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# Characteristics of Iron-Palladium alloy thin films deposited by magnetron sputtering

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ABSTRACT

The microstructural features, magnetic, nanomechanical properties and wettability behaviors of Iron-Palladium (FePd) alloy thin films are investigated by using X-ray diffraction (XRD), atomic force microscopy (AFM), vibrating sample magnetometer (VSM), nanoindentation and water contact angle (CA) techniques, respectively. The FePd alloy thin films were deposited on glass substrates using a magnetron sputtering system. The post-annealing processes of FePd alloy thin films were carried out at 400 °C and 750 °C and resulted in a significant increase of both the average grain size and surface roughness. The XRD analysis showed that FePd alloy thin films exhibited a predominant (1 1 1) orientation. The magnetic field dependence of magnetization of all FePd thin films are measured at room temperature showed the ferromagnetic characteristics. The nanoindentation with continuous stiffness measurement (CSM) is used to measure the hardness and Young's modulus of present films. The contact angle ($\theta_{CA}$) increased with increasing surface roughness. The maximum $\theta_{CA}$ of 75° was achieved for the FePd alloy thin film after annealing at 750 °C and a surface roughness of 4.2 nm.



## Introduction

The $L1_0$ Iron-Platinum (FePt) and Iron-Palladium (FePd) alloy thin films have attracted much attention in the magnetic recording media application [1–2] because of their high magnetocrystalline anisotropy (*K*u, $6.6 \times 10^7$ erg/cm$^3$ for FePt and $1.8 \times 10^7$ erg/cm$^3$ for FePd) [3–4] that provides a promising thermal stability of materials with the small grain size. Since FePd occurs at temperatures lower than that of FePt, $L1_0$ FePd may be suitable for nanoscale structures control, which is required for the applications in magnetic recording media [5]. Moreover, the Pd element has competitive advantage for industrial applications because its cost is lower than Pt.

Although FePd alloy thin films have been widely investigated and used in various nanoscale devices [6–7], their mechanical properties are largely ignored. Since for most device fabrication processes, the contact-induced damage may significantly affect the fundamental properties of the devices, and thus a quantitative assessment of the mechanical properties of the device material is very important. Recently, the nanoindentation technique has been widely used to characterize the mechanical responses (such as the hardness, Young's modulus and, the elastic/plastic deformation behaviors) of various materials [8–14].

Nevertheless, few studies have focused on the correlation between the structures and mechanical properties of FePd alloy thin films on nanoscale via annealing treatment [15]. The structural properties and surface features of FePd alloy thin films are analyzed using X-ray diffraction (XRD) and atomic force microscopy (AFM), respectively. The nanomechanical properties of FePd alloy thin films are measured by nanoindentation. In addition, it is further demonstrated that the wettability behaviors of thermal-treated FePd alloy thin films can be changed from hydrophobic to hydrophilic behavior. The magnetic properties of FePd alloy thin films are also discussed here.

## Experimental details

FePd alloy thin films deposited on Corning 1737 glass substrates by a magnetron sputtering system are using a $Fe_{50}Pd_{50}$ alloy target. The experimental conditions (the base pressure below $2 \times 10^{-7}$ Torr and the 10 mTorr working pressure) are used. The thickness of samples was about 200 nm. After deposition, FePd alloy thin

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films were subjected to the rapid thermal annealing (RTA) process at the temperatures of 400 °C and 750 °C for 10 min, respectively, with a background pressure lower than $2 \times 10^{-6}$ Torr. And, the heating rate of RTA process is kept at 40 °C/s.

The crystal structure of FePd alloy thin films are analyzed using an X-ray diffractometer (Panalytical X'Pert XRD, CuKα, λ = 1.5406 Å). The Scherrer's formula [16], $D = 0.9\lambda/(B\cos\theta)$, was employed to estimate the mean grain size ($D$) of FePd alloy thin films. Here, $\lambda$, $B$ and $\theta$ are the X-ray wavelength, the full-width-at-half-maximum (FWHM) of (1 1 1) peak and the corresponding Bragg's diffraction angle, respectively. The surface roughness ($R_{RMS}$) [17] of FePd alloy thin films is measured by an AFM (Topometrix-Accures-II). The magnetic properties of films are measured using a vibrating sample magnetometer (VSM) at room temperature. In addition, the wettability of thin films surface under ambient conditions was monitored using a Ramehart Model 200 contact angle goniometer with deionized water as the liquid at room temperature.

Nanoindentation experiments were performed by an MTS Nano Indenter® XP system with the continuous stiffness measurement (CSM) technique [18]. This technique was accomplished by imposing a small, sinusoidal varying force on top of the applied linear force that drove the motion of a three-sided pyramidal Berkovich indenter tip. Solving for the in-phase and out-of-phase portions of the displacement response gave rise to the determination of the contact stiffness as a continuous function of depth [18]. Thus, the change of mechanical properties with respect to the indentation depth can be obtained. First, prior to applying loading on measured films, nanoindentation was conducted on a standard fused silica sample to obtain the reasonable range. Then, a constant strain rate of 0.05 $s^{-1}$ was maintained during the increment of load until the indenter reached a depth of 50 nm into the surface. The load was then held at the maximum value of loading for 10 s in order to avoid the creep which might significantly affect the unloading behavior. The indenter was then withdrawn from the surface at the same rate until the loading was reduced to 10% of the maximum load. Finally, the indenter was completely removed from the material. Here, the constant strain rate is used to reduce the strain-hardening effects. In order to avoid the interaction, the distance between the adjacent indents was kept at least 10 μm.

