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Study of Nickel Silicide Formed by Ion Beam Mixing

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Abstract: The formation of Ni silicides has been successfully synthesized by ion beam mixing. Thin nickel films were deposited by electron beam evaporation to a thickness of 50 nm on crystalline silicon (c-Si). After deposition, the films were irradiated with 100 keV Kr+ and Xe+ ions at the same fluence of 5x1016 ions/cm2 at room temperature (RT). The samples were analyzed using Rutherford backscattering spectroscopy (RBS) and X-ray diffraction (XRD). The experimental results have shown that the Kr and Xe irradiations at RT leads to the formation of Ni silicides at room temperature (RT). The surface morphology of the irradiated sample was also studied by atomic force microscopy (AFM).

Keywords: Ion beam mixing; Nickel silicides; RBS; XRD; AFM.

1 Introduction

Transition metal silicides have attracted considerable interest due to their diverse physical properties that are of significance not only for fundamental investigations but also for practical applications [1- 4]. Among these silicides, Ni silicide is promising for next-generation silicide because it has greater advantages than Ti silicide and Co silicide, such as lower resistivity, temperature formation, line width dependence of sheet resistance, and silicon consumption during siliicidation [5]. The Ni-Si interface is a typical example of a system in which a number of surface phases appear during reactive diffusion. Among the various growth techniques for the transition-metal silicides, ion-beam mixing (IBM) has attracted considerable interest from both of scientific and the technological points of view [6].

Many applications of ion irradiation have been developed for the structuring of micro- and nano-materials of high technological interest. The ion beam mixing process can be described by collisional cascades and thermal spike effects at low substrate temperatures whereas radiation enhanced diffusion of point defects and atoms has a dominant impact on the properties of the intermixed region at elevated substrate temperatures. At the higher temperatures, extensive studies on metal/metal systems indicate that ion mixing yields chemical and structural properties in the intermixed layer that are similar to the equilibrium phase if kinetic constraints allow thermodynamically favorable states to be formed [7,8]. In this study, it was found that the various stoichiometric silicide phases are formed by ion mixing.

2 Experimental Details

The 50 nm thick nickel film was deposited by e-gun evaporation on the silicon substrate Si (100) in a vacuum better than 10^{-7} Torr. After deposition, the films were irradiated with 100 keV Kr^+ and Xe^+ ions at the same fluence of $5x10^{16}$ ions/cm^2 at room temperature (RT). According to Monte Carlo SRIM 2003 code [9] calculations, the mean projected range of 100 keV Kr^+ and 100 keV Xe^+ ions lies at 22.6 nm and 17.7 nm , with a large full width at half maximum of 10.3 nm and 6.8 nm respectively.

For analysis, a 1.7 MeV He^+ beam was employed. The backscattered particles were collected under normal incidence geometry using a Si-surface barrier detector with resolution of 16 keV from the full width at half maximum (FWHM), mounted in such a way that a scattering angle of 170° is defined. The experimental spectra were analyzed by SIMNRA computer program [10]. The phase structure of the intermixed region was monitored via X-ray diffraction (XRD) using CuK_α radiation. Atomic force microscopy (AFM) was applied to observe the surface morphology of the films.

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3 Results and Discussion

In this study, we try to form the nickel silicides nanostructures by ion beam mixing.

Figure 1 shows a typical 1.7 MeV RBS energy spectrum backscattered for the as-deposited sample. The solid curve represents the corresponding simulation generated using SIMNRA program. The thickness of the film was estimated to 50 nm, as can be seen at the low and high energy edge of the spectrum corresponding to Si and Ni signal, respectively. The boundary between the pure nickel film and the silicon substrate is clearly divided, this means that the intermixture does not occur in this condition. The RBS spectrum of 50 nm thickness nickel layer deposited on Si (100) irradiated at RT with 100 keV Kr^+ ions to a fluence of $5x10^{16}$ Kr^+/cm^2 is shown in Fig. 2a. It is clear (Fig.2) that the ion irradiation induces intermixing at Ni/Si interface.

