Study on Radiation induced Mechanical Degradation of Amorphous Silicon Carbide Films

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Abstract In this paper, the radiation effects of 1MeV protons on hydrogenated amorphous SiC films are studied by simulation and experiments. The molecular dynamics simulation by SRIM-2012 software package indicates that compared to crystalline SiC, hydrogenated amorphous SiC may suffer less radiation damage. SiC films with a thickness of 500nm are deposited on silicon substrates by PECVD, and then annealed at about 450℃. The prepared hydrogenated amorphous SiC films are irradiated by 1MeV protons in an electrostatic tandem accelerator at a flux of about $1.4\times10^{12}\,cm^{-2}\,s^{-1}$ for 2 hours. The mechanical changes in irradiated silicon carbide films are investigated by nano-indentation and nano-scratch method. The irradiated film suffers a decrease in hardness and Young Modulus, but keeps nearly the same friction coefficient and surface topography as the contrast films.

Keywords Silicon Carbide, Mechanical degradation, Radiation damage

1. Introduction

Silicon carbide was considered as an excellent candidate for Micro-Electro-Mechanical Systems, especially in harsh environments applications [1]. Compared to crystalline SiC, low-stress PECVD SiC thin film is more attractive for CMOS compatible MEMS structures and devices [2]. As with space applications, MEMS devices are working in a complex radiation environment with massive energetic particles and photons. Space radiation induces electrical and mechanical degradation in materials. MEMS structures and devices would suffer mechanical failures and electrical failures after large doses of radiation [3,4]. In recent researches, the radiation effects on crystalline SiC were studied. Microstructural, electrical, mechanical degradation and amorphization of crystalline SiC under ion and neutron irradiation were reported [5–7].

In this work, we focus on the radiation effects of 1MeV protons on amorphous SiC films. SRIM-2012 software package is used to calculate the ions distribution in multiple layers of SiC/Si target. PECVD SiC films are deposited and annealed. The prepared SiC films are irradiated by 1MeV protons at a flux of about $1.4\times10^{12}\,cm^{-2}\,s^{-1}$ for 2 hours. The radiation induced mechanical degradations are investigated by nano-indentation and nano-scratch method.

2. Simulation

SRIM-2012 software package, which concerns the stopping and range of ions in matter [8], is used to calculate the ions distribution in SiC and SiC/Si target.

Table 1. The projected range of crystalline SiC and H-SiC.

Samples	Atoms(%)			Projected Range (um)
	Si	C	H	
SiC	50	50		14.95
H-SiC	43	47	10	16.39

Since amorphous SiC films grown by PECVD generally contain a large number of hydrogen atoms, the projected ranges of 1MeV protons in crystalline SiC and hydrogenated amorphous SiC (H-SiC) were calculated. As the results shown in Table 1, the projected range of crystalline SiC is shorter than hydrogenated amorphous SiC. Due to the existence of hydrogen atoms, hydrogenated SiC with the same width as crystalline SiC may suffers less radiation damage. As the distribution of incident protons in multiple layers of SiC/Si target is showed in Fig. 1, the protons are clustered at the center of projected range.

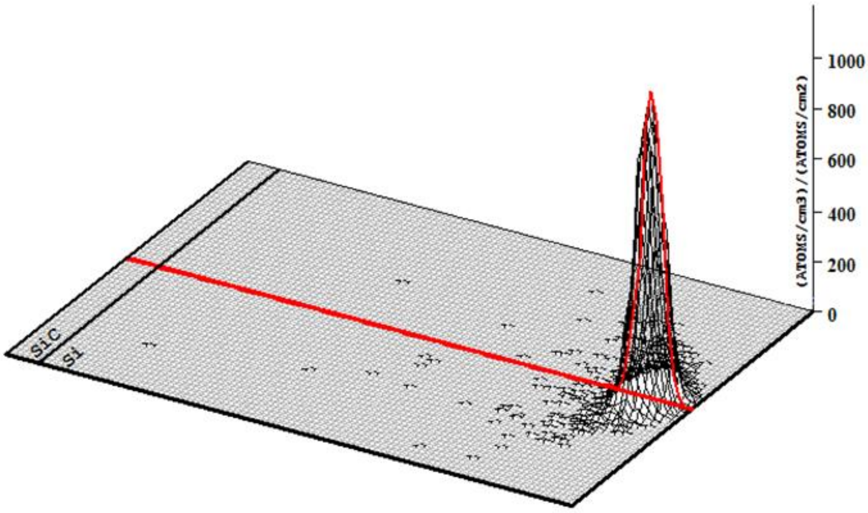

Figure 1. The distribution of incident protons in SiC/Si target.

