Research Journal of Physical Sciences ISSN 2320–4796
Vol. 3(10), 4-8, December (2015) Res. J. Physical Sci.

Thickness dependence of Structural and Magnetic properties of Ni/Al/Ni films

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Available online at: www.isca.in
Received 6th October 2015, revised 11th October 2015, accepted 30th November 2015

Abstract

Sandwiched films, Ni(100nm)/Al(t)/Ni(100nm) with t = 60nm, 70nm, 80nm, 90nm and 100nm were deposited at 473K by thermal and electron beam evaporation techniques in high vacuum. Scanning electron microscopy (SEM) and Atomic force microscope (AFM) were employed to study surface structure and grain sizes. Grain sizes are found to be increasing with increasing interfacer layer. Magnetization has been measured in a vibrating sample magnetometer (VSM). Coercive field, saturation magnetization, remanent magnetization were determined. The results revealed the existence of antiferromagnetic (AF) coupling between Ni layers through an interfacer Al layer. The strength of AF coupling was observed to be dependent on Al layer thickness. For the first time that Ni/Al/Ni films of varied Al thickness have been studied for structure and magnetic properties and the data has been thoroughly analyzed.

Keywords: Sandwich films, surface roughness, magnetization, coercive field.

Introduction

In the past few decades, multilayeres have been probed for magnetic and electronic properties. These systems were consisting of magnetic and nonmagnetic layers were studied due to their usefulness in devices like magnetic sensors[1]. The role of nonmagnetic spacer in tuning the interlayer exchange coupling (IEC) between two neighboring magnetic layers has been first reported by Grunberg[2]. Subsequently, giant magneto resistance (GMR) was simultaneously discovered followed by the detection of oscillations in IEC with varying width of the nonmagnetic spacer [3-5]. The studies of grain sizes in Al films of thickness in the range of 10 nm-200 nm grown on (111) Si revealed that grain size increases with increase in thickness[6]. In some studies, chromium (Cr), an ant ferromagnetic layer instead of a non-magnetic layer such as copper (Cu) has been used and investigated for interface roughness, magnetic and electronic structures[7-9]. The low temperature resistivity of the films, Co/M/Co (M = Cr or Cr/Ag or Ag/Cr) has been observed to be abnormal[10]. The effect of Cu interlayer on grain size and stress has been studied for sputtered Fe/Cu films[11]. The structural and magnetic properties as a function of Fe layer thickness were studied for Fe/Cu multilayers[12]. Some of the studies were aimed at optimizing the planar structure of (111) Au/Co/Cu trilayers[13]. The interlayer coupling is known to be influenced by the thickness of spacer layer. Hence, it is worth to compare the interlayer coupling with different interface roughness but identical spacer layer thickness. In this paper, we present the results of structural and magnetic studies on Ni/Al/Ni films with different Al layer thicknesses. The layer structure of these films are, [Ni(100nm)/Al(t)/Ni(100nm)]; t=60nm, 700nm, 80nm, 90nm and 100nm labeled as NAN6, NAN7, NAN8, NAN9 and NAN10 respectively.

