Ion beam induced effects on structural and magnetic properties of Ni_3N/Si thin film

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Nitrides, carbides and oxides are important ceramic materials for a wide range of applications in coating, nuclear reactor and semiconductor technology. Irradiation with ion beam induces the change in their bonding properties and modifies their structural, optical and magnetic properties. The present paper reports the irradiation induced effects using Au ions in Ni_3N layer deposited on Si substrate. GIXRD results confirm Ni_2Si phase formation along with the peak of Ni_3N (111) due to ion beam mixing. Analysis of the spectrum from Elastic Recoil Detection recommends no variation in areal concentration of nitrogen content which may be due to low volume density of nitrogen radicals. MOKE results show the formation of distorted hysteresis loop which may be attributed due to the grains of nickel silicide formed by ion-beam induced mixing.

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1. Introduction

Metal nitrides are an important class of ceramic materials which are useful in high temperature and radiation environments as protective coatings, electrical insulators and diffusion barriers [1]. Recently, the attention has shifted to ceramic materials such as carbides [2], nitrides [3-5] and oxides [6] to study the behavior of ceramic/semiconductor bilayers under ion irradiation. Nickel nitride is one such metastable nitride which has found tremendous applications in electronic industries.

The present paper reports ion beam induced effects in Ni_3N/Si system using Au ion. Several ion-beam induced processing techniques such as ion implantation [7], ion-beam mixing [8 - 10] and ion-beam assisted deposition [11] have been developed which allow to tailor new materials or modify the properties of thin films. The distinction between purely collisional and thermal-spike induced atomic mixing and the role of chemical forces have been established [12, 13]. Vempaire et al [14] synthesized nickel nitride thin film by plasma-based ion implantation and the structural and magnetic properties were studied using GIXRD and SQUID susceptometer. Neklyudov et al. [15] reported the formation and decay kinetics of nickel nitrides resulting from nitrogen ion implantation. Structural transformations in nickel films exposed to N^+ ions were investigated through the use of electron diffraction, RBS and thermal desorption spectroscopy. Zhigalov et al. [16] studied nanocrystalline nickel films deposited in a nitrogen atmosphere. It was shown that high-speed condensation methods can be used to prepare nickel nitride films in the nanocrystalline state. Leon Maya [17] reported the deposition of crystalline binary nitride films of nickel by reactive sputtering. Micron size metallic structures on Ni_3N films were obtained by laser heating.

The motivation for us to investigate the Ni_3N/Si system is to study a rather light ceramic/semiconductor bilayers system under swift heavy ion irradiation. These materials have many properties that manifest themselves in variety of ways, including, magnetic interactions and reactive catalytic surface structures.

Grazing Angle X-Ray Diffraction (GIXRD) studies have been carried out to study the phase formation and structural properties. Areal concentration of nitrogen content was found using Elastic Recoil Detection Analysis (ERDA) and magnetic properties were studied using Magneto Optic-Kerr Effect (MOKE).

2. Experimental procedure

2.1 Deposition and irradiation

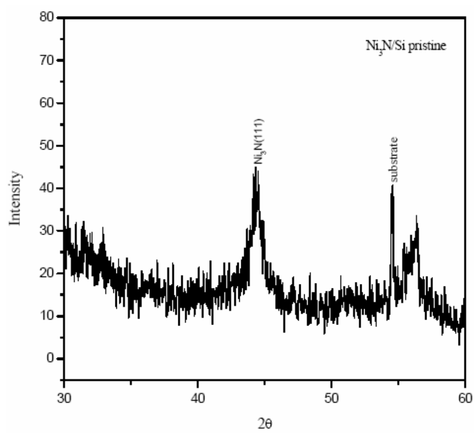
Nickel nitride thin films (80 nm) were deposited on Si (100) substrate using reactive ion beam sputtering. Nickel plates (99.99%) have been used as target. The substrate was loaded in the deposition chamber. Total gas flow rate was kept 3 sccm and the ratio of argon and nitrogen gas was kept 2.6:0.4. Ultimate vacuum of chamber was maintained at $2.2x10^{-7}$ torr. During the deposition overall pressure of argon and nitrogen was $1.2x10^{-4}$ torr. Sputtering was performed at room temperature with current 18 mA. Ni_3N thin films were irradiated by Au^{+8} at 1 pna current with 100 MeV energy from the 15 UD

Pelletron Accelerator of IUAC, New Delhi with fluence $3x10^{12}$ ions/cm^2.