3. Experiments

3.1 Preparing of amorphous silicon carbide films

500nm amorphous SiC films are deposited on 4 in. (100) silicon substrates by PECVD at 300 ℃. Some of the PECVD parameters are listed in Table 2. In order to get low-stress SiC films which are appropriate for fabricating MEMS structures, a furnace annealing process at about 450 ℃ for about 50 minutes is performed. Thus, the SiC films could be adjusted with a low tensile stress.

Table 2. Parameters of PECVD

Parameters of PECVD	Values
Flow rate of CH4 (sccm)	400
Flow rate of Ar (sccm)	400
Flow rate of NH3 (sccm)	5
Flow rate of SiH4 (sccm)	20
Pressure (mTorr)	1000
Power (W)	300
Temperature (℃)	300

3.2 Radiation on amorphous silicon carbide films

The prepared silicon carbide films were radiated by energetic protons in an electrostatic tandem accelerator at room temperature for 2 hours.

Table 3 illustrates some parameters of radiation experiments. In the accelerator, protons was accelerated to 1MeV. The protons beam was focused on a spot about 2×2 cm^2. The current of the protons beam is 0.9μA, thus the flux reaches 1.4×10^{12} cm^{-2} s^{-1}.

Table 3. Parameters of Radiation experiments

Current	Beam spot size	Flux	Time
0.9μA	4cm^2	1.4×10^{12}/cm^2 s	2h

4. Results and discussion

By nano-indentation, nano-scratch and other methods, the surface roughness, reflectivity, hardness, Young modulus and friction coefficient of irradiated SiC films are measured and analyzed. Deposited amorphous SiC films were employed as contrast samples.

4.1 Surface roughness and reflectivity

Surface topography of the films was observed by nano-indentation scan. As the 3D and plane topography showed in Fig. 2, the irradiated films demonstrates a similar surface topography with the contrast one. The average surface roughness of the irradiated silicon carbide film is 27nm, while the contrast one is 29nm.

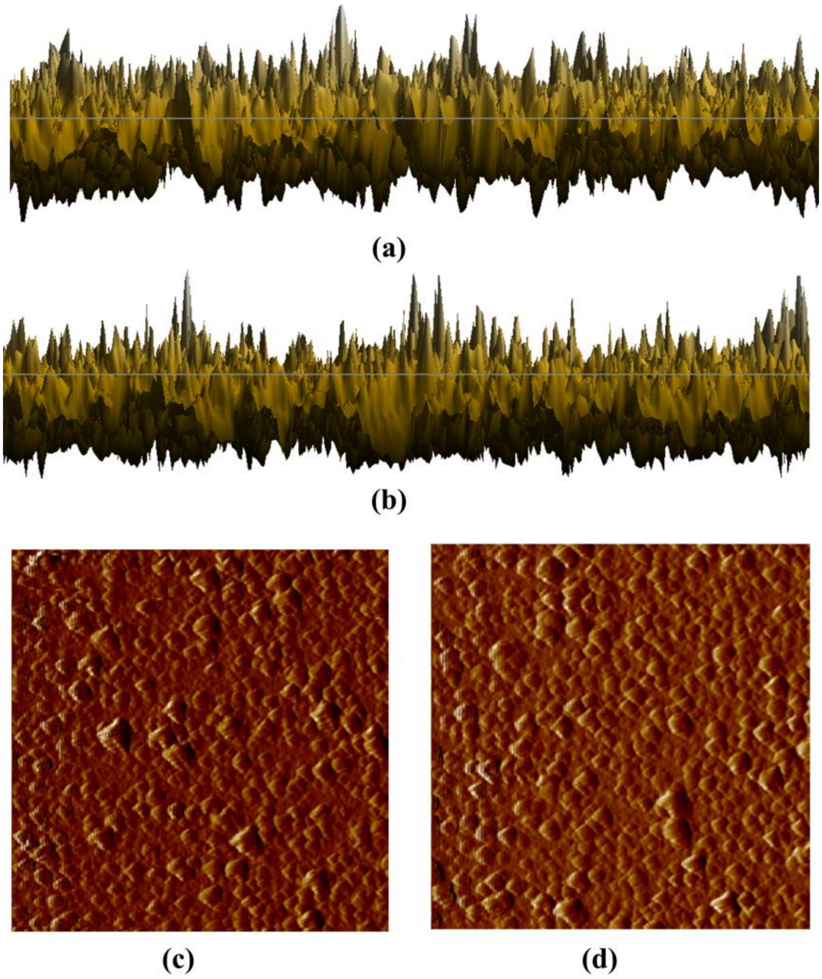

Figure 2. (a) 3D surface topography of irradiated SiC films;
(b) 3D surface topography of contrast SiC films;
(c) Plane surface topography of irradiated SiC films;
(d) Plane surface topography of contrast SiC films.