Methodology

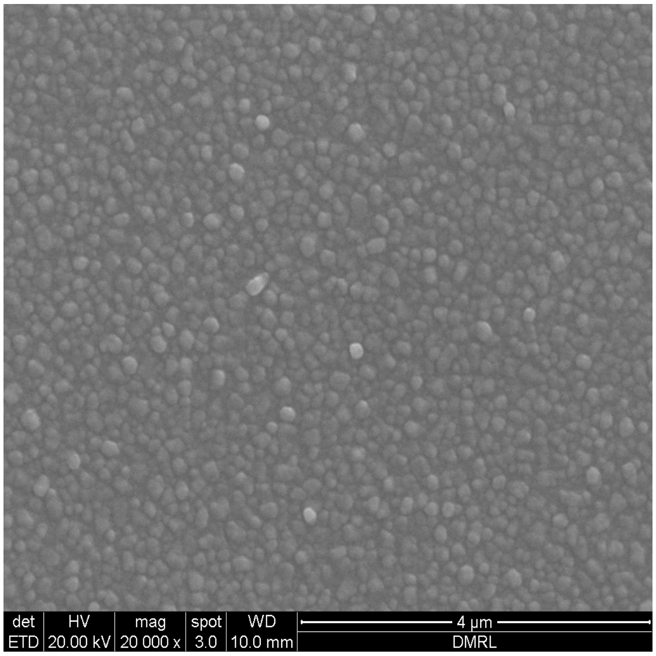
Present films were developed on glass substrates using electron beam gun and thermal evaporation techniques at a pressure 7 x 10^{-6} mbar and at a temperature 473K. The Ni and Al layers were deposited using electron beam gun and thermal evaporation techniques respectively. The microstructure of the films was probed using (FEI Quanta 400) Scanning Electron Microscope. Surface morphology of the films at nanometric scale has been investigated by AFM (Digital Instruments Nanoscope III). Average surface roughness of the films was determined on a scan area of 1 µm x 1 µm using Nanoscope software. Magnetization was measured at 300K using vibrating sample magnetometer (Model ADE-EV9) with a maximum applied field of 0.3 T.

Results and Discussion

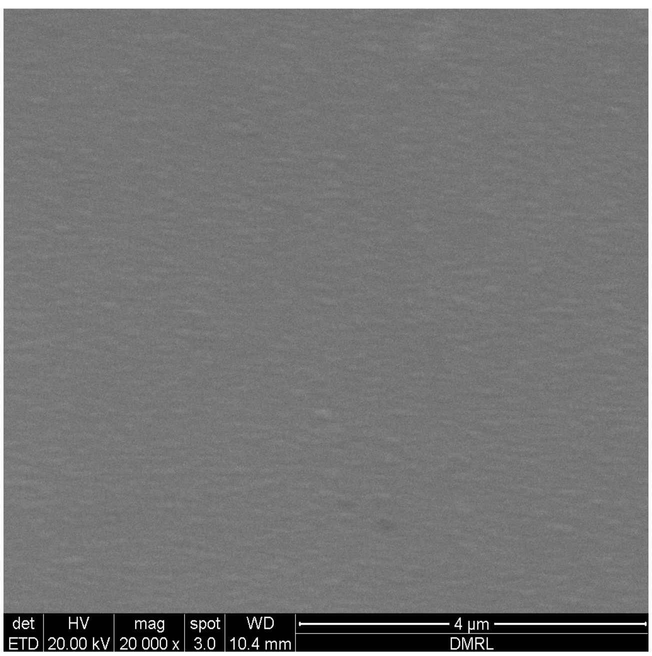
Scanning electron microscopy (SEM): The typical SEM images for NAN6 and NAN10 films are shown in Figure-1. The images appear smooth, compact and fine in structure revealing high concentration of nano graines. The size of the nanocrystallites increased with increase in Al layer thickness, t. This is evident from the figure- 1.

In NAN6 image (figure-1(a)), the grains can barely be observed and in NAN10 image (Figure-1(b)), the grains are quite observable. Images of other film of the present series have been closely looked at.

AFM: To investigate surface morphology, AFM images in contact mode with a scan area of 1 µm x 1 µm have been recorded. The AFM images in 2D and 3D for NAN10 film are depicted in Figure- 2.



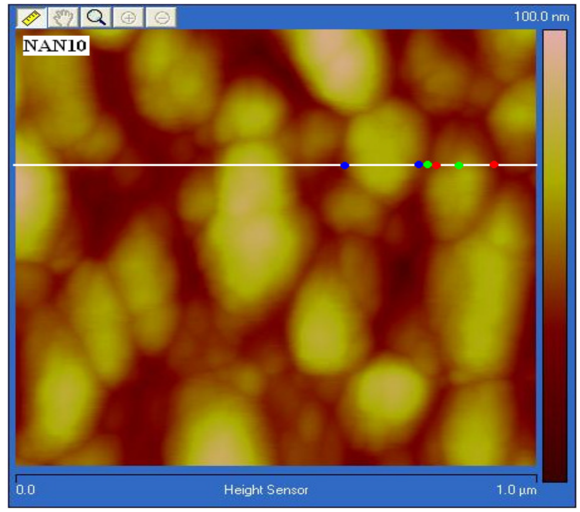
(a)