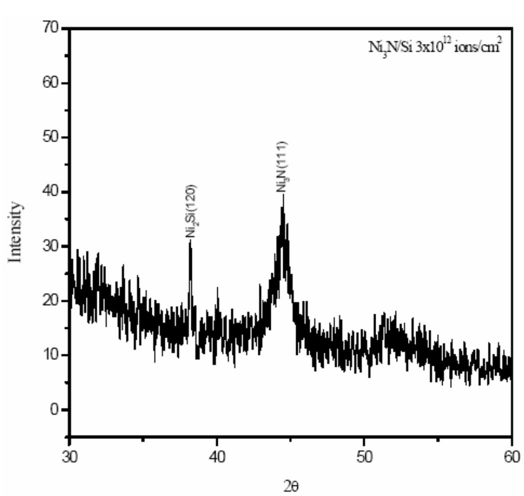
3. Results and discussion

3.1 Grazing incidence X-ray diffraction (GIXRD)

GIXRD measurements were carried out at IUAC, New Delhi using CuKα (λ = 1.5406Å) in the 2θ range of 30^0 to 60^0 for the as-deposited and irradiated samples. Figure 1 shows the diffraction pattern of pristine and irradiated Ni_3N/Si systems. Fig. 1 (a) indicates crystalline peak of Ni_3N (111) showing hexagonal structure of Ni_3N while fig. 1 (b) indicates the formation of Ni_2Si phase at the interface of system irradiated using Au ions with fluence $3x10^{12}$ ion/cm^2 due to ion beam mixing [12]. These GIXRD results are compared with Ni/Si system studied by Sisodia et al. [18]. They observed crystalline NiSi phase formation at the interface of Ni/Si bilayer system irradiated using Au ions of energy 95 MeV with $1x10^{13}$ ions/cm^2 fluence, while in the present study Ni_2Si phase formation is observed at the interface.



(a)

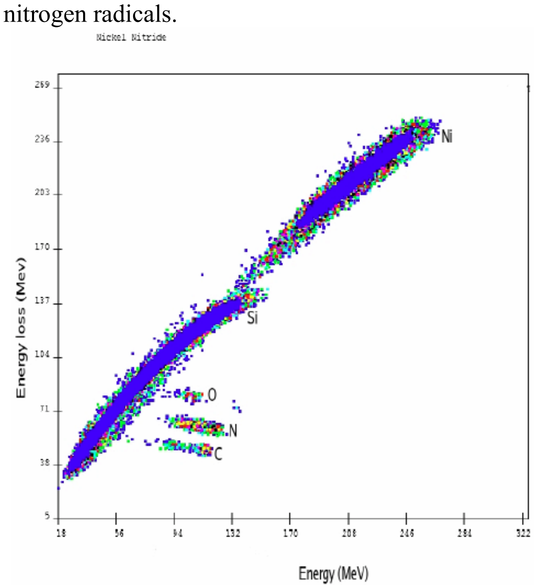


(b)

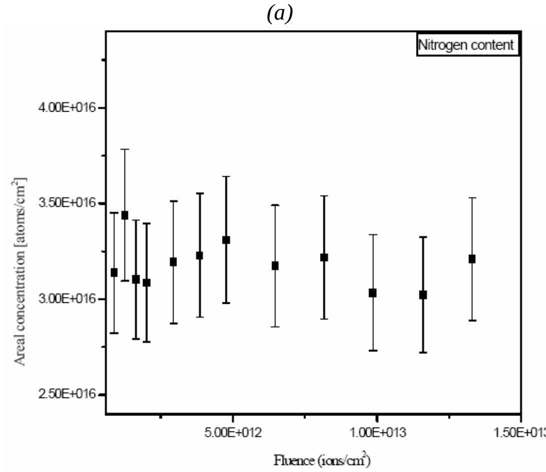
Fig. 1. GIXRD patterns of (a) as-deposited Ni_3N/Si (b) irradiated Ni_3N/Si.

