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Electrical, Magnetic and Morphological Properties of E-Beam Evaporated Ni Thin Films

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Abstract

Nickel (Ni) thin films in the thickness range 50−80 nm have been prepared by electron beam evaporation method at a base pressure of 4×10^{-5} mbar on silicon and glass substrates. Some samples have been annealed at 573 K for 1.5 h in open air. The resistivity of Ni films on silicon substrate is higher than the resistivity of Ni films on glass substrate. The TCR of Ni films is found to be positive which indicates that the Ni samples are metallic in nature. Coercivity of Ni films increases with increasing film thickness. The coercivity of 80 nm as-deposited Ni film on glass substrate is found to be ~ 9 Oe. The rms value of the surface roughness of 150 nm as-deposited Ni film on glass substrate is ~12 nm and it becomes ~ 7 nm after annealing. On the other hand, the coercivity of 90 nm and 160 nm as-deposited Ni films on silicon substrate are 50 Oe and 85 Oe, respectively. The rms value of surface roughness of 120 nm as-deposited Ni film on Si substrate is ~ 16 nm. It becomes ~ 3 nm after annealing.

Keywords: Magnetic materials; Coercivity; Surface roughness; Electrical properties; Thin films.

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1. Introduction

The spins of electron in ferromagnetic materials have been ignored for electronics application for many years. But ferromagnetic materials like Nickel (Ni) in the form of thin films have received much attention over decades due to their potential technological applications like magnetic sensors, ultra-high-density magnetic storage, spin polarized transistors etc[1-6]. Material scientists need to understand the relation between structures and magnetic properties of ferromagnetic films in order to improve

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the production methods and material quality. The influence of magnetic anisotropy, film thickness, substrate and deposition parameters on magnetic properties of Ni film is being studied worldwide [7-10]. Not only single layer but also multilayer Ni film is important for research. Haque *et al.* reported a two phase spin reversal [11] and dissimilar hysteresis loop [12] in multilayer Ni films. Not only magnetic properties but also electrical properties of thin film are influenced by film thickness [13,14], temperature [15], buffer layer [16], substrate etc. Morphological property such as surface roughness is also gaining much attention as it is directly related to optical scattering and resistivity due to grain boundary and thickness [17]. Zhao *et al.* [18] and Prosen *et al.* [19] reported that the surface roughness has effect on magnetic properties. Comparative study of electrical, magnetic and morphological properties of Ni thin films on different substrates have been investigated and reported in this paper.

2. Experimental

Ni thin films have been prepared on silicon and glass substrates using E-beam evaporation technique. Before deposition, glass substrates were cleaned with acetone and silicon substrates were cleaned with H_2O_2 (30 % solution). Pure Ni (purity 99.99%) was deposited onto glass and silicon (Si) substrates in vacuum by Edwards E306 vacuum coating unit at a base pressure of 4×10^{-5} mbar. The deposition rate was 2 nms^{-1}. Films having different thicknesses have been prepared and their properties have been investigated. The film thickness is measured by Fizeau fringes [20] method. After deposition, some as-deposited samples have been annealed at 573 K for 1.5 h at atmospheric pressure in a Carbolite heavy duty oven. The resistivity of both the as-deposited and annealed films has been measured by van der Pauw [21] method. The temperature coefficient of resistivity (TCR) was calculated from resistivity data. The magnetic behavior (hysteresis loop) of the film was studied by using a VSM at room temperature. The surface morphology of the film was observed by AFM [22]. The surface roughness of the films was calculated from AFM data.

3. Results and Discussion

The electrical resistivity of the films was measured by Van der Pauw four probe method. Dependence of resistance on temperature and thickness is studied in the temperature range 313 K – 483 K. The resistivity (ρ) versus temperature (T) curve for Ni film on glass substrate having thickness 70 nm, 90 nm and 120 nm is shown in Fig. 1. It is observed from the figure that the resistivity of both as-deposited (Fig. 1a) and annealed (Fig. 1b) films increases with temperature.

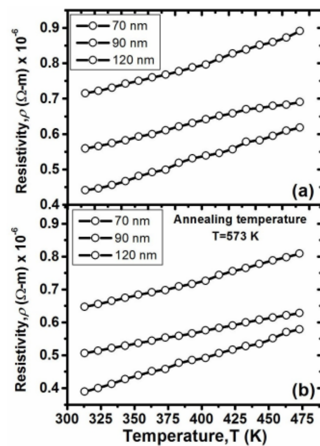

Fig. 1. Resistivity (ρ) vs. temperature (T) curve for (a) as-deposited and (b) annealed Ni films on glass substrate.