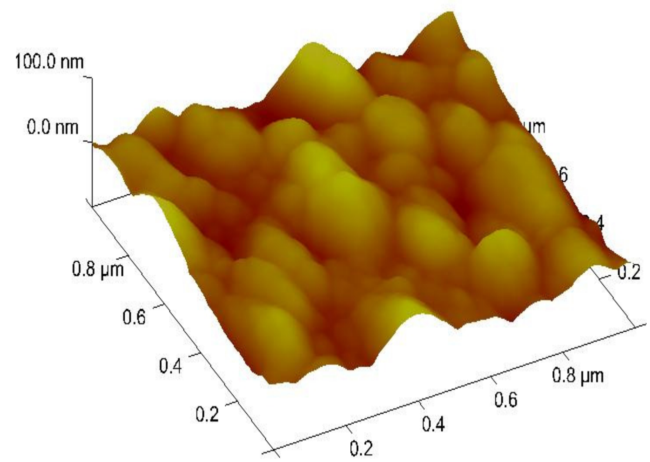
(b)

Figure-1
SEM images of (a) NAN6 and (b) NAN10 films

The images have been quantified using height versus distance profiles of the type shown in figure-3 across the length [white line drawn in figure-2(a)[14,15]. This analysis provided information on average grain size, D (pair of blue and red dots) and average surface roughness, h [pair of green dots in Figure- (2a)] of the films.



(a)



(b)
Figure-2
AFM image of NAN10 film in (a) 2D and (b) 3D

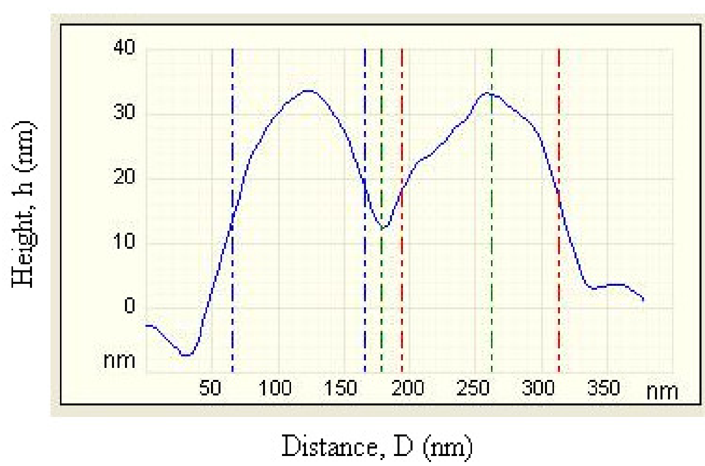
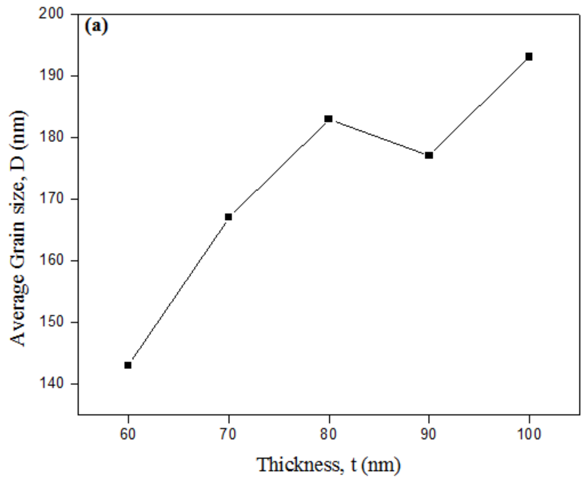
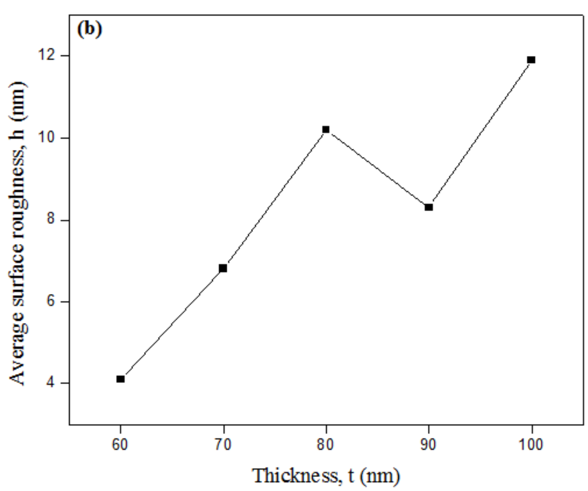