following phases Ni_2Si, $Ni_{31}Si_{12}$, NiSi and $NiSi_2$, these results agree well with those of the XRD. The formation ofion beam mixing as the implantation current and dose were ratherhigh. The Figure 2b illustrates the RBS spectrum of the as-implanted at RT with 100 keV Xe^+ ions to a fluence of $5x10^{16}$ Xe^+/cm^2. The intermixed layer was observed and the mean nickel silicides were formed, such as Ni_2Si, $Ni_{31}Si_{12}$, NiSi and $NiSi_2$. Figure 2c shows the double Xe ions mixing Kr/Ni(50 nm)/Si(100), as can be seen that from simulation, the amount of different nickel silicides increase comparing with those obtained separately by Kr^+ or Xe^+ ions mixing. In the present case, the temperature is sufficiently high that thermally activated diffusion is able to provide Si to the surface region so that the Si rich silicide can nucleate and grow. The elemental Ni, Si, Kr and Xe depth profiles extracted from the RBS spectra, are illustrated inset Figure 2a-c of each sample.

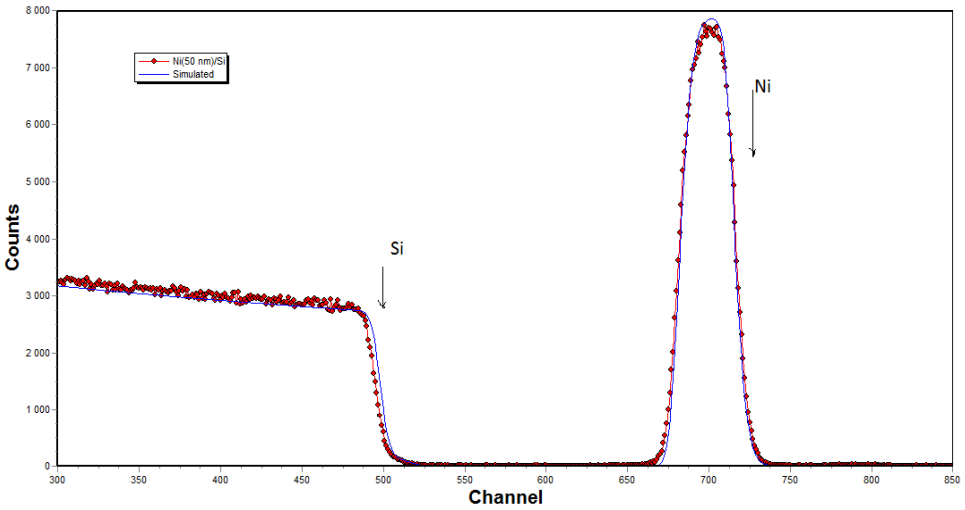
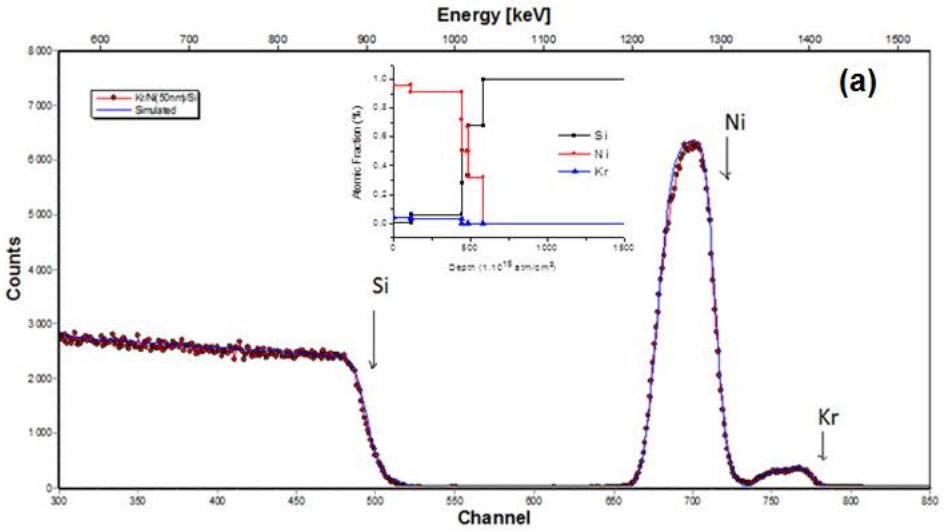


Fig. 1: RBS spectrum for the as-deposited samples.



