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Nanocrystalline Fe thin films on Si(100) substrate

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Abstract

In this research structural properties of ferromagnetic Fe thin films on semiconductor Si(100) substrate have been reported. We will present topography features of these layers by atomic force microscopy (AFM). The Fe thicknesses range from 5 to 150 nm. The Fe films through evaporation technique are successfully grown on Si substrates and the structural proprieties of them were studied due to thickness changing. We estimated root mean square (rms) between 0.5-1.5 with 45^0 texture direction and rms slope between 0.02-0.06 for Fe films. The XRD patterns show the formation of β-$FeSi_2$ after annealing at 700 ^{0}C and indicate that annealing has obvious effects on the texture of the Fe-Si alloy.

Keywords: thin film, root mean square, roughness, AFM, high temperature XRD

Introduction

The Fe/Si layered system attracts a lot of attention because of the strong anti-ferromagnetic interlayer coupling. Thickness, shape, and surface roughness of thin nanostructure metal/silicon films are more important than other factors, such as nanocrystalline structure. In other hand, interfaces of these nano-layers are attracting sustained attention for many years. Reduction the size or dimension of the magnetic structure have been studied by (Bland *et al.,* 1994; Khapikov, *et al*. 1998; Kim, *et al*. 2000; Weber *et al*. 1996),especially for the ultra-thin film and nanostructured magneto-devices has effects on the above mentioned parameters. These will strongly influence on transport properties, optical properties, structural parameters and diffusion current on interface of nanostructure layers. In order to estimate the samples roughness, AFM measurements were carried out. Fig. 1 and 2 show the results of AFM and XRD measurements performed on Fe/Si with four thicknesses of Fe layers on Si(100) substrate.

The rms value of the standard deviation from average position of sample surface was determined on a $5\mu m \times 5\mu m$ area for each sample. The rms was estimated between 0.5–1.5 with 45^0 texture direction. The rms slope is calculated between 0.02 – 0.06 for Fe films. These values are typical for Fe as reported in other works e.g. 0.5 and 2 nm for Fe thickness between 6-110nm by Ghebouli, *et al.* (2007). Also, Dreyer *et al.* (2002) reported a rms value of 0.51nm in a 20nm thick e-beam evaporated Fe/Si(001) . The rms value changes in a non-monotonous manner when the Fe layer thickness increases. Below some critical thicknesses, about 35nm, deposited Fe does not create a uniform Fe layer, but is randomly distributed on the surface in the form of small separated islands. Also, it is well known that intermixing occurs at interfaces and leads to appearance of various structures similar to Fe–Si phases (Vries, *et al.,* 1997; Lucinski, *et al.,* 2003) which may be responsible for the anti-ferromagnetic coupling. Dufour, *et al.* (1991) found that at the Fe/Si interface, a 1.8 nm thick mixture consisting of magnetic and nonmagnetic phases is formed.

Kläsges *et al.* (1997) found about 2 nm thick amorphous silicates layer with the composition close to Fe_3Si at the interfaces, and they showed that Fe/Si and Si/Fe interfaces are not symmetri-

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cal. In this paper, we reported the growth of highly oriented columnar-structured Fe thin films grown on n-Si(100) substrates by using evaporation technique. We focused on the Si Structural properties and topography features of these layers by (AFM).

Materials and methods

Eight Fe thin films were grown on 1cm×1cm substrates by thermal evaporation. Before loading the samples into evaporation chamber, their surfaces were refreshed in diluted HF and cleaned by the standard procedures, used in microelectronics technology. After evacuation down 10^{-8} torr and prior to evaporation, Si wafers were annealed in situ for 5 minuets at 800 ^{0}C. Iron ingots from a 99.99 % purified Fe powder evaporated using an electron gun, at an evaporation rate of 0.3-0.4 nm/s, at 10^{-8} torr. The film thicknesses were measured by vibrating quartz system. The Fe thicknesses vary from 5 to 150 nm. To identify the crystalline structure of the deposited films, X-ray diffraction measurements have been used. X-ray diffraction (Cu-Kα radiation, λ= 0.15405 nm, Breg Brentano geometry) method was used to investigate the structure and phase layer composition transitions. The surface morphology was also investigated by AFM unit.

