ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS037

RIPPLE PATTERN FORMATION ON SILICON CARBIDE SURFACES BY LOW-ENERGY ION-BEAM EROSION*

Divya Gupta† and Sanjeev Aggarwal, Ion Beam Centre, Department of Physics, Kurukshetra University, Kurukshetra 136119, India
G.R. Umapathy, Inter University Accelerator Centre (IUAC), New Delhi 110001, India
Rahul Singhal, Malviya National Institute of Technology (MNIT), Jaipur, Rajasthan 302017, India

Abstract

A versatile experimental facility air insulated high current medium energy 200 kV Ion Accelerator, with the terminal voltage in the range of 30-200 kV has been running successfully at Ion Beam Centre, KUK for carry out multifarious experiments in material science and surface physics. This system offers single charge state, switching magnet with five exit ports and large area irradiation/implantation using hollow cathode ion source.

Ion beam induced structures on the surfaces of semiconductors have potential applications in photonics, magnetic devices, photovoltaics, and surface-wetting tailoring etc. In this regard, silicon carbide (SiC) is a fascinating wide-band gap semiconductor for high-temperature, high-power and high-frequency applications. In this work, fabrication of ripple patterns is carried out on the SiC surfaces using 80 keV Ar^+ ion beam for different fluences at oblique incidence of 50^0. AFM study demonstrates that ripple wavelength and amplitude, ordering and homogeneity of these patterns vary linearly with argon ion fluence. The formation of such surface structures is attributed to the preferential sputtering of silicon in comparison to carbon. The evolution of high degrees of order is explained with the help of existing formalisms of coupling between surface topography and preferential sputtering.

INTRODUCTION

Oblique angle sputter erosion (OASE) is a versatile and cost effective tool for patterning and structuring solid surfaces at the nanoscale level [1-3]. This is a scalable method that fabricates a myriad of patterns in a single technological step and is applicable to most solid materials, ranging from metals to semiconductors, and from organic to inorganic materials [1-9].

Considering the stochastic nature of OASE at micro- to nano-scopic scales, the spontaneous formation of patterns by this technique is a highly non-trivial process, and has long drawn attention due to its potential applications in surface technology and applied sciences [1-4].

In this regard, a versatile experimental facility 200 kV Ion Accelerator with ion beams having energy in the range of 30–200 keV is running successfully at Ion Beam Centre, KUK for carry out patterning and structuring the surfaces of different classes of materials. This system offers single charge state, switching magnet with five exit ports and large area irradiation/implantation using hollow cathode ion source [7].

For binary compounds, non-stoichiometric sputtering of one element in comparison to other occurs. This preferential sputtering determines the degree of patterning and structuring by oblique angle sputter erosion. Hence, it becomes extremely vital to have detailed knowledge of the composition modulation as a result of non-stoichiometric sputtering [8, 9].

In this paper, we address the study of the temporal evolution of SiC surfaces with the aim of characterizing the features as a function of ion dose. This type of quantitative and qualitative analysis is required for designing large-scale ordered nanostructures on the sputtered surfaces.

MATERIALS AND METHODS

Silicon Carbide (SiC) thin films were deposited on Si(111) substrates employing RF sputtering method. These SiC thin films were then irradiated with 80 keV argon ions by 200 kV Ion Accelerator Facility available at Ion Beam Center, Kurukshetra University, Kurukshetra, India under a vacuum of 3.2 x 10^{-7} Torr. Argon ion fluence of 1×10^{18}, 2×10^{18} and 3×10^{18} ions cm^{-2} has been used at fixed incident angle of 50^0 [7].

Surface morphological evolution of these RF sputtered and argon irradiated SiC surfaces was profoundly evaluated by Atomic Force Microscopy (AFM) utilizing Bruker HR Mutlimode-8 available at Ion Beam Centre, Kurukshetra University, Kurukshetra. In order to get a better statistics, at least 5 AFM scans on each sample were performed.

RESULTS AND DISCUSSION

Figure 1 ((a)-(d)) shows the AFM images of RF sputtered SiC over Si(111) and SiC surfaces bombarded using 80 keV Ar^+ ions at fixed incident angle of 50^0 with fluences of 1×10^{18}, 2×10^{18} and 3×10^{18} ions cm^{-2} respectively. The corresponding Fast Fourier Transforms (FFT) is shown in insets of these micrographs.

Figure 1 (a) reveals that globular type particles of SiC can be easily distinguished. These particles are uniform in size, with a lateral dimension of about 30-40 nm. FFT image depicts the random nature of the SiC particles after RF sputtering.

