Magnetic and Magneto-Optic Properties of Transition Metal Films with Sub-Wavelength Antidot Arrays

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Magnetic thin films perforated with holes arranged in regular patterns (antidot arrays) present new and fascinating properties at reduced dimensions. In particular, patterning holes into ferromagnetic thin films is an effective way to engineer their magnetic properties. Simultaneously, patterning holes into metal thin films is an effective way to achieve extraordinary optical properties like the enhanced transmission through sub-wavelength hole arrays of metallic films (Ag, Cr, Au). In this work, we present a combined study of the interaction of light with periodically arranged nanostructures composed of magneto-optic active material (Fe, Co, and Ni) in the presence of a magnetic field. Our results could lead to exciting developments in the field of magneto-photonics.

Nanohole arrays in Co, Fe, Ni thin films have been prepared using self-assembly nanosphere lithography [1]. The arrays exhibited long range ordering with hexagonal symmetry (Fig. 1). Different meshes were used with holes diameters (d) ranging between 220 and 330 nm while the inter-hole distance has been kept constant at 470 nm. The film thickness was 100 nm.

According to the hysteresis loops the magnetization for all three magnetic materials lies mainly in plane. Nevertheless, the introduction of nanoholes in the films drives the appearance of out-of-plane magnetization components, which are getting stronger by increasing the hole diameter. For the case of Co (Fig. 2) the saturation field in the polar configuration decreases strongly and reaches 0.8 T for the sample with 330 nm holes, while perpendicular remanent magnetizations appear. The trend of magnetic hardening as the hole size increases is present for all of the magnetic films. The observed hysteretic behavior of the samples is straightforward connected with the magnetic domain imaging.

The magnetic domain structures have been studied by analyzing magnetic force microscopy images at remanent and at saturation states. Different domain structures have been observed depending on the geometrical characteristics of the films. Dark and bright regions, can be distinguished in the magnetic image without correlation to the topography. Such a case is presented in Fig. 3 for a Fe nanohole film with hole diameter 248 nm. A comparison with micromagnetic simulations is presented. The interplay between in and out of plane components to reduce the magnetostatic energy is discussed. The results reveal the capability to modify the magnetization dynamics of the films through the control of the hole pattern.

Magneto-optic measurements show a spectacular magneto-optic response for all the magnetic films at wavelengths where surface plasmon-polaritons are supported by the structure as deduced in optical measurements. The measured spectra show a higher polarization than a control Fe (Co, Ni) film (Fig. 4) and are a result of an enhancement effect closely related to surface plasmons excitations.

In conlusion, the results of the magnetometry reveal the dominant role of the presence of the holes in the reversal behavior over the intrinsic anisotropy of the magnetic films and demonstrate the ability to control the coercivities, remanences, anisotropies and switching characteristics of the films. The tuning of the magneto-optic behavior renders the structures important for technological applications in magneto-optic data storage media, and in the new field of magnetic photonic crystals since it leaves a further degree of freedom to manipulate light-matter interaction and thus control the propagation of light.

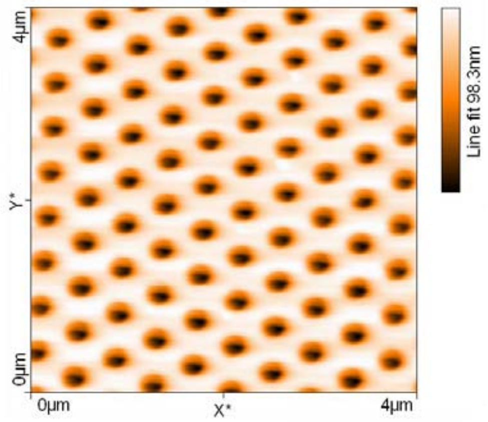

Fig. 1: AFM image of the Co hole array with d = 220 nm. A large defect-free area is present.

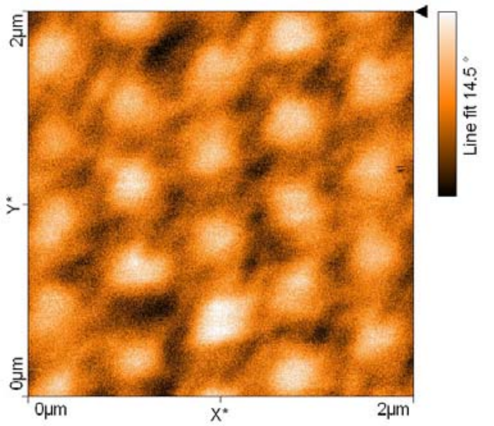

Fig. 3: Magnetic Force Microscopy (MFM) image of a Fe nanohole film with 248 nm holes in diameter.

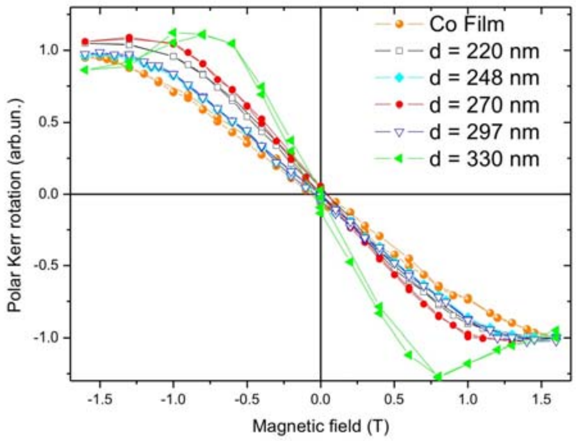

Fig. 2: Polar hysteresis loops for patterned Co films with different hole diameters.

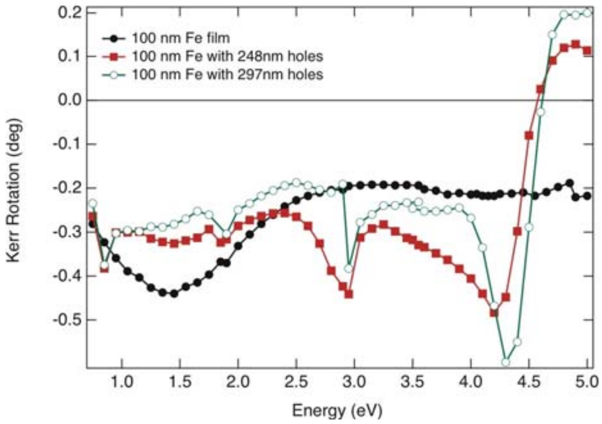

Fig. 4: Magneto-optic Kerr measurements for two different Fe hole diameters and for a continuous Fe film.

[1] G. Ctistis, E. Papaioannou, P. Patoka, J. Gutek, P. Fumagalli, and M. Giersig, "Optical and Magnetic Properties of Hexagonal Arrays of Subwavelength Holes in Optically Thin Cobalt Films", Nano Lett. **9** (1), 1 (2009).