3.2 Elastic recoil detection analysis (ERDA)

Energetic Au ions have been used to perform large area position sensitive detector telescope based ERDA experiments at IUAC. Fig. 2 (a) shows, for a Ni_3N/Si sample, the measured energy loss signals ΔE of the recoil ions as a function of ion energy E. Analysis of the spectrum shows that in addition to Ni and N, significant amounts of O and C are present in the film, while the substrate contains Si. The total fluence of projectile ions was of the order of $1x10^{13}$ ions/cm^2. After the irradiation, beam spot area was manually measured which was equal to 3.8 mm^2. Isobutane gas was passed through the detector at a pressure 26 mbar in ΔE-E detector telescope. Fig. 2 (b) shows areal concentration of content of nitrogen. The depletion of nitrogen does not take place because of low volume density of activated nitrogen radical due to which significant number of N_2 molecules could not be generated. Secondly, it may be possible re-incorporation of nitrogen radicals.



(a)

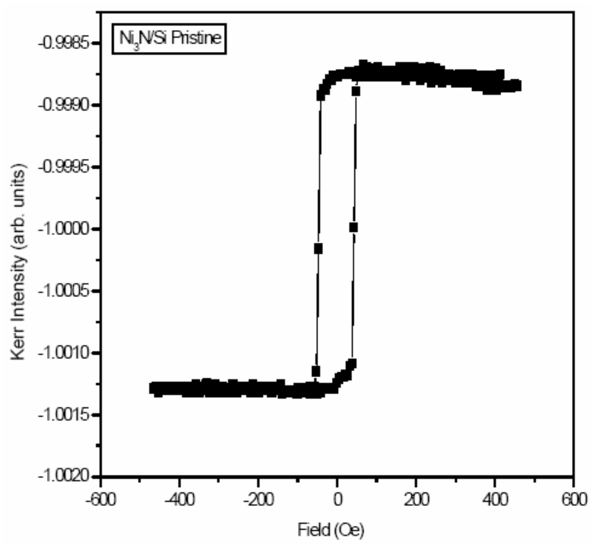


(b)

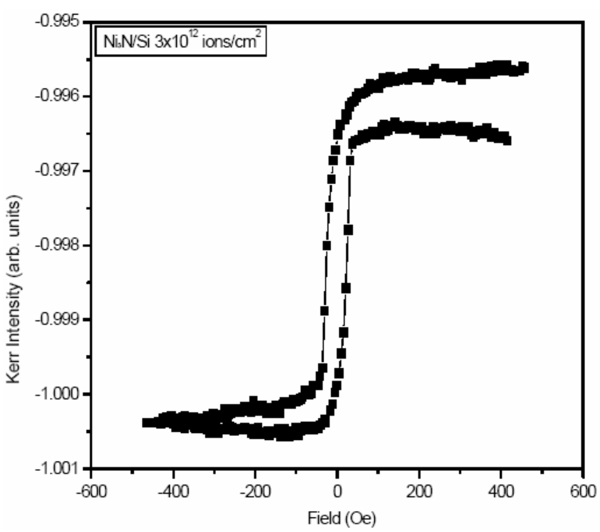
Fig. 2. (a) Two-dimensional spectrum from ERD analysis of Ni_3N film (b) nitrogen content versus fluence of Au ions.

3.3 Magneto optic-Kerr effect (MOKE)

The magnetic properties of the samples were characterized using MOKE at room temperature. Measurements in the longitudinal geometry were performed with the magnetic field applied in the sample plane, in the plane of incidence. Fig. 3 (a) shows the hysteresis loop of as-deposited Ni_3N/Si thin film. The coercivity of as-deposited sample is found to be 44.64 Oe. Fig. 3 (b) shows the formation of distorted hysteresis loop of irradiated Ni_3N/Si thin film which may be attributed due to the grains of nickel silicide formed by ion-beam induced mixing. The coercivity of distorted loop of irradiated sample is found to be 25 Oe.



(a)



(b)

Fig. 3. Longitudinal Kerr signal versus Applied Magnetic field of (a) Ni_3N/Si pristine System (b) irradiated Ni_3N/Si.

4. Conclusions

GIXRD results reveal the formation of Ni_2Si phase after ion irradiation along with the peak of Ni_3N (111) of Ni_3N/Si system. From ERDA results, we found no variation in nitrogen content. MOKE results show the formation of distorted hysteresis loop which may be attributed due to the grains of nickel silicide formed by ion-beam induced mixing.

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