Features of ordered nanostructure formation in ultrathin FePd films annealed in hydrogen

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MOTIVATION

Magnetic materials on the base of FePd with large perpendicular magnetic anisotropy are perspective for use as ultrahigh density recording media in HAMR and development of magnetic tunnel junctions for future spintronic memory and logic devices.

THE AIM

of this work was the investigation of the annealing environment (vacuum, hydrogen), temperature and duration of annealing on the phase composition, structural and magnetic properties of FePd(5 nm) films.

EXPERIMENTAL

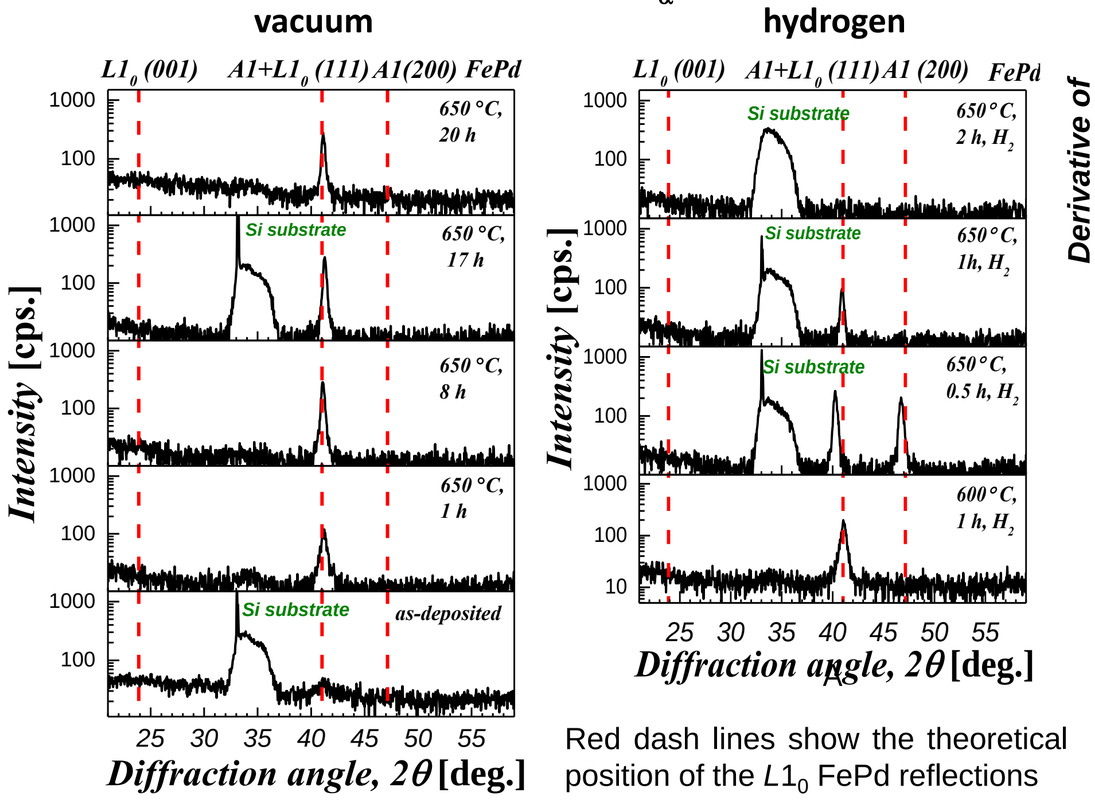
$Fe_{50}Pd_{50}$(5 nm)

SiO_2/Si(001)

Heat treatment conditions		
Annealing environment	Vacuum	H_2
Pressure	10^{-3} Pa	1 atm
Annealing temperature	650 °C	500 °C – 700 °C
Heating rate	5 °C/s	1 °C/s
Duration of annealing	from 0.5 h to 20 h	0.5 h, 1 h, 2 h
Cooling speed	0.25 °C/s	1 °C/s

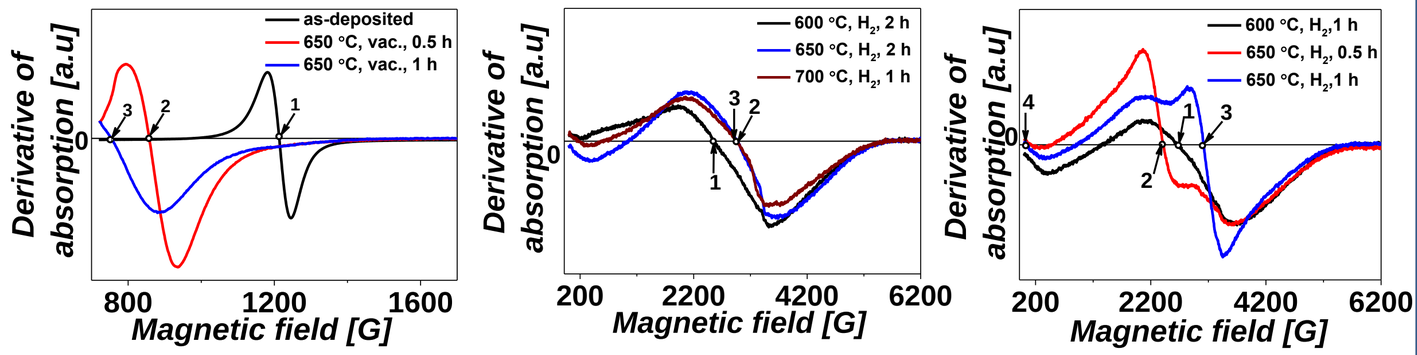
FePd films of equiatomic composition were deposited at room temperature by magnetron sputtering on $_{SiO2(100}$ nm)/Si(001) substrates. The as-deposited and post-annealed films were investigated by X-ray analysis, RHEED, SQUID, FMR and AFM methods.

