Magnetic lithography methods based on nanoindentation and ion irradiation

J. Sort[1,*], A. Varea[2], E. Menéndez[3], S. Suriñach[2], A. Concustell[2], M.D. Baró[2], E. Pellicer[2], J. F. López-Barberá[4], J. Montserrat[5], E. Lora-Tamayo[5] and J. Nogués[6]

[1]*Institució Catalana de Recerca i Estudis Avançats (ICREA) and Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*
[2]*Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain*
[3]*Instituut voor Kern- en Stralingsfysica and INPAC, Katholieke Universiteit Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium*
[4]*Institut Català de Nanotecnologia, Edifici CM7, Campus Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*
[5]*Institut de Microelectrònica de Barcelona (IMB-CNM), CSIC, Campus Universitat Autònoma Barcelona, E-08193, Bellaterra, Spain*
[6]*Institució Catalana de Recerca i Estudis Avançats (ICREA) and Institut Català de Nanotecnologia, Edifici CM7, Campus Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*

[*]*E-mail of presenting author*: jordi.sort@uab.es

Some atomically ordered alloys (e.g., $Fe_{60}Al_{40}$ at.%) exhibit a transition from paramagnetic to ferromagnetic when they are structurally disordered, for example by mechanical milling or macroscopic compression [1]. In recent years, this effect has been used to generate arrays of *ferromagnetic* dots embedded in a *paramagnetic* matrix. These arrays can be prepared following two different processing routes that generate structural disorder at localized regions of the specimen's surface: (i) selective mechanical deformation by means of nanoindentation and (ii) irradiation procedures, either through lithographed masks (e.g., pre-patterned PMMA, copolymers or alumina templates) or using focused ion beam (FIB). Concerning route (i), submicron structures have been obtained with two different geometries: periodic arrays of triangular dots (resulting from the pyramidal shape of the Berkovich indenter) and arrays of straight lines produced by scratch experiments [2]. Concerning route (ii), sub-50 nm structures have been created by FIB [3]. Moreover, irradiation through shadow masks (leading in some cases to sub-100 nm magnetic dots) has the advantage that, because of the low ion doses employed, no surface roughening accompanies the magnetic patterning, thus avoiding tribological problems. Overall, the fabricated entities exhibit a range of magnetic properties depending on their size and shape, which were investigated by means of a magneto-optical Kerr effect setup. The local character of the induced ferromagnetism was examined by magnetic force microscopy [3,4]. Furthermore, when the patterned $Fe_{60}Al_{40}$ sheets are annealed at sufficiently high temperatures (i.e., around 800 K), the magnetic properties can be easily erased due to the annealing-induced atomic reordering. This method may be easily extrapolated to a variety of other intermetallic systems such as Fe_2AlMn, Ni_3Sn_2, CoAl or CoGa. Furthermore, nanoindentation can be also used to obtain arrays of dots with perpendicular magnetic anisotropy at the surface of a metallic glass ribbon with in-plane magnetic anisotropy [5]. The obtained magnetic structures may have interesting applications, such as patterned recording media (free from tribological problems and detrimental exchange interactions) or magnetic sensors.

[1] J. Nogués et al., *Phys. Rev.* B **74**, 024407 (2006).
[2] J. Sort et al. *Adv. Mater.* **18**, 1717 (2006).
[3] E. Menéndez et al. *Small* **5**, 229 (2009).
[4] A. Varea et al., J. Appl. Phys. **109**, 093918 (2011).
[5] J. Sort et al. *Small* **6**, 1543 (2010).