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Pillars and pinning centers in superconducting prisms

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Abstract. We solve the Ginzburg-Landau equations for to study the vortex configurations in a superconducting prism with a square array of pillars or holes in the presence of a uniform applied magnetic field. The presence of the pillars (holes) changes the vortex structures in the superconducting prism considerably. We calculate magnetization, free energy and vorticity curves, which shows the transition between different vortex configurations as a function of magnetic fields.

1. Introduction

Superconducting samples with arrays of pinning or anti-pinning centers have received much attention over the last decade. Most interest has been focused on arrays of pillar and holes in mesoscopics squares, rectangles and disks [1, 2, 3]. The superconducting materials of high critical temperature have structural defects in a wide variety of shapes leading to complex dynamic and static processes. Therefore, it becomes of particular interest to simulate this class of defects for optimize the thermodynamical parameters for a given superconducting sample. Experimentally electron-beam technique allow one to design superconducting films with a large array of pillars of different shapes and sizes. These systems enable to study possible vortex configurations, to identify its stable and metastable configurations and consider the effect of the sample geometry on the final vortex state [4, 5]. In previous works we have used the Ginzburg Landau formalism to study the vortex matter in superconducting disks with different kinds of defects [6, 7, 8], in this work, we consider a superconducting prism with an array of superconducting pillars and holes.

2. Theoretical formalism

Let us consider a thin superconducting prism (square and circular) with a array of holes and pillars, immersed in an insulating medium in the presence of a perpendicular uniform magnetic field $\mathbf{H_e}$. Superconducting matter is described in the Ginzburg-Landau theory by the order parameter ψ and the potential vector $\mathbf{A}$, (for more details, see Ref. [9, 10, 11]) as:

$$\frac{\partial \psi}{\partial t} = -(i\nabla + \mathbf{A})^2\psi + \psi(1-|\psi|^2) \tag{1}$$

$$\frac{\partial \mathbf{A}}{\partial t} = \mathrm{Re}\left[\bar{\psi}(-i\nabla - \mathbf{A})\psi\right] - \kappa^2\nabla\times\nabla\times\mathbf{A} \tag{2}$$

The dynamical equations are complemented with the appropriate boundary conditions for the order parameter considering a superconducting/vacuum interphase: $(-i\nabla - \mathbf{A})\psi \cdot \mathbf{n} = 0$, $\hat{n}$ is the unity vector perpendicular to the surface of the superconductor [12, 13].

3. Results and discussion

The parameters used in our numerical simulations for a prism of pure Al were $\xi(0) = 1.2\ \mu m$, $T_c = 1.7K$, $T = 0.85$, the square and circular area of the prism was $S = 64.0\xi^2(0) = \pi R^2$. The area of the defects in the square is $d = 9.0\xi^2(0)$, the disk has point-like defects. G is the free Gibbs energy, M is the magnetization, N is vorticity in units of fluxoid Φ_0 and H_{01} is the first entry of vortices magnetic field, H_{02} is the second critical field and H_{03} is the upper magnetic field. The figures 1 (b, c, d, f, g) shown the contour plot of the order parameter for

Table 1. Thermodynamics values for a superconducting cylinder and square prism at H_{01}.

Sample	$-G(H_{01})$	$-4\pi M(H_{01})$	$N\Phi_0(H_{01})$	H_{01}	H_{02}	H_{03}
Square prism with defects	0.615	0.620	4.0	0.650	0.920	2.229
Square prims without defects	0.735	0.852	4.0	0.880	1.020	2.550
Cylinder with defects	0.725	0.722	3.0	1.275	1.45	2.750
Cylinder without defects	0.725	0.722	3.0	1.275	1.45	2.750