* The work has been supported by the Department of Science and Technology (DST) by funding major research project for utilizing 200 kV Ion Accelerator and related characterization facilities. Authors are highly grateful to the MHRD for RUSA 2.0 grants for Centre for Advanced Material Research (CAMR) to Kurukshetra University.
† divyagupta2017@kuk.ac.in

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS037

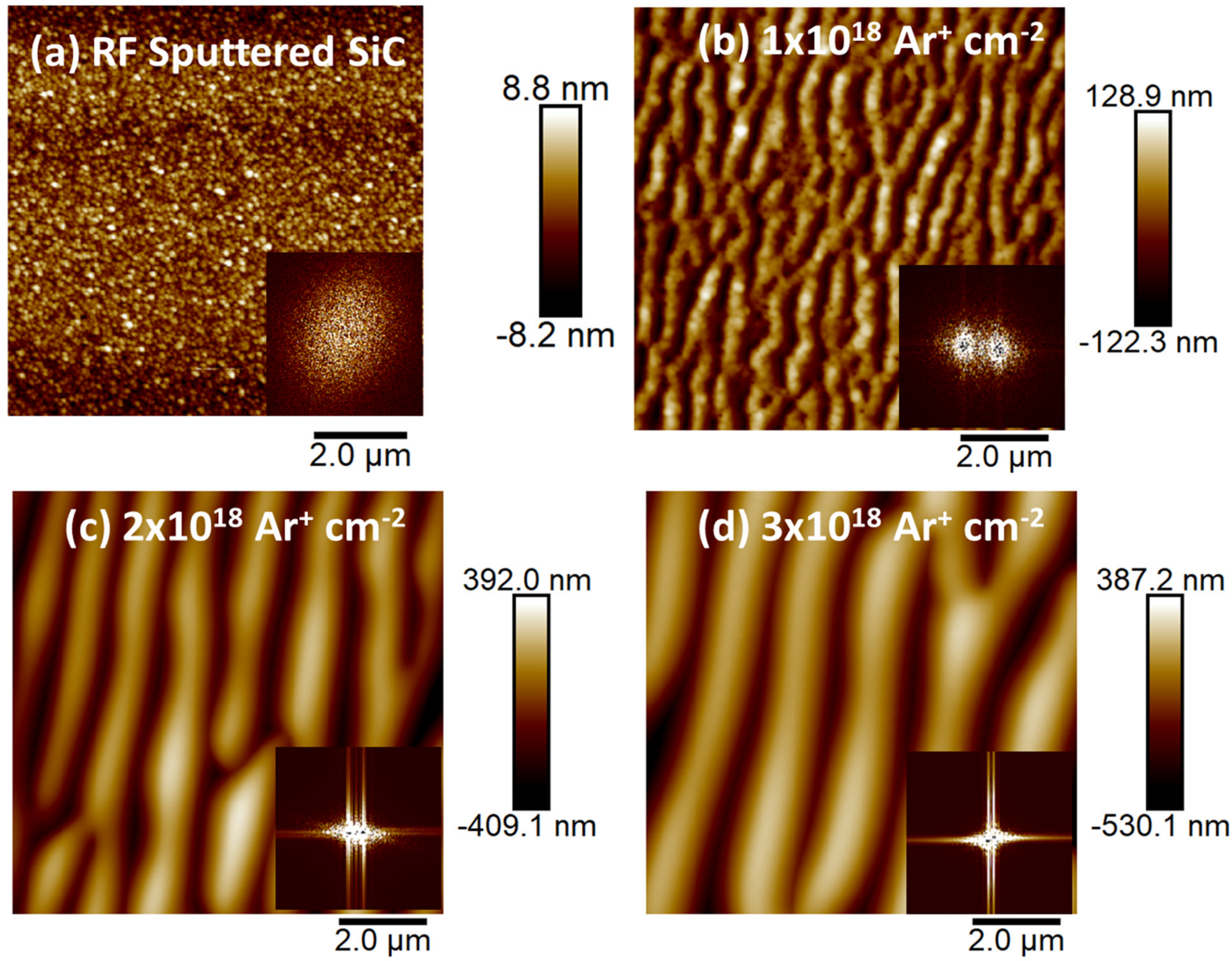

Figure 1(a-d): AFM micrographs of as-deposited SiC thin films and Ar^+ sputtered SiC surfaces at various fluences of 1×10^{18}, 2×10^{18} and 3×10^{18} ions cm^{-2}.

The temporal parameters i.e. wavelength and amplitude of evolved surface structures are calculated using the Nanoscope 1.8 software [8] and are plotted in Figs. 2 and 3 respectively.

For argon ion fluence of 1×10^{18} Ar^+cm^{-2}, periodic ripples of smaller dimensions have been observed (Fig. 1 (b)). Ripples having wavelength of 588.4±0.87 nm are seen on the sample surface due to the ripening and coalescence (Fig. 2). From the FFT, we can see that these surface structures display square self-linking and homogeneity.

