Vortex matter in the presence of magnetic pinning centra

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It is well known that the critical current is one of the most important properties of the superconductor. The large values of the critical currents in superconductors are usually attributed to pinning of vortices to different inhomogeneities in a superconductor of a second kind. In this respect, influence of random and ordered external and internal surfaces treated as inhomogeneities, such as arrays of holes were considered [1]. However, in the case of superconductor/ferromagnetic systems, the increase of the pinning effect by two orders of magnitude was predicted [2], although not verified. After substantial progress in the preparation of magnetic structures connected with superconductor [3] and considering the importance of such structures for magnetic storage technologies, these heterogeneous systems became very interesting both from theoretical and experimental point of view. Marmorkos *et al*. [4] investigated the problem of a magnetic dot with out–of–plane magnetization embedded in a superconducting film. They solved the non–linear Ginzburg–Landau (GL) equation numerically, with appropriate boundary conditions, and found a correspondence between the value of the magnetization and the vorticity of the most energetically favorable vortex state. More recently, the interest shifted to the pinning behavior of regular arrays of submicron ferromagnetic dots where additional pinning contributions arise due to the magnetic nature of the pinning centers [5–7]. These artificial pinning arrays have been successfully used to gain insight into the macroscopic commensurability effects, but the origin and microscopic nature of these phenomena has not yet been explained.

Here, we investigate the role of the self–magnetic field of a ferromagnet in the vicinity of the superconductor since creation of vortices due to this field, as well as their behavior strongly influence the pinning of additional external flux lines. Within the non–linear Ginzburg–Landau (GL) theory, we investigate the vortex structure of an infinite type II superconducting film thinner than the coherence and penetration lengths with a ferromagnetic dot on top of it. Spontaneous creation of vortex–antivortex pairs as well as specific arrangement of vortices is found (Fig).

Additionally, we consider the flux pinning properties of a regular magnetic dot lattice. We investigate matching phenomena and their dependence on the geometry of the lattice, i.e. size of the dots and distance between them. The latter determines if the vortex configurations with multi–quanta vortices at the pinning centers are more energetically favorable than those with a single vortex at each site. Thus, we compare the vortex lattice free energy for different occupation numbers n_s. Demagnetization effects are taken into account and we find the phase diagram which shows the occupation number as function of the radius of the dots, distance between them and effective GL parameter κ.

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Fig. The distribution of the superconducting electrons density for different values of the magnetic moment of the dot

matter˜.

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