Matching effect and dynamic phases of vortex matter in $Bi_2Sr_2CaCu_2O_8$ nanoribbon with a periodic array of holes

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We report investigations on the dynamics of vortex matter with periodic pinning in crystalline $Bi_2Sr_2CaCu_2O_8$ nanoribbons containing an array of nanoscale holes. We found that the matching effect is enhanced near the melting field and persists to higher fields beyond the melting line. We attribute this enhancement to the existence of a soft-solid phase and a mixture of solid-liquid phases near the melting line, enabling the vortices to pin more effectively. We observed distinct regions in the voltage-current curves attributed to transitions of various dynamic phases which also account for the driving current dependent appearance of the matching effect. © *2010 American Institute of Physics*. [doi:10.1063/1.3473783]

Present research on vortex matter with periodic pinning focuses on superconducting thin films with arrays of holes or magnetic dots.[1,2] Inherent vortex pinning defects in thin films can result in high critical currents at low temperatures and can cause Joule heating when high currents are applied to depin the vortices. Thus, transport measurements[2] are usually restricted to temperatures near the zero-field critical temperature T_{c0} while the low temperature vortex phases are studied via magnetization measurements.[1] As pointed out by Misko *et al.*,[3] both high pinning disorder and thermal fluctuation can hinder the observation of dynamic phases and their transitions by masking features in macroscopically measurable quantities. Furthermore, the interplay between pinning and thermal energy plays a crucial role in determining the critical current required to drive vortex matter.[4] Thus, a clean system with extremely weak random pinning, enabling driven vortex measurements at low temperatures is needed to explore the rich vortex dynamics related to periodic pinning. A $Bi_2Sr_2CaCu_2O_8$ (BSCCO-2212) crystal is a candidate for such studies, because it has been intensively studied for vortex melting[5,6] and is well-known for its relatively weak random pinning.[7,8]

This paper reports investigations on transport properties of vortex matter with a periodic pinning array over an extended temperature range $0.5T_{c0}<T<T_{co}$ utilizing BSCCO-2212 crystalline nanoribbons containing square arrays of nanoscale holes. We found that the vortex matching effect exists over a wide range of temperatures and magnetic fields and extends into the vortex liquid phase. Furthermore, the features associated with the matching effect, (i.e., dips in the resistance and peaks in the critical current) are relatively enhanced near the vortex melting line. In addition, we also observed features in the *V-I* characteristics associated with the transition of various vortex dynamic phases.

BSCCO-2212 nanoribbons with thicknesses of tens to few hundred nanometers and width of a few micrometers were grown via a melt-quench-growth method.[9] Nanoscale holes with the desired diameter and lattice spacing were patterned using focused ion beam milling (FEI Nova 600). A scanning electron microscopy (SEM) micrograph of a top down view of a patterned BSCCO-2212 nanoribbon with through-holes (sample A) is shown in Fig. 1(a). Two samples with square arrays of holes with diameter of 60 nm and lattice spacing of 500 nm were investigated with dc four-probe transport measurements. This geometry produces a matching field (where the number of vortices corresponds to the number of holes) of about $H_\Phi=82.8$ G. We measured resistance as a function of temperature, magnetic field, and current us-

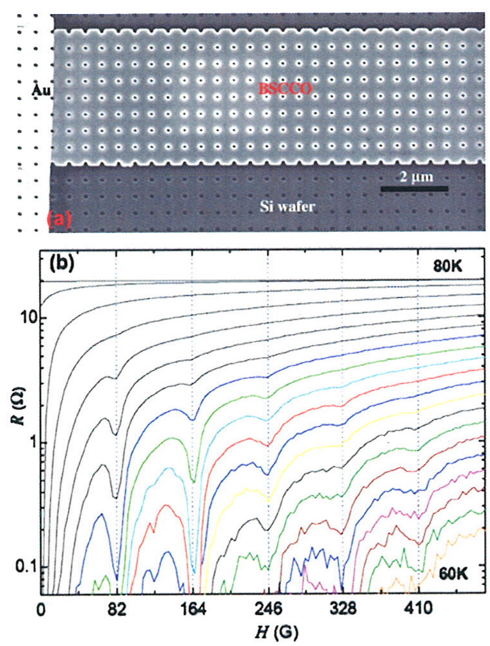

FIG. 1. (Color online) (a) SEM micrograph of a top-down view of a 600 nm thick BSCCO-2212 ribbon (sample A) with a square array of holes on a Si substrate. The diameter and spacing of the holes are 60 nm and 500 nm, respectively. Gold contacts were used for the current and voltage leads. (b) *R-H* curves obtained at 10 μA and at temperatures between 60 and 80 K at intervals of 1 K.

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