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Full Length Article

Synthesis of nano-patterned and Nickel Silicide embedded amorphous Si thin layer by ion implantation for higher efficiency solar devices

D. Bhowmik[a], S. Bhattacharjee[a], D. Lavanyakumar[a], V. Naik[a], B. Satpati[b], P. Karmakar[a,*]

[a] Variable Energy Cyclotron Centre, HBNI, 1/AF, Bidhannagar, Kolkata, 700064, India
[b] Saha Institute of Nuclear Physics, HBNI, 1/AF, Bidhannagar, Kolkata, 700064, India

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ABSTRACT

We report the ion beam based single step synthesis process of surface-patterned amorphous Silicon (a-Si) with a buried plasmon active nickel silicide layer for the realization of cost-effective, higher efficiency Silicon (Si) photovoltaic devices. Simultaneous amorphization, surface pattern formation and buried layer development are achieved by normal incidence 10 keV Ni^{1+} ion bombardment on Si(100) surface at a fluence of 1×10^{17}. Atomic Force Microscopy study shows rim-surrounded crater like periodic nanostructure on the surface whereas cross-sectional Transmission Electron Microscopy detects the amorphization and implant buried layer just below the surface. The distribution of implanted Ni ions and Si vacancies, obtained by the Monte Carlo simulation (SRIM) is consistent with the experimental results. Spatially resolved Electron Energy Loss Spectroscopy measurement detects that the buried layer is nickel silicide. The potential application of such nano-patterned and plasmon active system for future low-cost a-Si based higher efficient Photovoltaic devices is discussed.

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1. Introduction

Surface patterning, as well as metallic nanostructures incorporation in a semiconducting material, has attracted much attention because of its potential application in plasmonics, solar energy harvesting, storage devices and nanoelectronics [1]. The presence of plasmon active metal nanostructures in amorphous Si enhances the photocatalytic and photovoltaic properties of the semiconductor [2–4]. Surface texturing or patterning on a semiconductor is also another way of increasing light absorption efficiency. The pattern on surface increase the surface absorption area and simultaneously reduce the reflection of light, increase light trapping ability [5,6].

For solar energy harvesting, c-Si or a-Si is not good absorber of light in the visible solar spectrum [3]. However, it is still the best selection for solar devices because it is abundant, non-toxic, cheap and its processing technology is well known. Specifically, thin film a-Si solar cell technology is more attractive to make very cheap and flexible solar harvesting device. Therefore, an innovative cost effective and minimum steps processing approach is essential to increase the efficiency of a-Si based photovoltaic devices. Previous initiatives involve increasing the surface area [6] and incorporation of plasmon active particle [3,7]. For wafer based Si cells, 2–10 μm depth trenches are drawn for more light trapping [3]. But, for thin film solar cells, this much trench is not possible whereas nano-metre scale regular texturing by lithographic technique on a large area is not cost effective. The surface texturing done by chemical etching [5] generates random rough surface and also incorporate undesirable chemical contamination. Plasmon active metal ion implantation promised potential improvement of photovoltaic [2] and photocatalytic [8] behavior. Metal incorporation by simple deposition is a common practice; however, multi-step processing, as well as high-temperature annealing, is required [9]. Therefore, surface texturing and metal incorporation by such multi-step process could be expensive and complicated. KeV energy broad ion bombardment is a powerful technique to pattern a large surface area as well as implant metal atoms at a specific depth with a controlled concentration [10].

In the present article, we report an ion beam based approach where nanopatterning and plasmon active metal incorporation have been performed simultaneously by a single step low energy ion implantation on Si. We have observed rim type surface pattern and buried Nickel silicide layer formation by 10 keV Ni ions implantation on Si(100) surface at normal incidence. Amorphization of c-Si substrate is advantageous for the present study where this system becomes equivalent to thin film a-Si based solar cells. Crater sur-

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* Corresponding author.
E-mail address: prasantak@vecc.gov.in (P. Karmakar).

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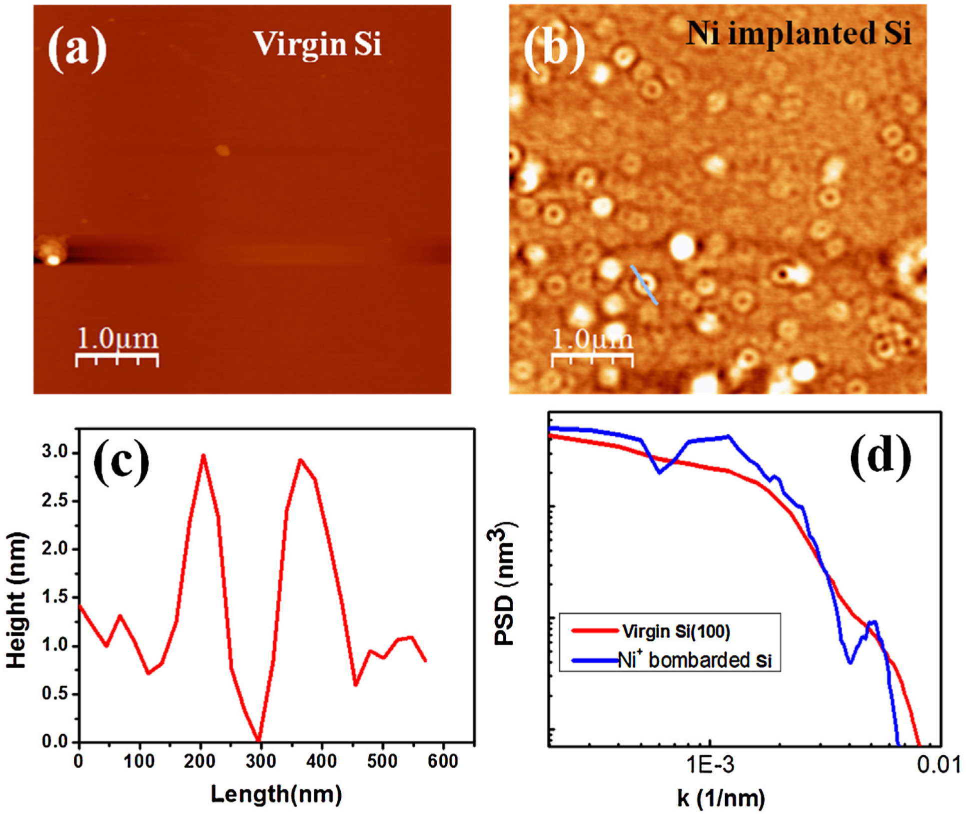