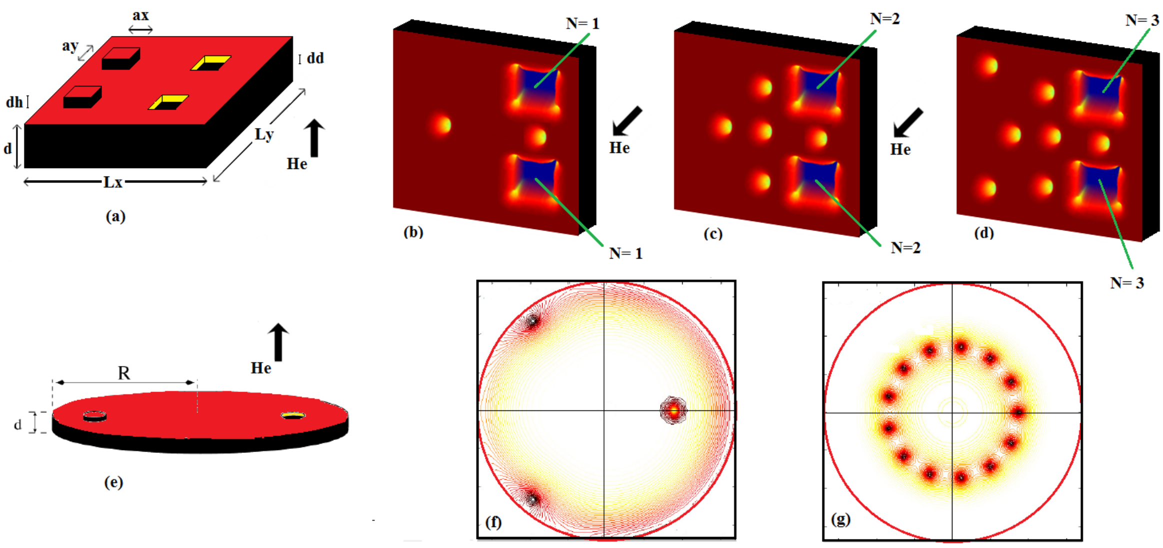

Figure 1. layout of the samples (a) Square prims with two square dots and two square anti-dots (e) Cylinder with one dot and one anti-dot. (b, c, d, f, g) Square modulus of the order parameter $|\psi|^2$ for at H_{01} with $N = 4, 9, 13$ vortices (square) and $N = 3, 13$ (cylinder).

several vorticities at magnetic field at H_{01} with $N = 4, 9, 13$ vortices (square) and $N = 3, 13$ (cylinder); $N = 2, 4, 7$ vortices remains in the superconductor region, while one, two and three vortices sit in the each hole of the square. Although they are not visible in the contour plot of the magnitude of order parameter, there is a change in the phase around the hole equal to $\Delta\Theta = 2N\pi$, these defects broken the typical symmetry of the vortex square configuration. In these figures we can appreciate the point like defect (pillar) in the cylinder, in this place never sit any vortices, because it acts like an anti-pinning defect. We can see in the table the Gibbs free energy G, the magnetization $-4\pi M$, vorticity $N\Phi_0$ (calculated at H_{01}), and the critical fields H_{01}, H_{02}, H_{03}, dependents of the size of the defects, for a point like defect (small defects) the magnetic fields are independent of its nature and size. The growth of the magnetization and free energy with big defects means that more diamagnetic the material is. Also, this defects allow the superconductivity be destroyed and nucleated at lower magnetic fields.

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References
[1] V Moshchalkov, M Baert, V Metlushko, E Rosseel, M Van Bael, K Temst, R Jonckheere and Y Bruynseraede 1996 *Phys. Rev. B* **54** 7385
[2] G R Berdiyorov, M V Milosevic and F M Peeters 2006 *Phys. Rev. Lett* **96** 207001
[3] G R Berdiyorov, V Misko, M V Milosevic, W Escoffier, I V Grigorieva and F M Peeters 2008 *Phys. Rev* **77** 024526
[4] I V Grigorieva, W Escoffier, J Richardson, L Y Vinnikov, S Dubonos and V Oboznov 2006 *Phys. Rev. Lett* **96** 077005
[5] I V Grigorieva, W Escoffier, V R Misko, B J Baelus, F M Peeters, L Y Vinnikov and S V Dubonos 2007 *Phys. Rev. Lett* **99** 147003
[6] J Barba-Ortega, Edson Sardella, J Albino Aguiar 2013 *Physica C* **485** 107
[7] J Barba-Ortega, Edson Sardella, J Albino Aguiar, E H Brandt 2012 *Physica C* **479** 49
[8] J Barba-Ortega, Edson Sardella, J Albino Aguiar, *Modern Physics Letter B* 2013 **27** 4 1350025
[9] W D Gropp, H G Kaper, G K Leaf, D M Levine, M Palumbo and V M Vinokur 1996 *J. Comput. Phys* **123** 254
[10] J Berger and J Rubinstein 2000 *Connectivity and Superconductivity* (Germany: Springer)
[11] Edson Sardella and E H Brandt 2010 *Supercond. Sci. Technol* **23** 025015
[12] P G de Gennes 1999 *Superconductivity of Metals and Alloys* (Colorado: Westview Press)
[13] M Thinkham 1996 *Introduction to Superconductivity* (New York: McGraw Hill)