Figure-3
Height versus distance profile along the line drawn in Figure-2

It is noted that D increases with increasing t. The h value is also increased with increase of t. The variation of D and h with t are shown in figure-4 (a and b). Grain sizes and surface roughness increased with thickness of the interfacer layer except for NAN9.



(a)



(b)

Figure-4

Change in average (a) grain size, D and (b) surface roughness, h with Al thickness, t

The sectional analysis carried out using the software Nanoscope III, on the AFM images of all the films indicated that grain sizes and their heights changes considerably over the distance[16]. That is why, D and h of the films have been worked out by measuring them for different grains over different cross sections of the image and then averaged[18].

Magnetization: Magnetization was investigated by Vibrating Sample Magnetometer (VSM) technique. The magnetization, M, as function of applied field, H, was measured at 300K by applying field parallel to the surface of the films. The recorded hysteresis (M-H) loop for NAN6 film is shown in figure-5. Similar loops were obtained for other films.

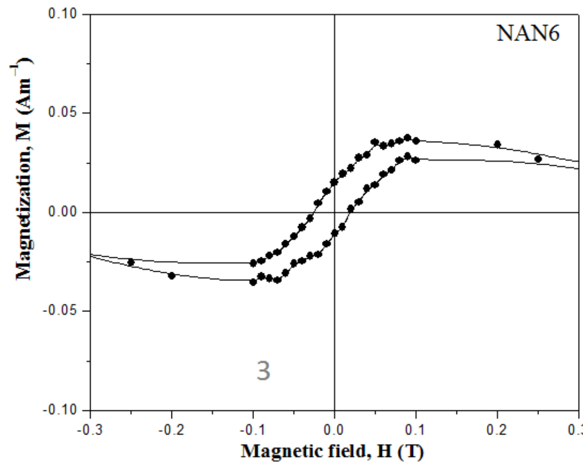


Figure-5

Plot of magnetization versus magnetic field for NAN6 film at 300K

The parameters such as coercive field, H_c, saturation magnetization, M_s, remanent magnetization, M_r, were extracted from the hysteresis loops. The t dependence of these parameters are plotted in figure-6(a-c).

It may be grasped that coercivity increases with increasing thickness. Coercivity has always been considered as an extrinsic quatity of materials, which is in fact very sensitive to metallurgical inhomogeneities, grain boundaries and dislocations.

Similar results have been reported for Ni/Cu and NiFe/Cu multilayers[17-19]. The saturation magnetization is increased with increase of thickness of Al layer except NAN9 film Similar results have been reported for FePt/M(Cu,C)/Fe multilayers[20]. The remanent magnetization initially decreased with increased t up to 70nm then increased for higher values of t[21]. Antiferromagnetic coupling, $(1-M_r/M_s)$ has been found to be increasing with increasing t up to 80 nm and decreased for further increase in t (figure-6(d).

Conclusion

Sandwich films, Ni(100nm)/Al(t)/Ni(100nm); t =60nm to100nm were deposited in high vacuum by thermal and electron beam evaporation methods at 473 K. The structure and surface roughness were investigated by scanning electron microscope (SEM) and atomic force microscopes (AFM). Magnetic hysteresis loops were recorded at 300K in a vibrating sample magnetometer (VSM). This data indicated magnetic coupling between the Ni layers through Al layer. The coupling increased up to Al layer thickness of 80 nm and decreased thereafter. For the first time that Ni/Al/Ni film of varied Al thickness have been studied for structure and magnetic properties at 300K and the data has been thoroughly analysed.