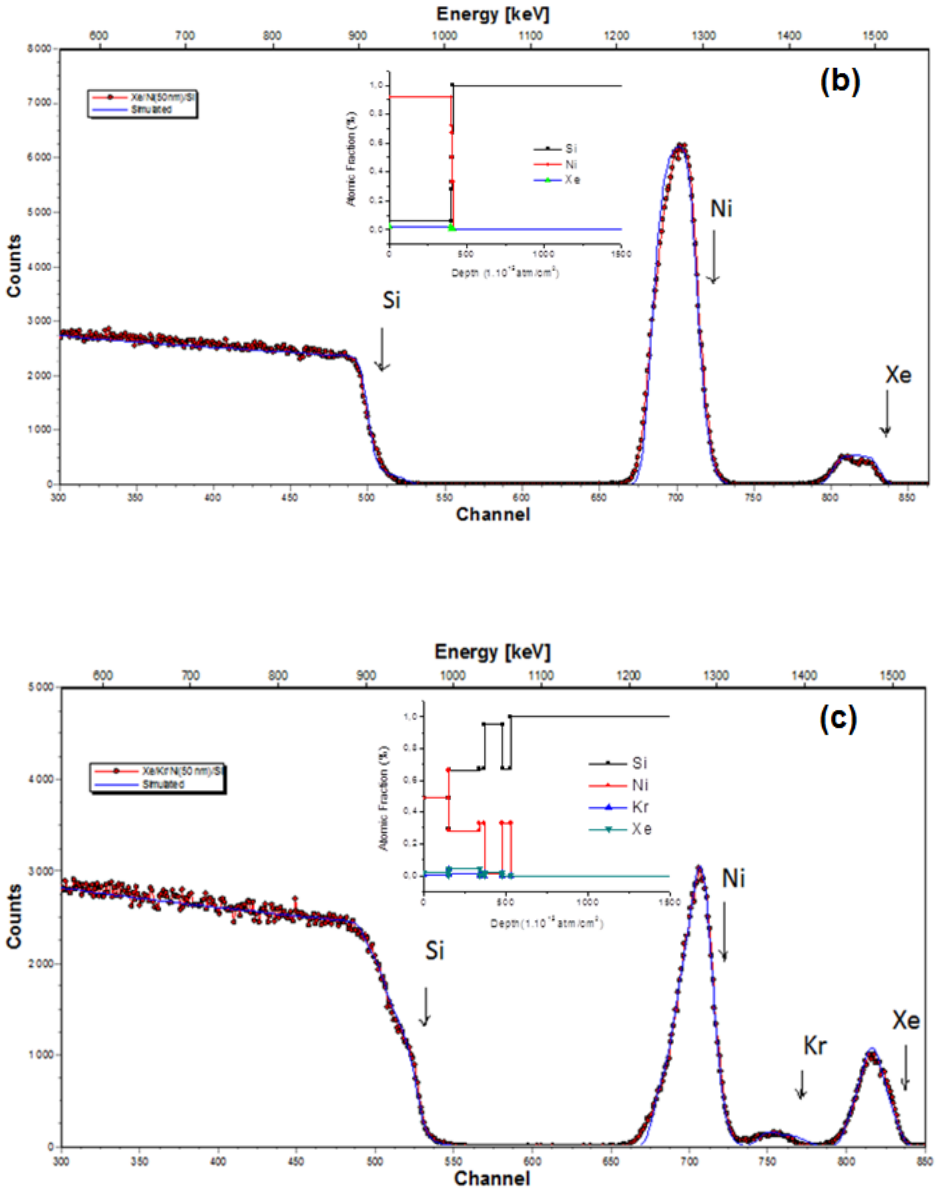


Fig. 2: RBS spectra for the irradiated samples at RT with (a) Kr^+, (b) Xe^+ and (c) double irradiation, respectively.