The hardness is defined as $H = P_m/A_p$, where $P_m$ is a maximum indentation load measured at the depth ($h$) and $A_p$ is the projected contact area between the indenter and the sample at $P_m$. The reduced elastic modulus ($E_r$), which is the combined elastic modulus of both the measured sample and the indenter, is calculated as $E_r = \frac{1}{2}S\sqrt{\pi/A_p}$, where $S = dP/dh$ (stiffness) is the slope of the upper portion of unloading curve in the load-displacement curve ($Ph$-curve). The elastic modulus of thin films ($E_f$) is then calculated as follows [19]:

$$E_f = (1 - v_f^2)\left(\frac{1}{E_r} - \frac{1 - v_i^2}{E_i}\right)^{-1} \quad (1)$$

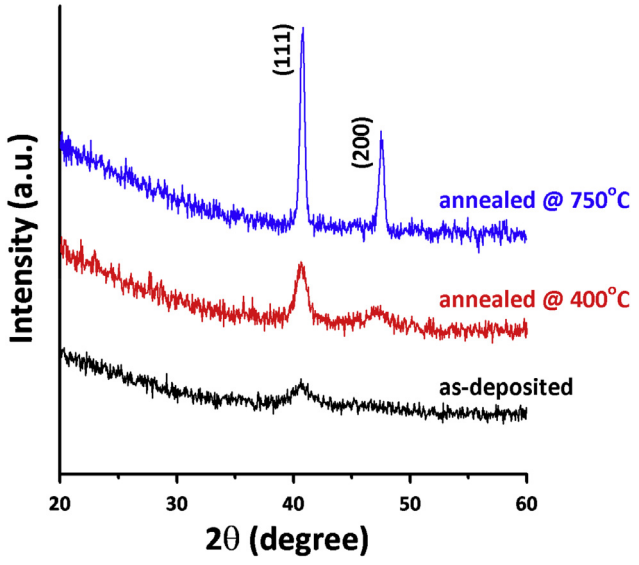


**Fig. 1.** XRD patterns of as-deposited and annealed FePd alloy thin films.

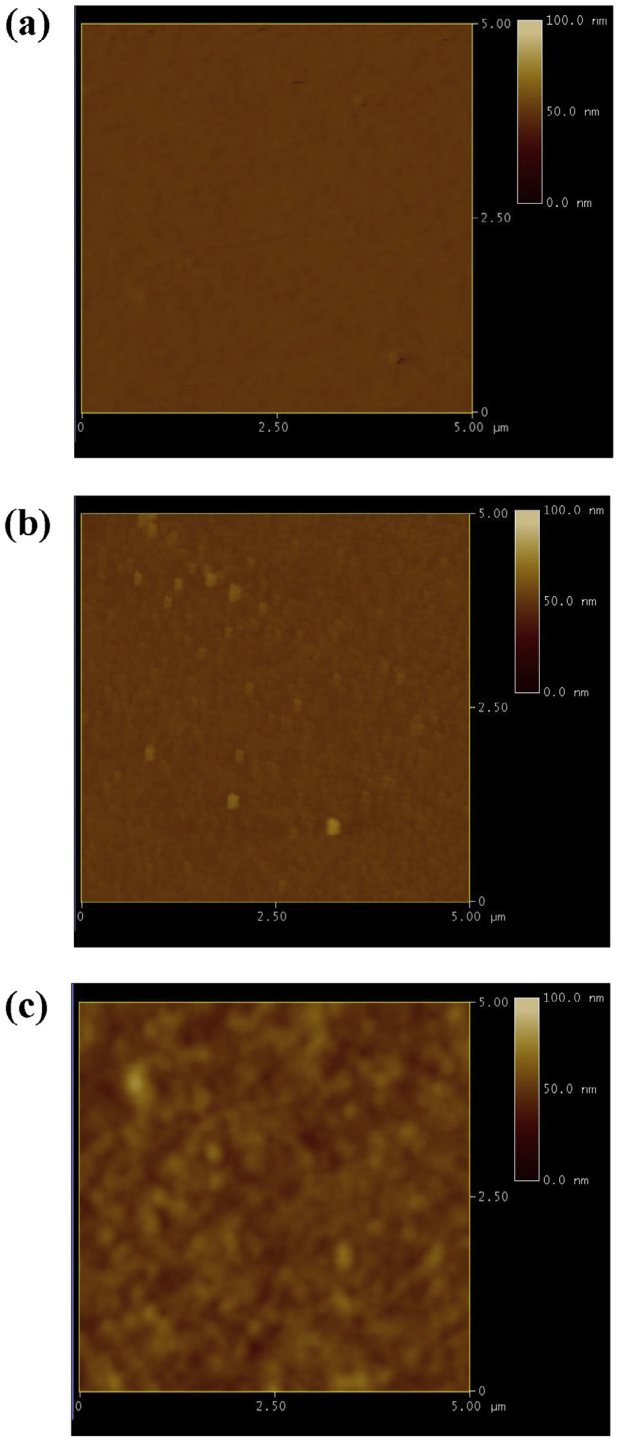


**Fig. 2.** AFM images of (a) as-deposited, (b) 400 °C and (c) 750 °C annealed FePd alloy thin films.