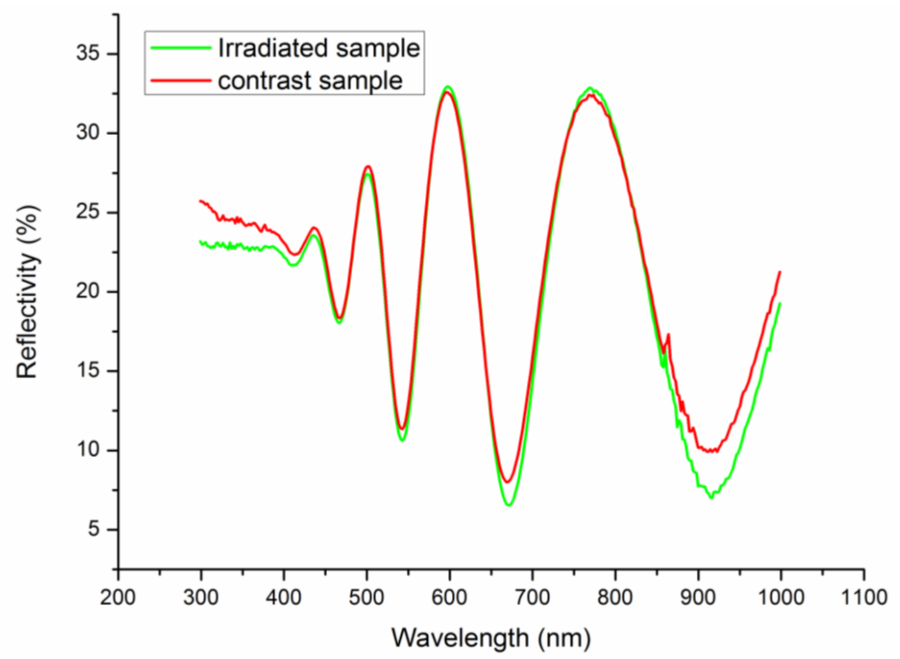

Figure 3. Integrating sphere reflectivity spectrums of SiC films

Integrating sphere reflectivity spectrums of the irradiated films and contrast films are measured at a wavelength range from 300nm to 1000nm. As Fig. 3 shows, the two kind of films demonstrate quite similar spectrums.

4.2. Hardness and Young modulus

Nano-indentation method was employed to measure and calculated the hardness and Young modulus of the films. The displacement in the irradiated films at the maximum load force of 10000μN is 367nm, while the contrast one is 230nm. Fig. 4 shows the load-displacement curves of the films at a load force of 1500μN.