It is also seen from the figure that the resistivity decreases with increasing film thickness which affirms the Fuchs and Sondheimer [23,24] theory of size effect. The resistivity has a linear relationship with temperature in the observed range of temperature. It is also observed from the figure that the the values of resistivity of as-deposited Ni film are higher than the resistivity of annealed Ni films. Recrystallization of Ni film occurs at high temperature. Defect density greatly reduced during annealing. Therefore, the resistivity of annealed Ni film is lower than the resistivity of as-deposited film.

Fig. 2 shows the temperature dependent resistivity of (a) as-deposited and (b) annealed Ni films on Si substrate having thicknesses 50 nm, 120 nm and 180 nm. It is observed that the resistivity of Ni film increases with increasing temperature but the resistivity decreases with increasing film thickness [23,24]. The resistivity of Ni film decreases after annealing.

The resistivity of Ni film on Si substrate is found to be higher than that of Ni films on glass substrate. Nickel forms NiSi at the Ni/Si interface [25,26]. It is known that the resistivity of NiSi is higher than that of ferromagnetic Ni film. It is also known that NiSi is a semiconductor having a resistivity of 14-20 μΩ-cm [27] but Ni is a ferromagnetic metal having lower resistivity when deposited on glass substrate. Ni does not react with glass substrate and the resistivity of Ni/glass is only due to pure Ni film. For Ni/Si system, some Si is consumed by Ni and became NiSi after annealing. Therefore, the overall resistivity of Ni films on Si subatrate is higher than the resistivity of Ni fims on glass substrate [26].

TCR versus temperature graph of (a) as-deposited and (b) annealed Ni films on glass substrates is shown in Fig. 3. It is observed that the T.C.R is always positive for both the as-deposited and annealed films. This is evident from the above result that the samples are metallic in nature. It is also observed that the TCR curve is not linear over

the entire temperature range. This is due to the fluctuation of temperature during the measurement.

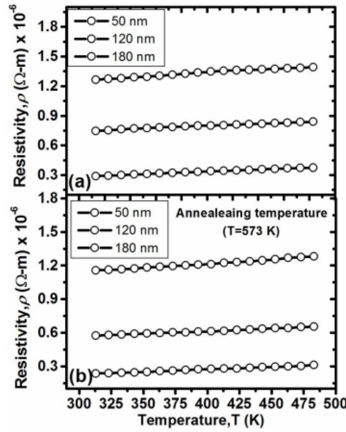

Fig. 2. Resistivity (ρ) vs. temperature (T) curve for (a) as-deposited and (b) annealed Ni films on silicon substrate.

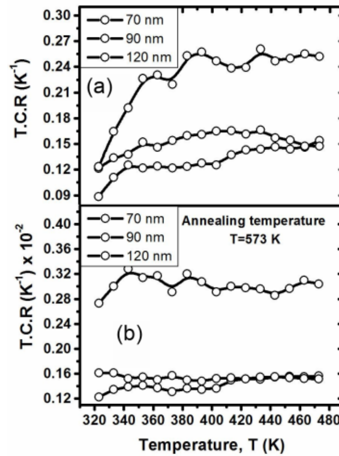

Fig. 3. TCR variation against temperature; (a) as-deposited, (b) annealed Ni films on glass substrate.

Magnetization of Ni films on both the glass and Si substrates was measured at room temperature. It is known that the magnetization process of ferromagnetic materials is affected by substrates. To study the effect of substrates on the magnetization process, Ni films of different thicknesses are deposited on both the glass and Si substrates. Fig. 4 shows the hysteresis loop of 80 nm as-deposited Ni film on

glass substrate. The coercivity and squareness of the film is 9 Oe and 0.17, respectively.

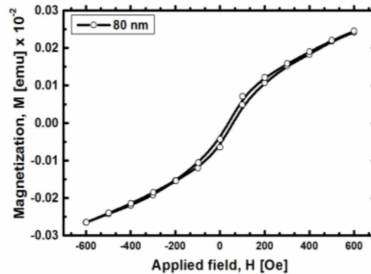

Fig. 4. Hysteresis loop (M-H curve) of 80 nm as-deposited Ni film on glass substrate.

Hysteresis loop of 90 nm and 160 nm Ni films on Si substrate is shown in Fig. 5. It is clear from Fig. 5(a) and Fig. 5(b) that the coercivity, squareness and remanent magnetization increases with increasing film thickness. This result complies with the result reported by Haque *et al*. [7]. The coercivity of 90 nm and 160 nm as-deposited Ni films are 50 Oe and 85 Oe, respectively. The squareness of 90 nm Ni film is 0.1 but it is increased to 0.2 for 160 nm film.