XRD was performed to investigate the formation of the Ni silicide phases and Si crystal orientation. Figure 3 is a XRD spectra showing Si peaks from the irradiated Ni(50 nm)/Si(100) by Kr ions induced poly-Si films. Si peaks of (220) and (400) were observed at 47.30° and 69.13°, respectively.

Irradiation with Kr ion gave rise to the formation of different silicides such as $Ni_{31}Si_{12}$, Ni_2Si, NiSi and $NiSi_2$. All reflections are indexed. We note also, an epitaxial $NiSi_2$ (220) and (400) layers located at the angle 47.41° and 69.34°, respectively, growth above the Si(220) and (400) due to a small lattice mismatch between Si and $NiSi_2$. Therefore, the influence of the Kr ion irradiation is to nucleate the high temperature phase, $NiSi_2$. As shown in XRD spectra for the irradiated sample by Xe ions and doubl irradiation case (Kr and Xe ions) the Si (220) and $NiSi_2$ (220) peaks disappeared, which are caused by increases in damages. Ion mixing is essentially an athermal, nonequilibrium process which depends upon the deposited ion energy for the reaction. This includes not only the energy to activate the interfacial transition but also the diffusion necessary to maintain the silicide growth.

Figure 4(a)–(c) shows AFM images of the surface after Kr, Xe and double irradiation samples surfaces, respectively. We observe a slight degradation of the film surface morphology. However, the average surface roughness of the Ni film still remains high, which is 9.09 nm on Kr, 9.54 nm on Xe and 9.61 nm on double irradiation surfaces.