Fig. 1. AFM topography of (a) Virgin Si(100) surface, (b) 10 keV Ni$^+$ (fluence 1×10^{17}) bombarded Si(100) surface showing rim surrounded crater structure, (c) line profile along the marked line on (b), (d) The Power Spectral Density profiles of the virgin and the irradiated Si, calculated from AFM data of (a) and (b).

rounded by rim type regular surface pattern formation due to Ni ion impact is explained as well as the system is cross sectionally probed by TEM and verified with SRIM calculation. The enhancement of light absorption by patterned and nickel silicide embedded Si is presented.

The commercially available polished Si (100) samples were cleaned and degreased with trichloroethylene in an ultrasonic bath and then washed with methanol and distilled water. The samples were bombarded with 10 keV Ni$^+$ at normal incidence with a fluence of 1×10^{17} ions/cm^2. The ion beam was extracted from the 2.4 GHz ECR ion source of the Radioactive Ion Beam Facility at Variable Energy Cyclotron Centre Kolkata. During the experiment, target chamber pressure was 3×10^{-7} mbar. The surface morphology of the Si(100) samples before and after the implantation was examined in air using Bruker Atomic Force Microscopy (AFM), Multi-Mode V at VECC, Kolkata.

Cross-sectional TEM (XTEM) specimens were prepared using the standard method of mechanical grinding and dimpling with final thinning using a precision-ion- polishing system (PIPS, Gatan, and Pleasanton, CA). The ion polishing was carried out at 3.0 keV followed by 1.2 keV cleaning process at SINP, Kolkata. TEM including Electron Energy Loss Spectroscopy (EELS) and Energy Dispersive X-ray spectroscopy (EDX) investigations were performed using a FEI, Tecnai G^2 F30, S-Twin microscope operating at 300 kV with Gatan Imaging Filter (model 963) and EDAX detector (EDAX Inc.), respectively attachments also at SINP, Kolkata.

Grazing incidence X-ray diffraction (GIXRD) profiles from Ni implanted Si samples have been recorded at grazing incidence angle of 0.5° by a Bruker D 8 Advance X-ray diffractometer using Cu Kα radiation. Optical measurements are performed by a Perkin Elmer Lambda 750 UV/VIS spectrometer in the wavelength range 190–800 nm.

Fig. 1 shows the AFM images of virgin and Nickel ion bombarded Si surfaces. The virgin Si (100) is shown in Fig. 1(a). The measured rms roughness of the virgin sample is 0.11 nm. Fig. 1(b) shows the topography after 10 keV Ni$^+$ ion bombardment at fluence of 1×10^{17} ions/cm^2. Craters surrounded by rims are observed on the surface, and the surface roughness increased to 0.78 nm. The line profiles of the structures are shown, the average crater diameter varies from 105 nm to 115 nm.

The nuclear stopping power of 10 keV Ni on Si(100) surface is 82 eV/Å. High density energy deposition of Ni ions changes the initially flat Si surface by removing a volume of material at the impact point and also rearrange the target atoms around the depression. With continuous bombardment, combined effects of individual ion impact develop the rim pattern on the surface. Kalyanasundaram et al., [11] demonstrated the effect of 500 eV Ar$^+$ ion bombardment on Si at normal incidence and determined the change of local surface height by molecular dynamic simulation. Bradley and Harper predicted that low energy ion induced erosion leads to linear instability for all ion incidence angle followed by a structure formation on the surface [12]. Khang et al., [13] included the nonlinear terms and explained the hole or mount formation on the surface due to ion bombardment at normal incidence. Nevertheless, if only sputtering removal is considered, the decrease of height (hole) formation is expected, but the observed rim formation could not be explained. Davidovitch et al., [14] demonstrated that surface height change is not due to purely erosive but mass redistribution is very much important. The effect of sputtering and mass redistribution leads to create reduced and increased height, or crater and rim, respectively [11]. However, the crater function model without the consideration of local curvature, could not explain the structure formation properly at normal incidence [15]. Recently, Harrison and Bradley [16] showed that the incorporation of curvature in crater function model

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