XRD patterns of the as-deposited FePd(5 nm) films and after heat treatment. Cu K_α radiation

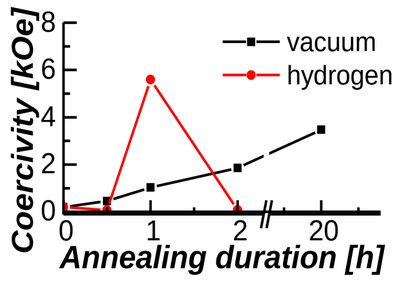


Red dash lines show the theoretical position of the $L1_0$ FePd reflections

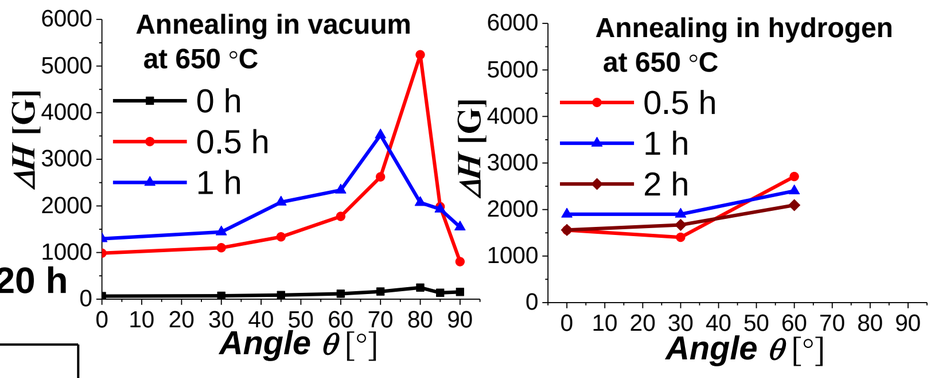
FMR spectra of the FePd(5 nm) film obtained in-plane applied magnetic field after deposition and annealing in vacuum and hydrogen



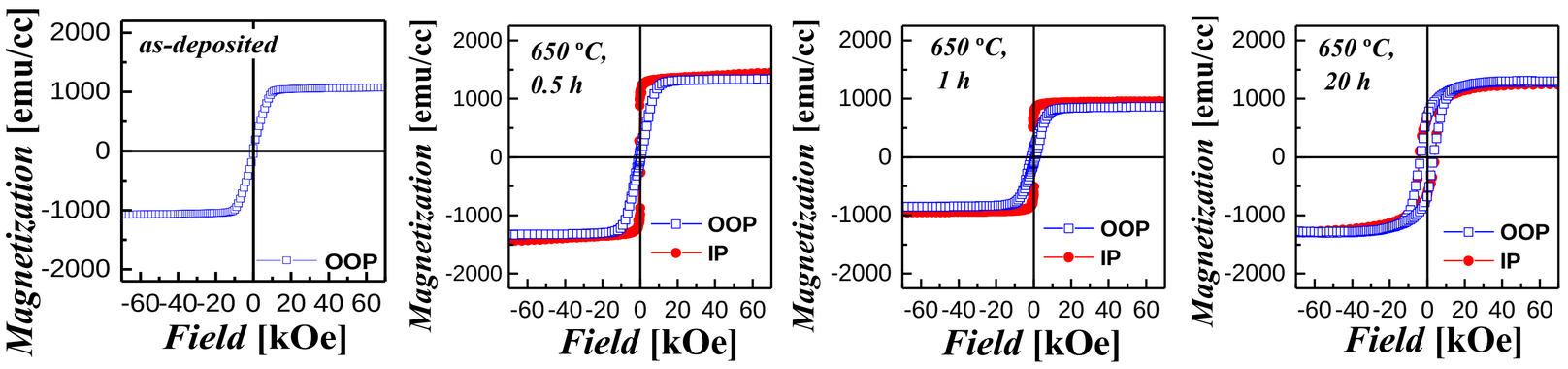
Change in the coercivity of the FePd(5 nm) film annealed at 650 °C in vacuum and H_2 with the annealing duration