Notably as the sputtering proceed to ion fluence of 2×10^{18} Ar^+cm^{-2} (Fig. 1 (c)), wavelength of these ripple pattern increases to 1280±1.83 nm. Close inspection of the FFT reveals that 2 fold symmetry increases significantly in comparison to earlier stage of sputtering. Moreover, the habit of these evolved patterns is sinusoidal.

Further increase in ion fluence to 3×10^{18} Ar^+cm^{-2} leads to ordered ripple patterns with pronounced increase in wavelength and amplitude. At this stage of sputtering, the wavelength and amplitude is 1804±0.21 nm and 153 nm respectively as plotted in Fig. 2. Interestingly, the perfect square ordering among the evolved ripples can be easily inferred from the corresponding FFT image as shown in inset of Fig. 1(d). The variation of wavelength and amplitude of ripple patterns is shown in Fig. 2.

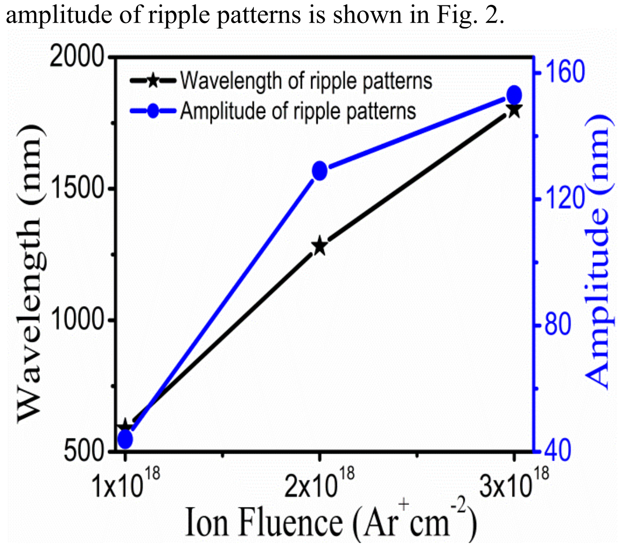

Figure 2: wavelength and amplitude of surface nano-structures over SiC exposed to 80 keV Ar^+ ions at 50^0 oblique incidence for different fluences.

Homogenous distribution of the wavelength observed for the sputtered SiC surfaces is plotted in Fig. 3.

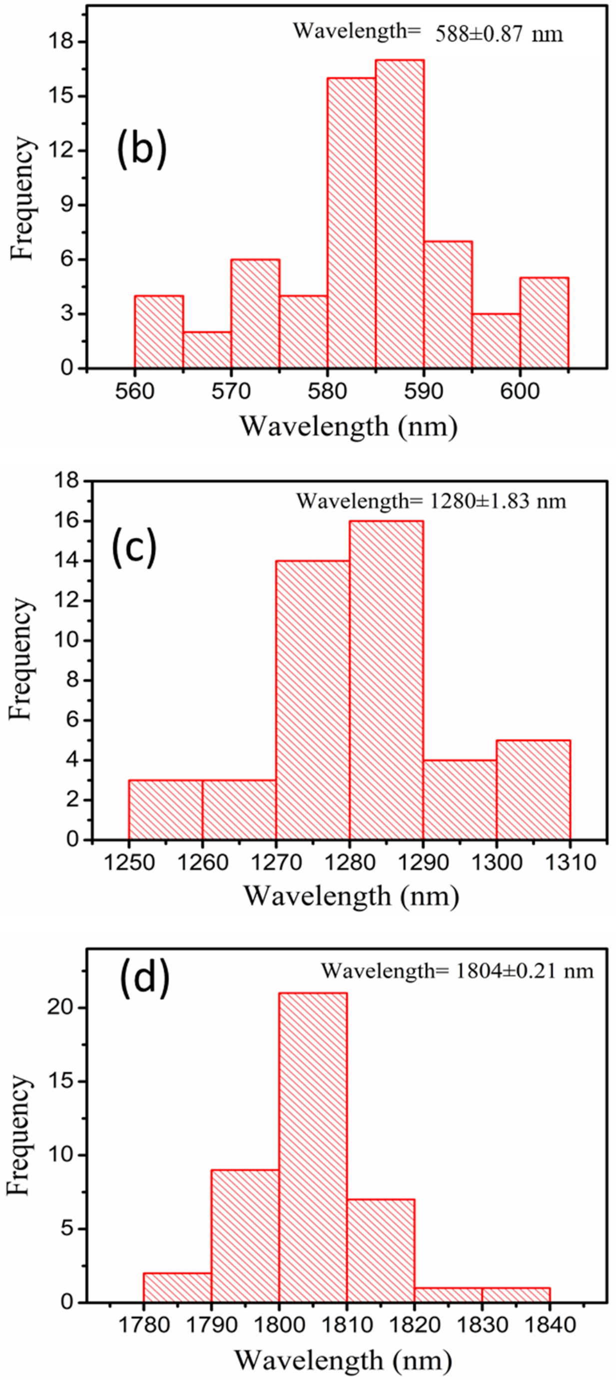

Figure 3: wavelength distribution of surface nano-structures over SiC exposed to 80 keV Ar^+ ions at 50^0 oblique incidence.