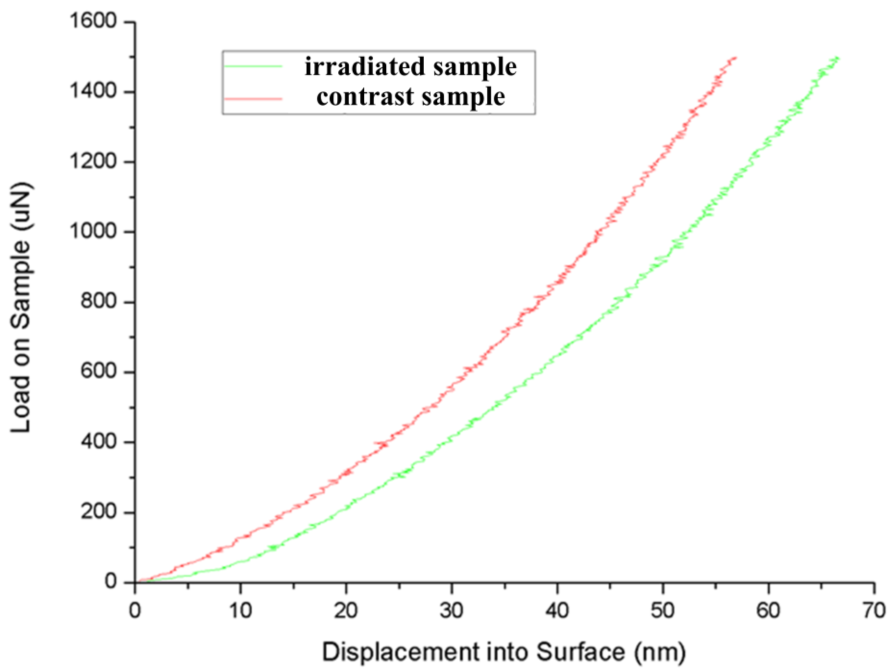

Figure 4. Load-displacement curves of the films in nano-indentation process

The average hardness and Young modulus of the films are calculated and listed in Table 4. The irradiated films demonstrate both lower hardness and young modulus than the contrast one, i.e., the contrast film is more robust than the irradiated film.

Table 4. The average hardness and Young modulus of the films.

Samples	Hardness (GPa)	Young modulus (GPa)
Irradiated samples	9.22	103.54
Contrast samples	10.66	114.46
Difference	15.6%	11%

4.3. Friction coefficient

Nano-scratch method was employed to measure friction coefficients of the films. Load force of 2000μN and 5000μN were used, the results are listed in Table 5. Allowing for the influence of surface roughness of the films, the friction coefficients of the two kinds of films demonstrates no significant difference at each load force. Fig. 5 shows the friction coefficients of the films at a load force of 5000μN during a nano-scratch scan process of 6μm.

Table 5. Friction coefficients at different load force.

Samples	Load Force(μN)	Friction coefficient
Irradiated sample	2000	0.108
	5000	0.154
Contrast sample	2000	0.096
	5000	0.151

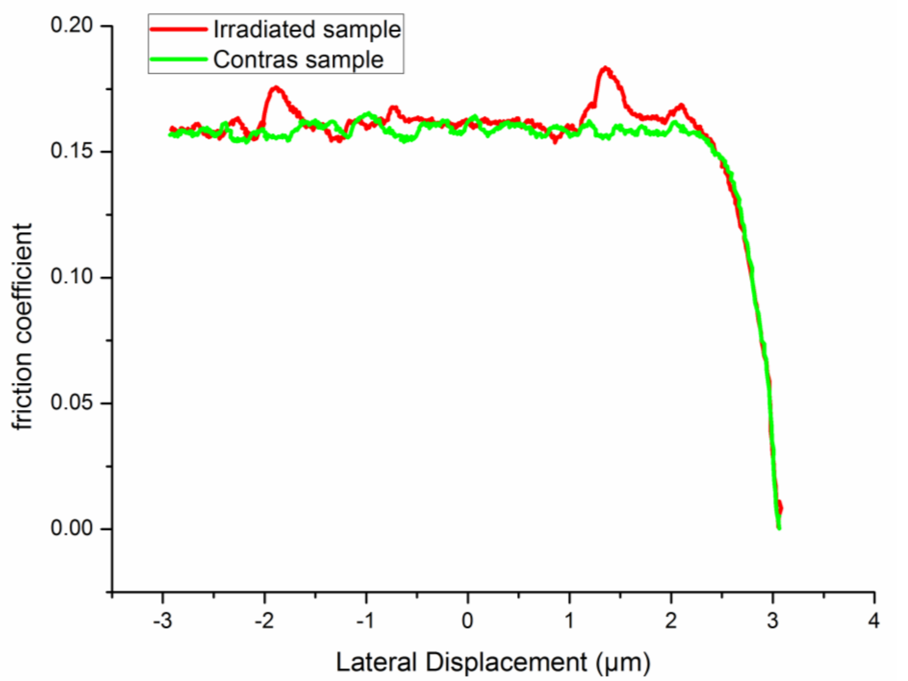

Figure 5. Friction coefficients at a load force of 5000μN during a nano-scratch scan process .

5. Conclusion

The radiation effects of 1MeV protons on amorphous SiC films are studied. According to calculated results of SRIM-2012 software package, the projected range of crystalline SiC is shorter than hydrogenated amorphous SiC. Hydrogenated SiC with the same width as crystalline SiC may suffers less radiation damage. 500nm SiC films are deposited on 4 in. (100) silicon substrates by PECVD, and then annealed to obtain low stress SiC films. The prepared SiC films are irradiated by 1MeV protons in an accelerator at room temperature for 2 hours. The irradiated film suffers a decrease in hardness and Young modulus, but keeps the same in friction coefficient and surface topography as the contrast films.

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