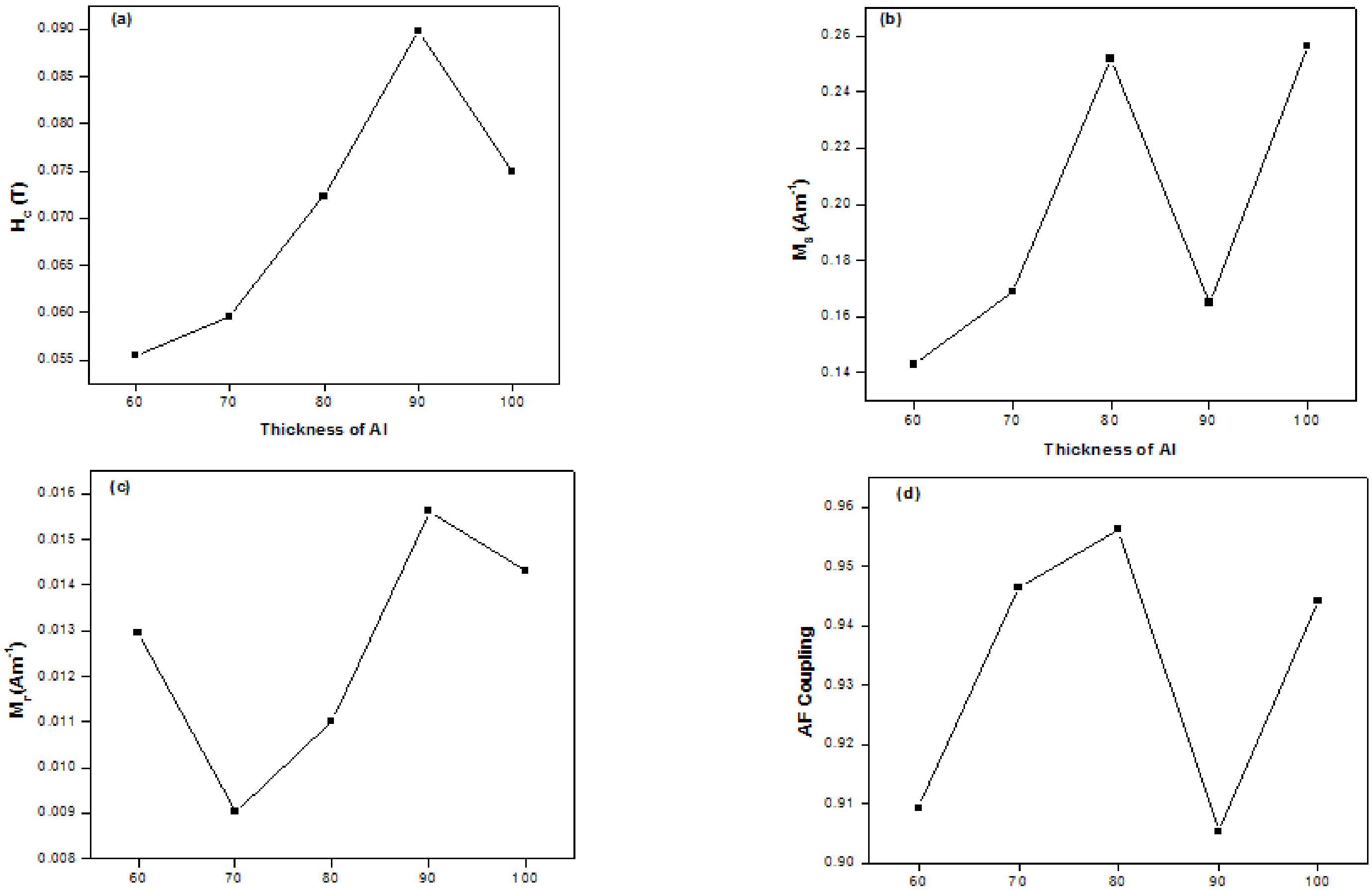


Figure-6
Thickness dependence of (a) coercive field, H_c (b) saturation magnetization, M_s (c) remanent magnetization, M_r (d) AF oupling.

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