FABRICATION OF HYDROPHOBIC SURFACES FROM HYDROPHILIC BeO BY ALPHA-IRRADIATION-INDUCED NUCLEAR TRANSMUTATION

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Abstract

Hydrophobic surfaces were simply fabricated by irradiating hydrophilic BeO surfaces with an alpha particle beam from a cyclotron. In this research, BeO disks were irradiated under conditions of ~25 MeV in alpha particle energy and ~315 nA/cm^2 in beam current density with different fluences.

After the alpha irradiation, the wetting property of alpha-irradiated BeO surfaces was analyzed by measuring water contact angles (CAs). The changes in the morphology and chemical composition of BeO surfaces were analyzed using a 3D optical surface profiler and X-ray photoelectron spectroscopy.

C and F atoms were created, and consequently, hydrophobic CF_2 functional groups were formed by the alpha irradiation of hydrophilic BeO. The amount of CF_2 functional groups on the surface increased as the fluence increased. Accordingly, the CA of alpha-irradiated BeO surfaces gradually increased as the fluence increased. In conclusion, hydrophilic BeO surfaces could be easily converted to hydrophobic surfaces by the alpha irradiation.

INTRODUCTION

Wettability is one of the most important properties related to various phenomena such as adhesion, printing, cleaning, painting, lubrication, and so on [1].

It has been revealed that the wettability is controlled by two factors, the surface roughness related to the morphology and the surface energy concerned with the chemical composition [2]. Among various methods to control the wettability, irradiation technique is known to be a simple process that can modify both the surface roughness and the surface energy simultaneously [3,4]. Although many irradiation methods using ion implantation, plasma treatment, and synchrotron radiation have been developed [5-7], the method utilizing irradiation-induced nuclear transmutations has not been reported as far as we know.

Here, we present a simple route to change hydrophilic BeO into a hydrophobic surface via alpha-irradiation-induced nuclear transmutation. The alpha-irradiated BeO disks were characterized using a 3D optical surface profiler, an X-ray photoelectron spectroscopy, and contact angle measurement. The wettability of BeO was controlled from hydrophilicity to hydrophobicity by simply increasing the fluence.

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EXPERIMENTAL

BeO disks with a diameter of 35 mm and a thickness of 2 mm (BeO >99.5%, Thermalox995^{TM}, Materion, USA) were used as irradiation targets. BeO disks 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 energy of the alpha particle beam was ~25 MeV, and the current density of the beam was ~315 nA/cm^2. Fluences of the alpha particle beam irradiating the samples were 5.97 x 10^{14} and 4.53 x 10^{15} cm^{-2}.

The wettability was analyzed by a water contact angle (CA) measured with a CA measurement system (SEO Co., Ltd., Phoenix 300 Plus). The volume of a water drop used for the CA measurement was 4 μL.

The morphologies of pristine and alpha-irradiated BeO disks were characterized with a 3D optical surface profiler (Nano System Co. Ltd., NV-2000). The chemical compositions of pristine and alpha-irradiated BeO disks were investigated with X-ray photoelectron spectroscopy (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 [8,9].

RESULTS AND DISCUSSION

Main nuclear transmutations which can be induced by the alpha irradiation of BeO are ^{16}O(α, n)^{19}Ne and ^{9}Be(α, n)^{12}C. Fluorine atoms are created by the formal reaction and following β^+ decay with a half-life of 17.22 s. On the other hand, Carbon atoms are directly produced by the latter reaction.

To evaluate the effect of the alpha irradiation to the wettability of BeO, water contact angles (CAs) of pristine and alpha-irradiated BeO disks were measured (Fig. 1). The pristine BeO disk showed a CA of 42.1±1.2° indicating that the surface was originally hydrophilic. When the fluence was 5.97 x 10^{14} cm^{-2}, the CA slightly increased to 50.3±2.5°, but the surface of the alpha-irradiated BeO disk was still hydrophilic. The CA further increased, and finally a hydrophilic surface transformed to a hydrophobic surface with a CA of 90.8±1.7° when the fluence was further increased to 4.53 x 10^{15} cm^{-2}.

In order to explain the behavior of CA change, changes in the morphology and the chemical composition were investigated as follows because the wettability is determined by the surface chemistry as well as by the

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morphology.

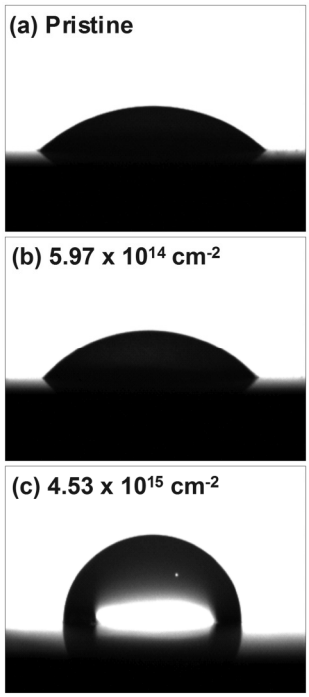

Figure 1: Images of water droplets on the pristine and the alpha-irradiated BeO surfaces.

3D surface profile data of the pristine and the alpha-irradiated BeO disks clearly demonstrate the morphology of their surfaces (Fig. 2). The pristine BeO disk exhibited a root-mean-square (RMS) roughness of 1.083±0.046 μm. Meanwhile, BeO disks alpha-irradiated with fluences of 5.97 x 10^{14} and 4.53 x 10^{15} cm^{-2} showed the RMS roughness of 1.065±0.034 and 1.090±0.014 μm, respectively. This result indicated that the surface morphology of BeO disks was hardly influenced by the alpha irradiation.

