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## Magnetic Properties and Structural Changes in $\text{Co}_{50}\text{Pt}_{50}$ and $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$ Solid Solutions Films

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*We studied the thin films of  $\text{Co}_{50}\text{Pt}_{50}$  and  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  with thicknesses between 20 and 1000 Å. Thinner films after annealing showed formation of tetragonal ordered crystallites in their fcc lattice, which are oriented so that the easy magnetization axis is perpendicular to the film plane. The coercivity depends on the thickness of film. These properties are discussed with respect to the annealing treatment and long-range order degree of the films.*

*Keywords: thin films, atomic ordering, magnetic anisotropy.*

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The perpendicular magnetic anisotropy is one of the properties which favor the use of such materials as a medium for data storage. One class of such materials is Co-Pt systems [1, 2], they are the subject of this paper.

The studied films of  $\text{Co}_{50}\text{Pt}_{50}$  and  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  ( $x=1-10$  at. %) had thicknesses of 20–1000 Å. They were produced by magnetron and vacuum sputtering and had fcc lattice. Monocrystalline films, grown on MgO and LiF substrates had fcc lattice parallel to the base plane. Initially all films regardless of their thicknesses had two perpendicular easy magnetization axes in plane of films. The squareness ratio of hysteresis loop was 0.6–0.8 and coercive force was about 500 Oe for all the samples. In order to obtain the desired ordering in films they were annealed in vacuum at 600°C for 3 hours. After that films showed appearance of ordered phase  $L1_0$  (tetragonal face centered with axes ratio  $c/a < 1$ ) with the orientation of these tetragonal regions dependent on the film thickness. Films in the range 20–200 Å had tetragonal phase crystallites oriented with their  $c$  axis normal to the film (no  $\{100\}$  reflexes on the electron diffraction patterns). In thicker films (three different orientations of the  $c$  axis) there were regions with stripes of the varying contrast in the  $[100]$  direction. Magnetic anisotropy of films undergoes significant changes because of tetragonal ordered phase formation. Since the  $c$  axis of tetragonal crystallites of  $\text{Co}_{50}\text{Pt}_{50}$  and  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  is their easy magnetization axis, thin ordered films become magnetically uniaxial with easy axis perpendicular to the film. The coercive force for films thicker than 200 Å varied in the range of 8–12 kOe. The thinner films coercivity was significantly dependent on the

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thickness Fig. 1. The squareness ratio of hysteresis loop was close to 1. Easy direction coercive force varied from 1.5 kOe to 9 kOe with thickness increased from 50 to 200 Å.

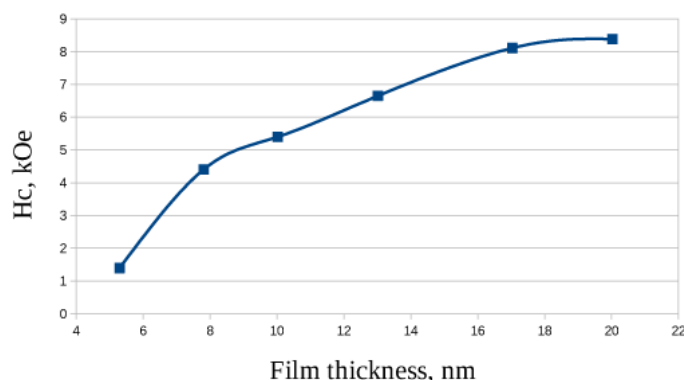


Fig. 1.  $H_C$  against the film thickness of  $\text{Co}_{50}\text{Pt}_{43}\text{Pd}_7/\text{MgO}$

The measured values of the coercivity  $H_C$  of  $\text{Co}_{50}\text{Pt}_{50}$  and  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  on MgO substrates thinner than 200 Å and hysteresis loop squareness of 1 constitute the differences between the magnetic crystallographic anisotropy field and the demagnetizing shape field of a film. Therefore, the experimentally derived dependence of the coercive force on the thickness of a film could be used to find the value of the fundamental characteristic of a ferromagnet the constant of crystallographic anisotropy and its dependence on the thickness of a film.