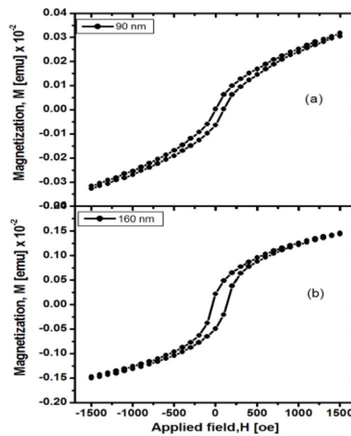

Fig. 5. Hysteresis loop of (a) 90 nm and (b) 160 nm as-deposited Ni film on silicon substrate.

It is seen from Figs. 4 and 5(a) that the coercive field of Ni film on glass substrate is lower than the coercivity of Ni film on Si substrate. This may happen due to better short-range order of the films deposited on the crystalline substrates [28].

The relationship between coercivity and roughness for a relatively thick film is complicated, rather than a simple monotonic relationship [18]. In general, films cannot be grown perfectly. Roughness appears in the film plays significant role in modulating the magnetic properties. For in-plane magnetization, local magnetizing fields at the surface reduce its anisotropy. The surface roughness of ferromagnetic thin film depends on both the annealing temperature and substrates. In order to understand the effect of surface roughness on coercivity, the roughness was studied by an AFM.

Fig. 6 shows the AFM images of 150 nm as-deposited and annealed Ni film on glass substrate. The rms value of the surface roughness of as-deposited film is 12 nm which becomes 7 nm after annealing.

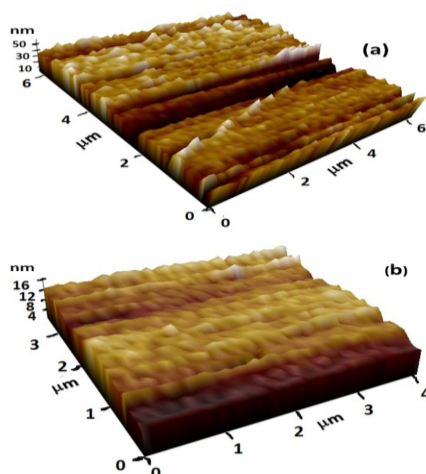

Fig. 6. AFM image of 150 nm (a) as-deposited and (b) annealed (at 573K for 1.5 hours) Ni films on glass substrate.

To observe the effect of substrate on the surface roughness, Ni thin film of 120 nm was prepared on Si substrate. The AFM image of the film is shown in Fig. 7. The rms value of surface roughness of as-deposited Ni film on Si substrate is 16 nm which becomes 3 nm after annealing. It is seen that the surface roughness of Ni film on glass substrate changes 42 % after annealing. On the other hand, the change is 81 % for Ni films on Si substrate. It is known that the surface roughness decreases after annealing [29]. Ni forms Nickel silicide (NiSi) at relatively low temperature but it becomes Nickel disilicide ($NiSi_2$) at high temperature [26]. For glass substrate the interfacial reaction is zero. It is evident from the above discussion that the change in surface roughness of Ni films on Si substrate is much higher than the change in surface roughness found in Ni films on glass substrate. This may be due to the formation of Nickel silicides or disilicides at the interface of Ni/Si.

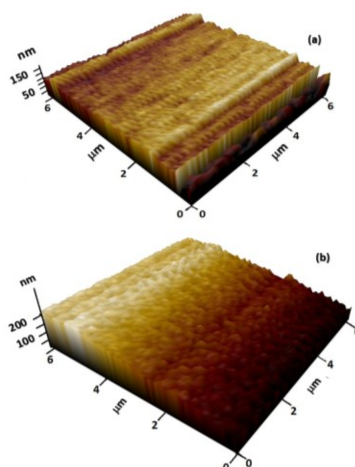

Fig. 7. AFM image of 120 nm (a) as-deposited and (b) annealed (at 573K for 1.5 hours) Ni film on Si substrate.

3. Conclusion

The resistivity of as-deposited and annealed Ni films on glass and Si substrates increases with increasing temperature. It is speculated that the NiSi is formed at the interface of Ni and Si substrate. The resistivity of Ni on Si is higher than the resistivity of Ni on glass substrate. This is due the formation of NiSi at the interface. TCR of both as-deposited and annealed films on glass substrate is positive which indicate the metallic nature of the film. The coercivity of Ni films on glass and Si substrates increases with increasing film thickness. It is evident from results that the coercivity of Ni on Si is 5 times higher than the coercivity of Ni film on glass substrate. Morphological studies of as-deposited and annealed Ni films on glass and Si substrates show that the surface roughness of Ni film is reduced after annealing.

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