It can be inferred from Figs. 2 and 3 that both wavelength and amplitude of the ripple pattern increases with increase in argon ion fluence. Thus, SiC surfaces display ripple patterns with temporal parameters such as wavelength, self-assemble, spatial ordering under oblique angle sputtering. These temporal parameters exhibit dependence on the fluence of the bombarding ions.

This peculiar behaviour can be explained in terms of Sigmund's theory of sputtering for binary compounds [5]. The sputtering yield of silicon will be more in comparison to carbon due to significant difference in mass of both the elements in binary compound i.e. SiC. Thus, for all argon ion fluence, sputtered SiC surfaces will be rich in carbon because of preferential erosion of Si atoms from the surface region [2, 10, 11].

CONCLUSION

The process of 80 keV argon ion irradiation induced sputtering at off-normal incidence of 50^0 is observed to be a promising tool for large area surface patterning of SiC. Ripple topography is developed on the sputtered surfaces, which becomes ordered with the increase in ion fluence. The specific role of sputtering time i.e. ion-fluence on argon sputtered SiC has been discussed. The formation of such surface structures is attributed to the preferential sputtering of silicon in comparison to carbon.

These structured SiC thin films; fabricated by oblique incidence of ions from particle accelerators; have been preferred for optoelectronics, MEMS, RF MEMS and TFT's due to relatively their high temperature resistance and slow degradation, which guarantees a larger compatibility with silicon-based technology.

ACKNOWLEDGEMENTS

The work has been supported by the Department of Science and Technology (DST) by funding major research project for utilizing 200 kV Ion Accelerator and related characterization facilities. Authors are highly grateful to the MHRD for RUSA 2.0 grants for Centre for Advanced Material Research (CAMR) to Kurukshetra University.

REFERENCES

[1] R. Cuerno and J.S. Kim, A perspective on nanoscale pattern formation at surfaces by ion-beam irradiation, J. Appl. Phys. 128 (2020), 180902. doi: 10.1063/5.0021308

[2] D. Gupta, G.R. Umapathy, R. Singhal, S. Ojha, and S. Aggarwal, Ripple patterns over oblique Ar+ sputtered SiC/Si(111) surfaces: Role of Preferential Sputtering, Materials Letters 307 (2022). doi: 10.1016/j.matlet.2021.131011

[3] U. Valbusa, C. Boragno, and B.F. Mongeot, Nanostructuring surfaces by ion sputtering, J. Phys.: Condens. Matter. 14 (2002), 8153–8175. doi: 10.3390/ma3104811

[4] D. Gupta, R. Kumari, G.R. Umapathy, R. Singhal, S. Ojha, P.K. Sahoo and S. Aggarwal, Self-assembled nano-dots structures on Si(111) surfaces by oblique angle sputter-deposition, Nanotechnology 30 (2019), 385301. doi: 10.1038/s41598-020-68873-8

[5] P. Sigmund, Sputtering by ion bombardment: Theoretical concepts. in Sputtering by Particle Bombardment I, Topics in Applied Physics 47 (Ed. R. Behrisch) 9-71 (Springer-Verlag, Berlin, 1981). doi: 10.1007/3540105212_7

[6] R.M. Bradley and J.M.E. Harper, Theory of Ripple Topography Induced by Ion Bombardment, J. Vac. Sci.

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS037

Technol. 6 (1988), 2390–2395. doi: 10.1116/1.575561

[7] D. Gupta, S. Aggarwal, A. Sharma. S. Kumar and S. Chopra, 200 kV Ion Accelerator facility at Kurukshetra University, India, Materials Letters 308 (2022) 131294. doi: 10.1016/j.matlet.2021.131294

[8] https://www.bruker.com/en/products-and-solutions/microscopes/materials-afm/multimode-8-hr-afm.html

[9] R.M. Bradley and P.D. Shipman, Spontaneous pattern formation induced by ion bombardment of binary compounds, Phys. Rev. Lett., 105 (2010), 145501. doi: 10.1103/PhysRevLett.105.145501

[10] D. Gupta, M. Chawla, R. Singhal and S. Aggarwal, Nanoscale structural defects in oblique Ar^+ sputtered Si(111) surfaces, Sci. Rep 9 (2019), 15531. doi: 10.1038/s41598-019-52099-4

[11] V.I. Zaporozchenko and M.G. Stepanova, Preferential sputtering in binary targets, Prog. Surf. Sci., 2 (1995), 155. doi: 10.1016/0079-6816(95)00036-X