The change of chemical composition was measured using X-ray photoelectron spectroscopy (XPS). To investigate whether CF_x functional groups providing low surface energy for hydrophobicity were formed, XPS F 1s peaks of the pristine and the alpha-irradiated BeO disks were analyzed (Fig. 3). The pristine BeO disk naturally exhibited no peaks in its F 1s spectrum. When BeO disk was alpha-irradiated with the fluence of 5.97 x 10^{14} cm^{-2}, a small peak centered at 688.9 eV indicating CF_2 molecular bonds appeared. Intensity of the peak increased when the fluence was further increased to 4.53 x 10^{15} cm^{-2}. This result informed that CF_2 functional groups were produced on the surface and the amount of them increased as the fluence increased.

In this research, the behavior of CA change can be simply explained by the change of the chemical composition because the surface morphology was scarcely changed by the alpha irradiation. The formation of CF_2 functional groups induced gradual increase in the CA of hydrophilic BeO surfaces. If sufficient increase in CA was caused by the production of enough amount of CF_2 functional groups, CA could exceed 90° and therefore hydrophilic BeO surfaces could become hydrophobic.

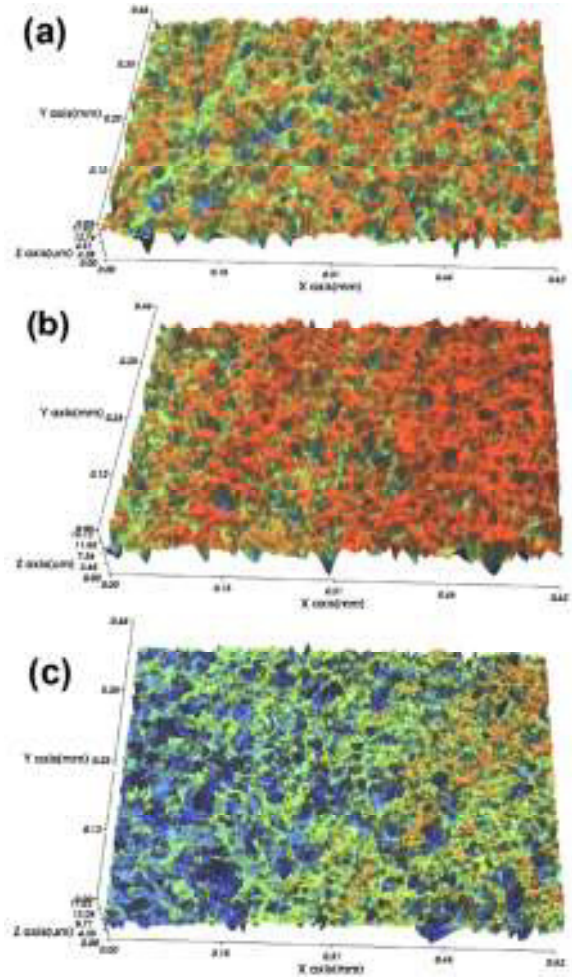

Figure 2: 3D surface profiles of the pristine (a) and the alpha-irradiated BeO disks with fluences of 5.97 x 10^{14} (b) and 4.53 x 10^{15} cm^{-2} (c), respectively.

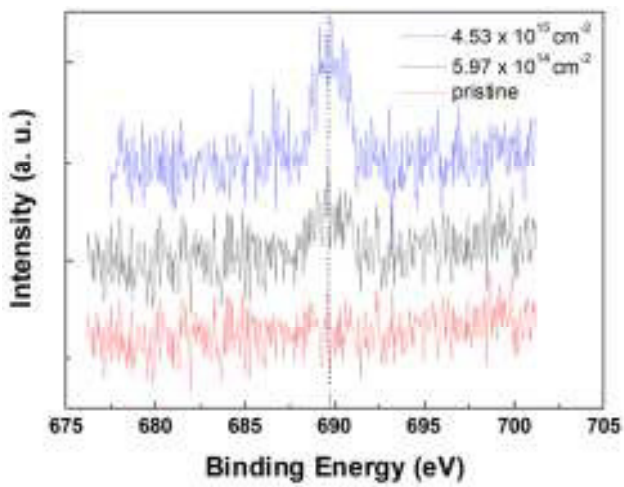

Figure 3: XPS F 1s peaks of the pristine and the alpha-irradiated BeO disks with fluences of 5.97 x 10^{14} and 4.53 x 10^{15} cm^{-2}, respectively.

CONCLUSION

A facile route to fabricate hydrophobic surfaces from hydrophilic BeO was presented on the base of the alpha irradiation. After the alpha irradiation, C and F atoms were created from Be and O atoms, and consequently CF_2 functional groups were formed while the microstructure of BeO surfaces was almost intact. As the fluence increased, the CA gradually increased, and finally hydrophilic BeO surfaces became hydrophobic. Therefore, the wettability of BeO could be easily controlled by adjusting the fluence.

The alpha irradiation method is a simple one-step process, and therefore no additional process is required. Furthermore, this method might be successfully extended to control the wettability of various material surfaces if they are coated with BeO, and then alpha-irradiated.

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