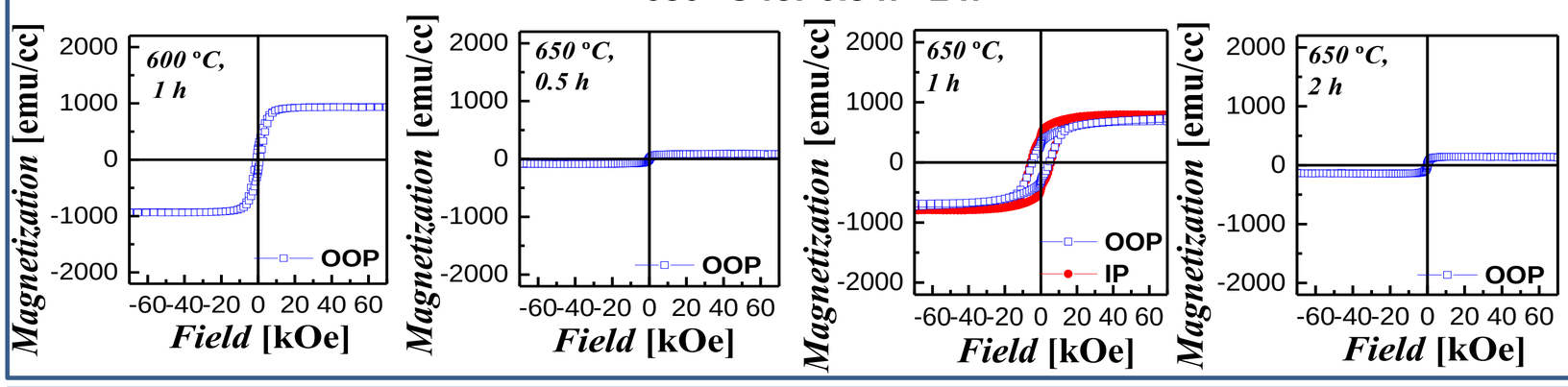
Dependence of the line width ΔH on the angle θ_H of the applied external magnetic field and the annealing time at 650 °C in films annealed in vacuum and hydrogen



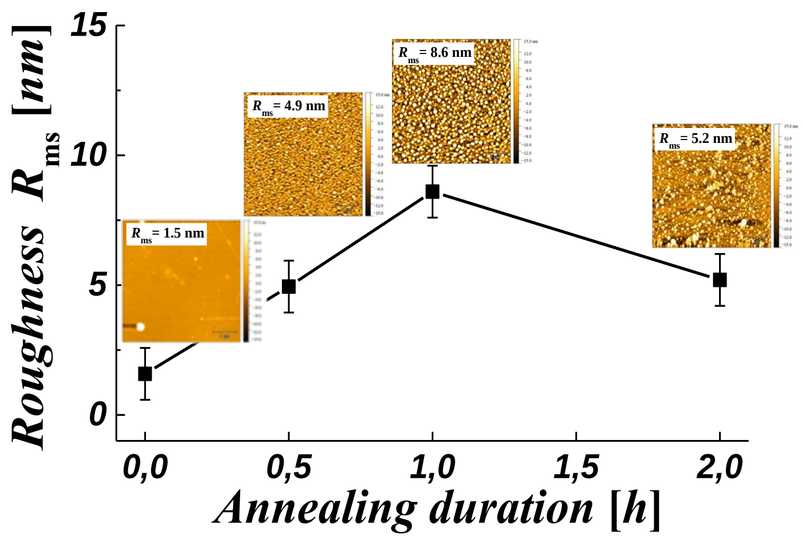
M–H hysteresis loops of the FePd(5 nm) films annealed in vacuum at 650 °C for 0.5 h – 20 h



M-H hysteresis loops of the FePd(5 nm) films annealed in hydrogen at 600 °C for 1 h and 650 °C for 0.5 h - 2 h



Dependence of the $Fe_{50}Pd_{50}$(5 nm) films roughness on annealing duration in hydrogen and AFM images of the surface morphology



CONCLUSIONS

In as-deposited films, a disordered *A*1 FePd phase was observed. The ordering process occurs by a thermally activated solid-phase reaction of transition from the soft magnetic *A*1 to the hard magnetic $L1_0$ FePd phase. In this case, annealing in hydrogen significantly activates this process.

Thus, upon annealing at 650 °C for 1 h in hydrogen, the $L1_0$ FePd phase with a coercivity value of 5 kOe is formed. In the same time, upon annealing in vacuum the ordering processes proceed much more slowly and the coercivity reaches ~ 1 kOe. In addition, hydrogen atoms affect the electronic structure of the film. During heat treatment in hydrogen (650 °C, 0.5 h), in contrast to annealing in vacuum, a paramagnetic state appears in the film during the ordered $L1_0$ phase formation. With an increase in the annealing time to 1 hour, it is replaced by a hard magnetic state. A further increase in the annealing duration to 2 h or temperature up to 700 °C, is again accompanied by the paramagnetic state formation. In this case, the crystal structure of the ordered $L1_0$ phase is mainly preserved. Thus, the annealing of the FePd(5 nm) film in hydrogen leads to a reversible change in the magnetic properties and states.

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