Abstract

When the applied magnetic field is higher than the lower critical field but below the upper critical field, a type-II superconductor allows magnetic flux to penetrate it in the form of vortices, a tiny normal area surrounded by supercurrents. Driven by the Lorentz force of a passing external current or by thermal activation, vortices can move. Their motion induces energy dissipation and eventually can destroy the superconductivity. Recent advances in nanofabrication have led to tremendous possibilities for implementing superconducting pinning structures and controlling the motion of vortices. The dynamics of vortices in confined superconducting geometries has generated much interest, including studies of fundamental properties about vortex matter and devices based on the motion of the vortices. During the past decades, a lot of efforts have been devoted to introducing artificial pinning centers into superconductors to stabilize and pin the vortex lattice against the external driving force, thus giving rise to higher critical currents [1–10]. This is of practical importance since superconductors are required to maintain high critical currents for potential technological applications. Generally there are two different kinds of artificial pinning centers. The first one are the random imperfections, for example heavy-ion radiation damage [11], cold work induced dislocations [12], disordered hole arrays [13–15], etc. The other one are periodic defect arrays such as antidots (holes) [1–4, 7, 16], dots [6], and magnetic dots [5, 17, 18].

Recent advances in micro- and nanofabrication technologies have made possible to produce superconductors with carefully controlled arrays of artificial defects [4–10, 19–21] with pores size and interpore spacing comparable to the relevant length scales of

superconductors such as the coherence length $\xi(T)$ and the penetration depth $\lambda(T)$, which are generally under submicron scales. As one of the most efficient and easiest methods, introducing periodic hole arrays into superconducting films has attracted much interest [4, 7–9]. Moreover, superconducting films containing periodic hole arrays also provide a unique platform to understand vortex motion and pinning in the presence of regular pinning centers. The interplay between the periodic pinning forces and the elastic repulsive vortex-vortex interaction generates a variety of novel vortex phenomena such as the commensurate effect [19, 22], the rectification and phase locking of the vortices [20], composite fluxline lattices [23], which are not observed in the continuous superconducting films.

The commensurate effect between the vortex lattice and the underlying periodic artificial pinning array is one of the intriguing properties in superconducting films with periodic hole arrays [7, 8, 23, 24]. It appears as minima in the magnetic field dependence of the resistance, $R(H)$, or as maxima in the field dependence of the critical current, $I_c(H)$, when the vortex lattice is commensurate with the underlying periodic artificial pinning array, i.e., when the external magnetic field corresponds to integer multiples or fractions of the so-called first matching field H_1. This effect is normally interpreted as a result of the pinning enhancement [25–28], i.e., vortices are more difficult to move at matching fields. Thus, a pinning enhancement occurs and high critical current (or resistance minima) are achieved. A similar effect has also been observed in superconducting wire networks [29–31]. The wire networks are one dimensional (1D) multiconnected superconducting thin strips whose width w is comparable to the superconducting coherence length $\xi(T)$. So, a superconducting film containing a periodic hole array can resemble a superconducting wire network at temperatures close to T_c. Both these mechanisms have been used to interpret the commensurability effects observed in transport measurements on superconducting films containing an array of holes at temperatures close to T_c. For example, in aluminum films containing periodic hole arrays, Fiory et al. associated the magnetoresistance oscillations to commensurate vortex pinning [1], whereas Pannetier et al. attributed these oscillations to wire network properties [30]. In order to understand the related physics and for possible applications, it is necessary to distinguish these two mechanisms and identify the real origin of the commensurability effect.

This thesis presents some investigation of vortex dynamics in superconducting Nb ultrathin films with different artificial pinning centers: magnetic and non-magnetic. Evidence of 1D superconductivity observed in these structures will be also discussed.

In chapter 1, after a brief introduction to the main aspects of the superconductivity, the relevant concepts of the vortex dynamics, such as flux-flow resistivity and the vortex pinning, are discussed. Implementation of artificial defects, including pinning holes, magnetic dots, and different pinning arrangements of periodic and quasi-periodic pinning arrays, are presented. Finally the basics of 1D superconductivity are introduced.

In chapter 2 the different stages of the porous silicon formation are explained. The anodization parameters that influence the final characteristics of the fabricated layers are also discussed and the porous silicon photoluminescence is briefly described.

In chapter 3 transport properties of perforated Nb ultrathin films deposited on porous silicon are presented. Resistive transitions and critical current measurements as a function of the applied magnetic field show matching effect between the vortex lattice and the structure of the pinning array.

In chapter 4 the electromagnetic interaction between the vortex lattice and magnetic pinning centers in Nb films deposited on nanoporous Al_2O_3 substrates containing an array of Ni nanowires was investigated by transport measurements in the presence of magnetic field applied perpendicularly to the samples surface. The (H,T) phase diagram was studied for these systems and compared to the one of a plain Nb film.

In chapter 5, resistive transitions and current-voltage characteristics measured on perforated Nb ultrathin bridges deposited on porous Si are reported. Due to the reduced dimensions of the pores diameter as well as of the interpore distance the experimental observations strongly call to mind features of 1D superconductivity.

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