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Effects of Proton Irradiation on Compressive Strength of Single-crystalline 6H Silicon Carbide at Room Temperature

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1. Introduction

Silicon carbide (SiC) has excellent physical and electrical properties with potential for nuclear applications and power semiconductors [1]. Recently, the critical resolved shear stress (CRSS) of 6H-SiC for slip at room temperature has been evaluated using micro-pillar compression tests in [2]. The mean compressive fracture strength of single crystalline SiC was determined to be 23.8 GPa for micro-pillars diamgeters between 1.17 and 2.13 μm. Plastic deformation occurred in micro-pillars with diameters below 0.47 μm. The CRSS was found to be 9.85 GPa. The calculated Peierls stresses of 2H- and 4H-SiC were 9.5-9.6 GPa, while that for 3C-SiC was 8.9 GPa [3]. besides, plastic deformation was found to occur in other brittle materials, such as Si [4], GaAs [5], $MgAl_2O_4$ [6], as decreasing the micro-pillar size.

The radiation-induced defects are known to increase the critical strength of the material [7]. In this study, we evaluate the effect of irradiation dose on the fracture strength and CRSS of proton-irradiated 6H-SiC.

2. Experimental

2.1 Proton irradiation

For proton irradiation, we used MC-50 cyclotron in Korea Institute of Radiological Medical Sciences (KIRAMS). We fix the energy of proton to 10MeV, and change the fluence of proton between 10^{10} to 10^{13} cm^{-2}.

2.2 Fabrication and compression of micro-pillars

Micro-pillars with a diameter of 500 nm were fabricated on the proton-irradiated 6H-SiC specimen. The wafer orientation is <0001>; hence, the wafer plane corresponds to the basal (0001) plane of the hexagonal close-packed crystal structure. Micro-pillars whose symmetric axis is at 40° with respect to <0001> direction were fabricated using FIB. The tilting of the wafer and FIB milling is schematically shown in Fig. 1.

The fabricated micro-pillars were compressed using a nanoindenter (NHT2, CSM instruments) equipped with a conical flat diamond punch with an end diameter of 20 μm. The 40 μm diameter annulus was used to locate micro pillars under an optical microscope, and provided space in which to compress the flat diamond punch as shown in Fig. 1(b). Load is applied with a constant load rate of 1 mN/min.

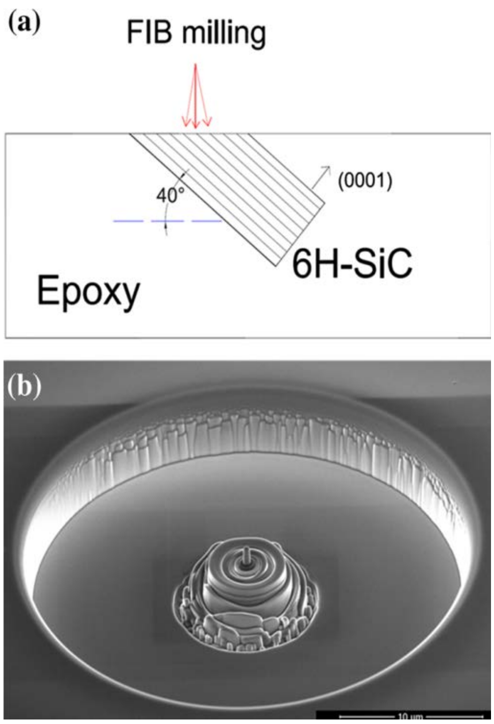

Fig.1. (a) Schematic of micro-pillar fabrication,
(b) representative micro-pillar fabricated by FIB milling

3. Result and discussion

Fig. 2 shows the representative displacements of the flat indenter with time during micro-compression test. The displacement curves in Fig. 2 show that the indenter initially approaches and begins to compress the micro-pillar surface. A burst in indenter displacement follows. This burst is related to the brittle fracture of the micro-pillar, since the maximum displacement nearly corresponds to the length of each pillar. Several small displacement bursts occur before sudden burst during the compression of micro-pillars.