Results and discussion

In order to estimate the samples roughness, AFM measurements were carried out. Fig.1 shows the results of AFM measurements performed on Fe/Si with four thicknesses of Fe layers. The rms) value of the standard deviation from the average position of the structures at the sample surface was determined on $5\mu m \times 5\mu m$ area for each sample. The rms was estimated between 0.5–1.5 with 45^0 texture direction. The rms slope is estimated between 0.02–0.06 for Fe films. Fig.2a shows XRD pattern of Si(100) substrate before deposition layer. After deposition, for the very thick Fe on the substrate, no peaks were seen in XRD spectra. It is due to distributed of randomly oriented grains, thus the peaks are too weak to be detected by the instrument, so no diffraction peak could be clearly seen [3]. When the thickness of grown Fe film reaches up to about 50nm on Si(100) substrate, the Fe will be grown (110) texture with a bcc structure, see Fig.2b.

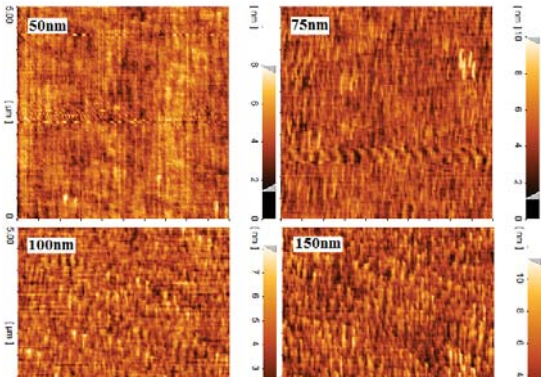

Figure 1. 5μm × 5μm AFM scan of Fe layer with different thicknesses on Si(100).

Fig.2c shows HT-XRD patterns for Fe on Si. All samples were annealed up to 600^{0}C for 120 min. After annealing at 250^{0}C, the substrate surface is covered by a thin Fe rich layer and that Si diffused into the Fe layer. After annealing at 450^{0}C, the Fe/Si atomic ratios become almost independent of the excitation energies. This indicates the chemical composition is even from the surface to the largest analysis depth.

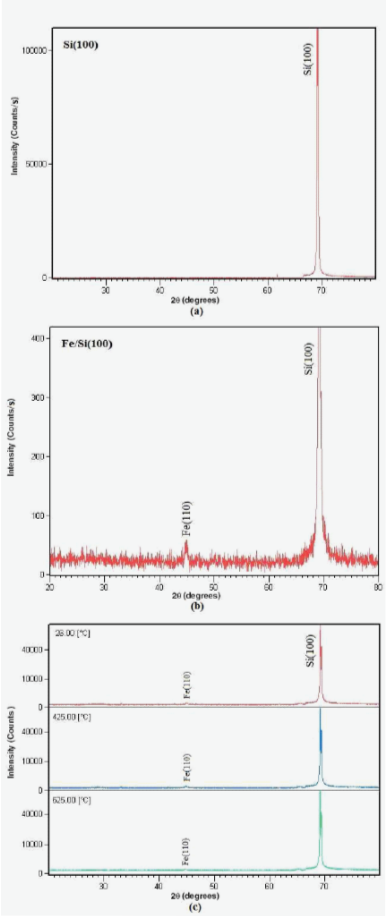

Figure 2. (a)XRD pattern for Si(100) substrate before deposition of Fe layer, (b) after deposition of Fe layers and (c) patterns of Fe/Si film were annealed up to 600 ^{0}C for 120 min film thickness is 100 nm.

Conclusions

The Fe films through evaporation technique grown were successfully fabricated on Si substrates and the structural proprieties of them were studied due to thickness changing. We estimated rms between 0.5-1.5 with 45^0 texture direction and the rms slope between 0.02-0.06 for Fe films. An XRD pattern shows the formation of β-$FeSi_2$ after annealing at 700 ^{0}C and indicates that magnetic annealing has obvious effects on the texture of the Fe-Si alloy.

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