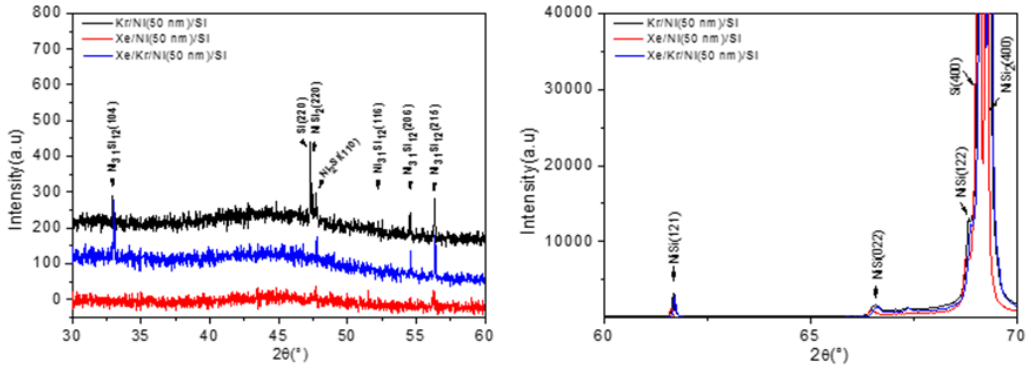
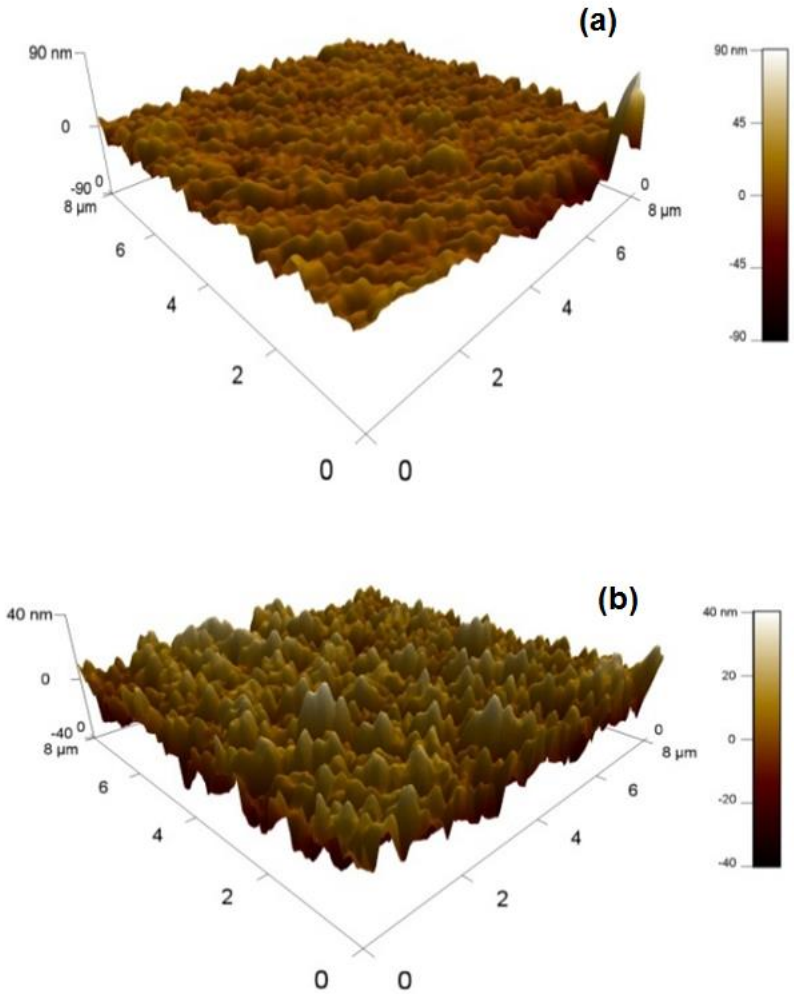


Fig. 3: XRD patterns of the implanted samples at RT.



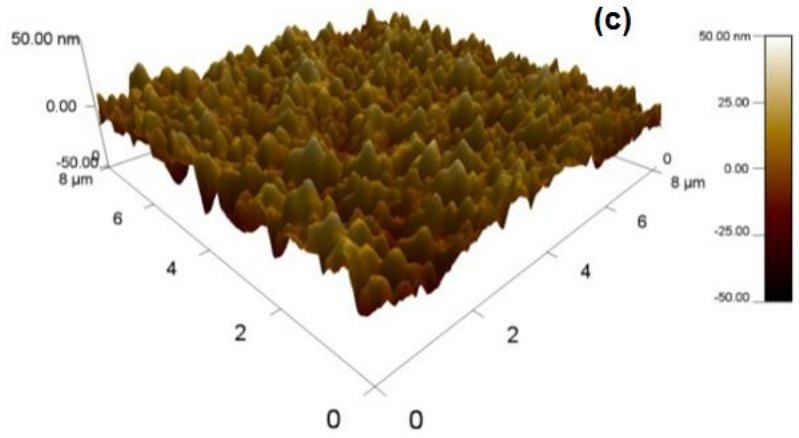


Fig. 4: AFM micrographs of the irradiated samples: (a) Kr^+, (b) Xe^+ and (c) double irradiation.

4 Conclusions

Ion beam mixing at RT of Ni(50 nm)/Si(100) system with 100 keV Kr^+ and Xe^+ ions with a same dose of $5x10^{16}$ ions/cm^2 allows the formation of $Ni_{31}Si_{12}$, Ni_2Si, NiSi and $NiSi_2$. The $NiSi_2$ (400) layer grown an epaitaxial with Si (400). The Si (220) and $NiSi_2$ (220) peaks are disappeared in the double irradiation by Kr^+ and Xe^+ ions. The average surface roughness of the Ni film increases with mass of ion irradiation.

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