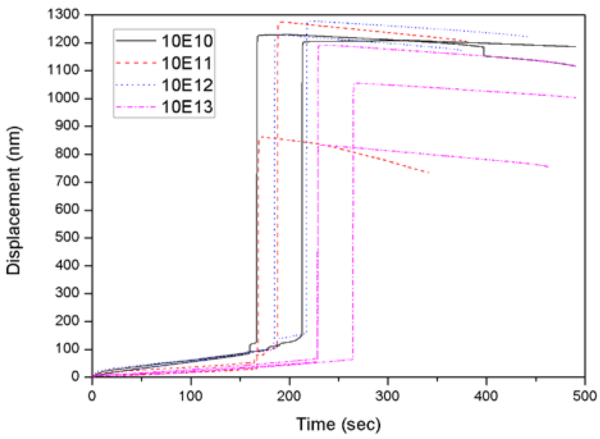

Fig. 2. Displacement-compression time curve

Fig. 3 shows the engineering stress-strain curves of micro-pillars. Plastic deformation has occurred in micro pillars which have been irradiated at fluence lower than 10^{13} cm^{-2}. However, brittle fracture has occurred in micro-pillars with fluence above $10^{13}/cm^{-2}$. This shows that brittle to ductile deformation has occurred with increasing irradiation dose.

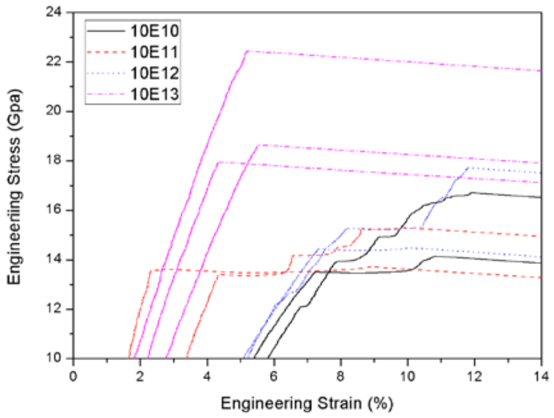

Fig. 3. Engineering stress-engineering strain curve

Table I shows the evaluated CRSS of each micro-pillars. Note that the strength of fluence 10^{13} corresponds to compressive fracture strength.

Table I: Specimen data

Fluence (cm^{-2})	10^{10}	10^{11}	10^{12}	10^{13}
CRSS (GPa)	13.5~14	13.5	14~15.4	18~23

As shown in Fig.4, the CRSS increases as irradiation dose increases and approaches the fracture strength.

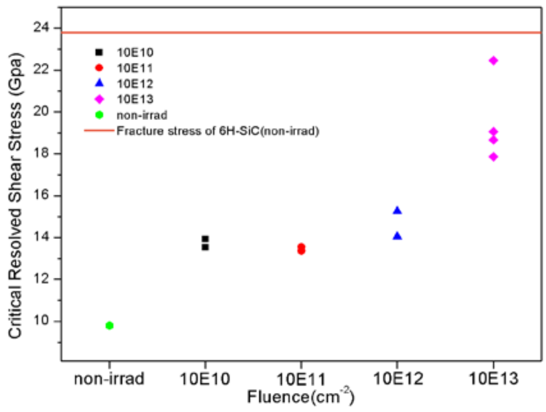

Fig. 4. CRSS with respect to fluence

3. Conclusion

In this study, the effects of proton irradiation on the deformation of micro-pillars were evaluated. As is shown in [2], 6H-SiC showed brittle-to-ductile transition as the size of the micro-pillar decreases at room temperature. At the size of micro-pillar showing ductile deformation, ductile-to-brittle transition was found to occur as irradiation dose increases. The radiation defects formed by proton irradiation are thought to increase CRSS by hindering the dislocation motion, and finally the CRSS becomes higher than fracture strength and brittle fracture occurred. Fig. 5 shows the brittle-to-ductile transition with pillar size and ductile-to-brittle transition (increasing CRSS) with irradiation dose.

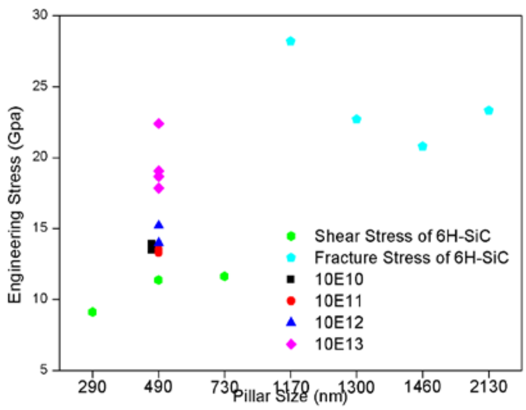

Fig. 5. Brittle-to-ductile transition with size and fluence.

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