Magnetic and morphologic properties of Alnico-based rare-earth free permanent magnets

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Abstract

Due to recent dramatic increases in the price of rare-earth elements, rare-earth free permanent magnet research is nowadays a very active field [1]. Alnico V alloys, first discovered in the 30's, are hard ferromagnets, with high working temperatures, albeit with modest coercivity, below 1 kOe [2]. This makes their energy product (~12 MGOe) compare unfavorably with rare-earth based NdFeB magnets (~55 MGOe). Recently, an unusually high coercivity value, up to ~ 10 kOe, was reported for DC-sputtered Alnico V thin-films on Silicon substrates [3, 4], due to the formation of a novel Body Centered Tetragonal Fe-Co-Si phase, a result of diffusion of Si ions from substrate to thin film. This diffusion mechanism is still unclear, and the chemical composition and saturation magnetization of this novel phase are not yet characterized.

We report on the effects of deposition temperature and post heat treatments on the morphology and magnetic properties of Alnico V thin films prepared by RF-sputtering. The sputtering target was of commercial Alnico V alloy, and substrates were of 700 µm thick Si(100). Samples of 180 nm thickness were prepared at different deposition temperatures, ranging from room temperature to 560˚C. Post-deposition heat treatments in vacuum at 600, 800 and 900˚C, followed by quenching in liquid Nitrogen and slow-cooling, were performed.

Atomic Force Microscopy (AFM) shows that both an increase of deposition temperature as well as post heat treatments lead to a considerable increase of roughness, from < 0.8 nm to 80 nm, for heat treatments at 600˚C, and 50 nm for a deposition temperature of 500˚C (Figure 1).

The chemical composition of the thin films was analyzed by Electron Dispersion Spectroscopy (EDS) in a Scanning Electron Microscope (SEM). The composition of films deposited at room temperature, matches that of the target, while for higher substrate temperatures the ratio between transition metals is altered, and post-deposition heat treatments introduce contaminations to the thin films. Figure 2 shows the cross-section SEM image of the as-made and heat treated films.

Magnetization analysis using a Vibrating Sample Magnetometer (VSM) shows that substrate temperature affects the saturation magnetization, lowering it drastically for high temperatures. In the case of heat treatments this decrease is smoother, but still quite substantial, particularly for quenched samples. Coercivity is unaffected by deposition temperatures in this range, while increasing considerably (from < 20 Oe for as-deposited films up to 480 Oe) in heat-treated samples (Figure 3).

Future studies will focus on film thickness and substrate temperature optimization, and the control of surface roughness under heat-treatments, by adding a capping layer to the films (Ag, Ta), preventing also the observed oxidation of the surface during heat treatment and quenching.

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References

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Figures

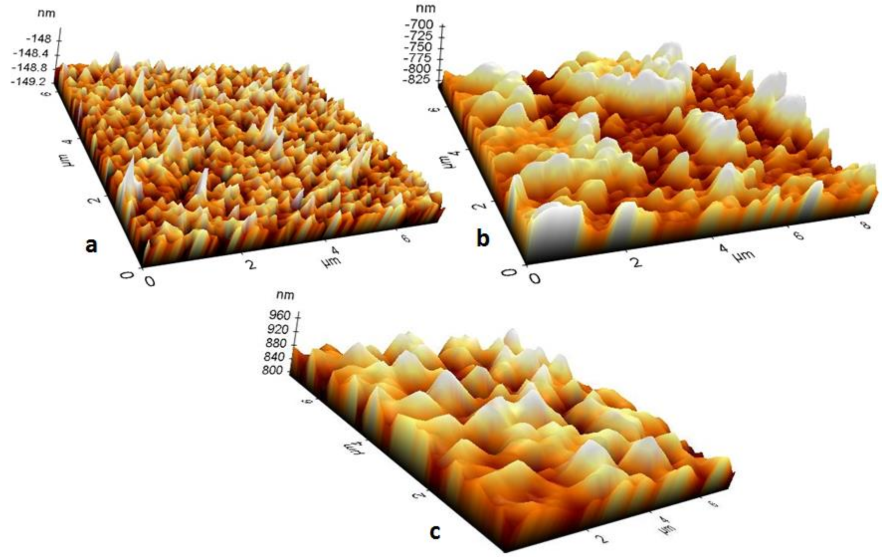

Figure 1 AFM image of a) as-deposited, b) after heat treatment and c) deposited at 560℃.

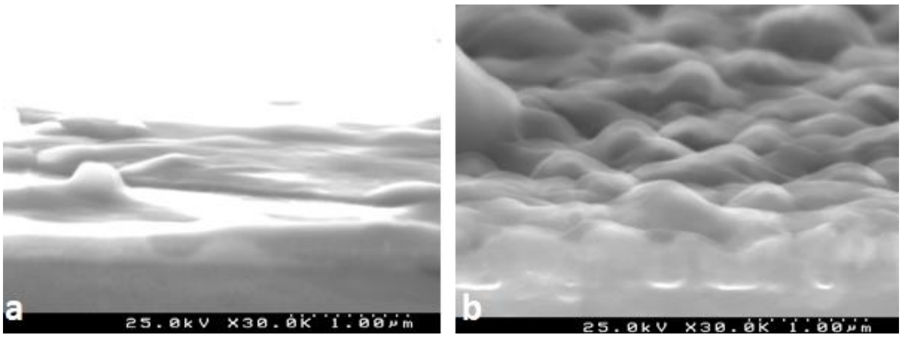

Figure 2 Cross sectional SEM image of a) as-deposited, b) after heat treatment

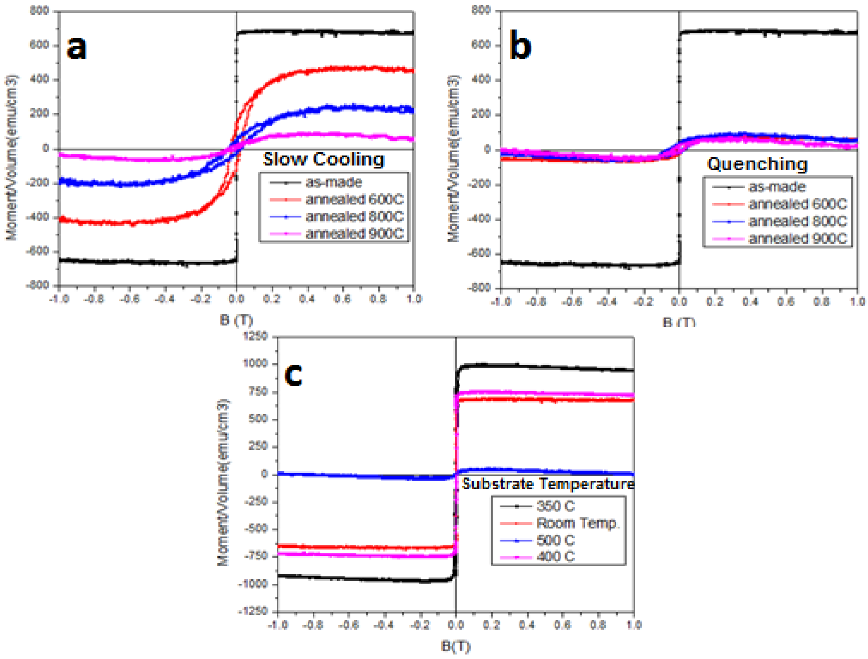

Figure 3 Effects of a) heat treatment followed by slow cooling, b) heat treatment followed by quenching and c) deposition temperature on hysteresis loop