Finite size effects in patterned magnetic permalloy films

G. Gubbiotti, a) L. Albini, and G. Carlotti
Dipartimento di Fisica dell’Università, INFN, Via Pascoli, I-06100 Perugia, Italy

M. De Crescenzi
Dipartimento di Matematica e Fisica dell’Università, INFN, I-62032 Camerino, Italy

E. Di Fabrizio
TASC-INFN, Area della Ricerca, Padriciano 99, 43100 Trieste, Italy

A. Gerardin
IESS, Via Cineto Romano 42, 00156 Roma, Italy

O. Donzelli and F. Nizzoli
Dipartimento di Fisica dell’Università, INFN, Via Paradiso 12, I-44100 Ferrara, Italy

H. Koo and R. D. Gomez
Department of Electrical and Computer Engineering, University of Maryland, College Park, Maryland 20742

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In the last two years, a number of experimental studies were carried out in order to investigate the static and dynamic properties of permalloy patterned structures, with circular and elliptical dot shapes, using both conventional static and dynamic properties of these structures have been investigated by complementary techniques such as magneto-optic Kerr effect (MOKE), magnetic force microscopy (MFM), and Brillouin light scattering (BLS). Longitudinal MOKE enabled us to compare the hysteresis loops of the specimens with different dot size and interdot separation, showing a marked influence of the demagnetizing field inside the dots. MFM images recorded at zero applied field showed that, depending on the interdot spacing, there is a prevalence of either four- or seven-domain patterns together with a minority of nonsolenoidal patterns that possess a net magnetic moment. BLS from thermally activated spin waves were then used to determine the intrinsic magnetic parameters of the permalloy films and to show evidence of the discretization of the spin-wave peak due to the wavevector resonance condition within each dot. © 2000 American Institute of Physics.

The samples consist of permalloy (Ni_{81}Fe_{19}) films with nominal thickness of 250 Å, deposited in ultrahigh vacuum on the 7×7 reconstructed (111) surface of a Si substrate cleaned by thermal annealing at 1200 °C to remove the native oxide. Details about the evaporation procedure and the deposition chamber are found elsewhere. Six different periodic arrays of 1 and 2 μm square dots were prepared having 1, 2, and 4 μm separations. The patterned areas were 1×1 mm² while the spot size of the laser beam used in the MOKE measurements was typically of about 200×200 μm². Part of the magnetic film was left unstructured to compare the consequences of patterning as measured by Kerr magnetometry and BLS. Scanning electron microscopy and atomic force microscopy images confirmed that the morphology of the patterns was of very good quality as far as both the uniformity and the dimensional control of the width and periodicity were concerned.

Representative longitudinal MOKE loops with the external field parallel to the array are shown in Fig. 1. The reduction of the Kerr intensity with increasing dot separation is due to the decreasing density of magnetic dots. A significant observation from these measurements is the appreciable variation of both the loop shape and the saturation field in comparison with the continuous film, whose loop is shown in the inset of Fig. 1 (upper panel). The loop of the continuous film is highly rectangular and has a coercive field of about 3

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a)Author to whom correspondence should be addressed; electronic mail: gubbiotti@pg.infn.it
domain patterns, reveals an important and unexpected influence of the interdot separation. For instance, in the case of the 2 µm dot size, one has a large prevalence (90%) of seven-domain structures for 1 µm separation. On increasing the separation to 2 µm, one observes almost equivalent populations of the four- and seven-domain configurations, while four-domain patterns prevail (60%) for 4 µm separation. Correspondingly, the percentage of nonsolenoidal multidomain patterns increases with interdot separation from a few percent to 24%. This complex experimental evidence suggests the presence of some interdot dipolar coupling which, however, must be rather weak (a few Oersted) in order to be compatible with Kerr data. With respect to the domain evolution under the applied field, the nonsolenoidal configuration persists after saturation but transforms into a closure pattern after applying a relatively weak reverse field. In Fig. 2(b), the configuration at 90 Oe shows the growth of domains whose magnetizations are parallel to the applied field. In the image, this is best observed by the increase in size of one of the triangular domains in the four-domain pattern. The fact that either the top or bottom domain increases in size has to do with the clockwise or counterclockwise sense of the magnetization closure direction. The process of domain expansion continues with increasing field. The configuration just below saturation (220 Oe) is presented in Fig. 2(c). The islands have relatively featureless internal structure that indicates constant magnetization inside, and strong bright/dark contrast on the ends, representing the concentration of magnetic poles. An interesting observation is that despite the relative uniformity of the islands, variations in net moment exist at any given field below saturation. This is best seen by carefully noting the variations of the sizes of the favorable domains in the 90 Oe set, as well as the extent of separation of the bright and dark areas of some of the islands in the 220 Oe image. The bottom-right island, for example, still shows the merger of the bright/dark areas at the lower part of the element, in contrast with the full separation observed in the top-left island. These variations in the net moment of the islands for a given field are responsible for the appearance of “knees” in the Kerr measurement, as well as the gradual approach to saturation and the finite remanent magnetization of about 50% for all the specimens investigated.

Concerning the dynamic properties of the permalloy dots, the spin-wave spectra were studied using a 3 × 3 pass Sandercock type Fabry–Pérot interferometer in the backscattering configuration. The sample was illuminated by an Ar⁺ ion laser at a wavelength 5145 Å with an incident power of 200 mW. Figure 3 shows a comparison between Brillouin light scattering spectra of patterned sample with a dot width of 2 µm and separation of 2 µm (upper curve) and the unstructured permalloy film (lower curve) for a wave vector $q = 0.8 \times 10^{-5}$ cm$^{-1}$ (angle of incidence $\theta = 20^\circ$). The values of film thickness (285 ± 5 Å), as well as of the saturation magnetization (4π$M_s = 10 ± 0.5$ kOe) and of the g factor (2.12 ± 0.02) have been determined from the frequency dependence of the Damon–Eshbach (DE) spin wave of the continuous film on the incidence light angle. No significant variation of the DE spin-wave frequency of the pat-
terned samples with respect to that of continuous film was measured because of the low aspect ratio of the magnetic dots. However, Brillouin spectra show a discretization of the peak corresponding to the surface spin wave, absent in the continuous unpatterned layer, as shown in Fig. 3. In fact, on the Stokes side of the spectrum, near 11.8, 10.7, 9.7, and 8.4 GHz four distinct modes of magnetic excitations are visible. The observed discrete modes, first observed on permalloy stripes by Gurney et al., can be interpreted as resulting from the width-dependent quantization of the dipole-dominated surface spin-wave mode of an infinite film. A similar effect has been observed by Hillebrands et al. in the case of an array of permalloy wires of 1.8 μm width and separation of 2.2 and 0.7 μm, who reported the complete spin-wave dispersion for q up to 2.3 × 10^5 cm^{-1}. Finally, by comparing spectra taken for different interdot separations, no evidence of any measurable interdot coupling was found by BLS, due to the large prevalence of the internal field felt by the processing spins of the order of H + 4πM_s, i.e., thousands of Oe over the weak interdot coupling field, together with the discussed broadening of Brillouin peaks which prevents us from measuring small frequency shifts.

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