So it was found that monocrystalline ordered (partially ordered) films with  $L1_0$  structures, which showed their perpendicular magnetic anisotropy, had the value of magnetic crystallographic anisotropy constant in the range from  $7 \times 10^6$  erg/cm<sup>3</sup> to  $4.5 \times 10^7$  erg/cm<sup>3</sup> for  $\text{Co}_{50}\text{Pt}_{50}$  films and  $(3.5 - 4) \times 10^7$  erg/cm<sup>3</sup> for  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  films, depending on the film thickness. These values exceed the shape anisotropy so films stay uniformly magnetized perpendicular to the plane without external magnetic field. If Pd content is increased the coercive force of  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  films goes down and reaches 6–9 kOe at  $x=7-8$  at. %.

The behavior of magnetic anisotropy in the annealing process is due to atomic ordering which takes place in the films.

In equiatomic  $\text{Co}_{50}\text{Pt}_{50}$  and  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  ( $x=1-10$  at. %) during the annealing the forming of highly anisotropic CoPt phase takes place. The crystallographic  $c$  axis of it is an easy magnetization axis.

The way the crystallites are distributed in the film and their long range ordering Fig. 2 defines the films magnetic anisotropy. In the thinner films (under 200 Å for CoPt and under 180 Å for  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$ ) after annealing all the tetragonal regions are oriented with their  $c$  axis perpendicular to the film plane. The crystallographic anisotropy constant of this phase is greater than shape anisotropy field of the film. Such films stay uniformly magnetized in perpendicular direction without external magnetic field. Since the films are crystallographically uniform, their uniaxial anisotropy constant equals to the first crystallographic anisotropy constant of the ordered phase. These constants depend on the details of the annealing process, such as the annealing temperature, and, ultimately, on the long range order.

Crystallographic magnetic anisotropy constants of CoPt and  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  ordered phases depend on the annealing temperature and the long-range order degree. It was found that mono-crystalline ordered films with  $L1_0$  structures, which showed their perpendicular mag-

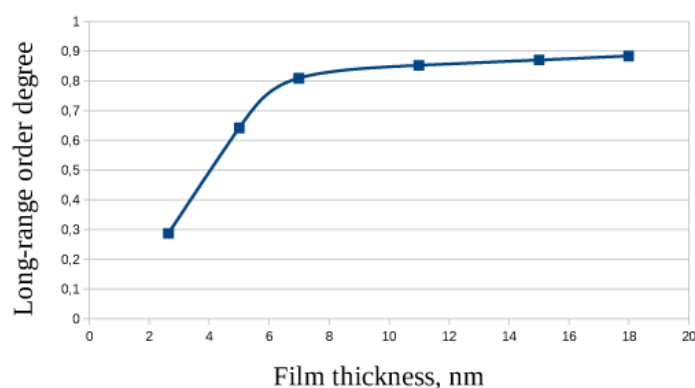


Fig. 2. Long-range order degree against the film thickness of  $\text{CoPt}/\text{MgO}$

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## Магнитные свойства и структурные изменения в пленках твердых растворов $\text{Co}_{50}\text{Pt}_{50}$ и $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$

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Были изучены тонкие пленки  $\text{Co}_{50}\text{Pt}_{50}$  и  $\text{Co}_{50}\text{Pt}_{50-x}\text{Pd}_x$  толщиной от 20 до 1000 Å. Среди исследованных образцов более тонкие пленки после отжига показывают наличие в их ГЦК решетке тетрагональных упорядоченных кристаллитов с осью легкого намагничивания, направленной перпендикулярно плоскости пленки. Коэрцитивная сила меняется в зависимости от толщины пленок. Обсуждается влияние на эти свойства режима отжига и степени дальнего порядка.

Ключевые слова: тонкие пленки, атомное упорядочение, магнитная анизотропия.