperature, as shown in Figure 1(b). The solar furnace traced the sun to keep the Fresnel lens normal to the sun. For the sun tracking, an automatic sun tracker (Green Source Technology, GST-200) was used.

The sample used in this study was made from the mixture of silica formed using Shirasu volcanic ash and graphite and placed in the carbon crucible inside the reacting furnace. The high purity nanoporous silica was fabricated using Shirasu volcanic ash as a starting material. The materials with Shirasu were melted at 1400°C . A mother glass was formed by quenching the melt in pure water. Leaching was performed by immersing the mother glass into a hydrogen chloride (HCl) solution. Nonsilica phases formed by phase separation in the mother glass were leached out with acid solution. The obtained porous silica was more than 99% pure [9, 10].

After that, the air inside the reacting furnace was discharged so that it will be in vacuum condition with the pressure of 0.1 MPa. The Ar gas was then flowed into the reacting furnace until it reached the atmospheric pressure. Next, the sample was irradiated with the high concentrated sunlight for 3 hours while the Ar gas kept on flowing at 3 l/min into the reacting furnace. After the irradiation process, the furnace was left until the sample cooled down to room temperature under Ar atmosphere. Finally, the sample was

FIGURE 2: Direct normal irradiance (DNI) when the sample was irradiated with the high concentrated sunlight.

evaluated by X-ray diffraction (XRD, PANalytical, X'Pert PRO) and Raman spectroscopy (SPEX, 1877).

3. Results and Discussion

The solar furnace system used the Fresnel lens to collect sunlight and focused it onto the reacting chamber. The system can only use the direct beam component of sunlight. Figure 2 shows direct normal irradiance (DNI) when the sample was irradiated with the high concentrated sunlight. DNI during the experiment was stable and high. Since the solar furnace is equipped with the sun tracking system, temperature of the furnace depends on the intensity of DNI. Therefore, it is necessary to use a stable and high DNI.

Figure 3 shows XRD patterns of the sample before and after the irradiation process. Through the XRD analysis before irradiation, the pattern showed only diffraction peaks from graphite (C). From this result, the silica that had been prepared by using Shirasu volcanic ash was proved to be noncrystalline. On the other hand, the result of XRD analysis

FIGURE 3: X-ray diffraction patterns of samples before and after irradiation process of concentrated sunlight.

FIGURE 4: Raman spectra of samples before and after irradiation process of concentrated sunlight.

after irradiation confirmed that five diffraction peaks, which were not seen in the result before irradiation, appeared. The diffraction peak labeled with (111) was the characteristic of SiC (α - or β -SiC), while the other peaks labeled with (220), (311), (200), and (222) were based on β -SiC [15]. From XRD results, the sample was found to have produced the β -SiC component. As mentioned in the introduction, the temperature higher than 1500°C is needed for the formation of β -SiC. It is found that the temperature in the carbon crucible reaches more than 1500°C.

Figure 4 shows the result of Raman spectra analysis of the sample before and after the irradiation process. The result before irradiation showed only two peaks due to graphite (C). On the other hand, in the Raman spectra after irradiation, two strong peaks were observed. The peak at 978 cm^{-1} is assigned to longitudinal optical (LO) phonon peak of SiC, and the other at 798 cm^{-1} is assigned to transverse optic (TO) phonon peak reported by Feldman et al. [16]. Small peaks around 1540 cm^{-1} and 1590 cm^{-1} are assigned to SiO_2 and

the remaining graphite, respectively. The noncrystalline SiO_2 in the sample before irradiation was crystallized by the high temperature. This Raman spectrum's results also indicated that SiC was formed in the sample after the irradiation process.

The quantitative determinations of the irradiated portion of the sample were carried out by calibration curves derived from XRD analysis to clarify the SiC content. First, standard specimens were made from mixture of SiC and raw materials (SiO_2 and C) in different weight ratios %. Those standard specimens were measured, respectively, by XRD analysis. From peak area ratios $[\text{SiC}_{\text{area}}/(\text{SiC} + \text{C})_{\text{area}}]$ of SiC and C and weight ratios % $[\text{SiC}_{\text{wt}}/(\text{SiC} + \text{C})_{\text{wt}}\%]$ of SiC and C, the calibration curves were obtained. From the result of the calibration curves it was found that $\text{SiC}_{\text{wt}}/(\text{SiC} + \text{C})_{\text{wt}}\%$ of the sample after irradiation process was 90.5%.

Previously, SiC was produced by the equipment which used electric power as energy source. For the formation of SiC, the high temperature over 1500°C is needed and the energy consumption of these methods is high [7, 8]. In this study, we used solar energy as energy source and SiC was successfully formed with the high temperature evolved from concentrated sunlight. The method implemented in this study could effectively avert the shortage of energy resources by using renewable energy.

4. Conclusion

We prepared SiC from volcanic ash using the solar furnace, which has never been performed before. The solar furnace was composed of two parts: Fresnel lens and reacting furnace. The sample was made from the mixture of SiO_2 formed from volcanic ash and graphite and placed in the carbon crucible inside the reacting furnace. The XRD and Raman spectra indicated that SiC was formed in the sample after the irradiation process. The type of the SiC was β -type (3C-SiC). It is expected to be the valid utilization method with volcanic ash as the natural resource, to form superior materials using renewable energy.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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