

# Matching effect and flux pinning force in a Nb superconducting thin film with a triangular lattice of artificial pinning centers

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## Abstract

A strong pinning force in a Nb superconducting thin film is formed by a triangular lattice of defects due to the structural corrugation that acts as pinning centers. The magnetoresistance measurement close to the transition temperature shows a set of minima of magnetoresistance at equal external field intervals. A crossover in current–voltage relations with matching field and half-integer matching field occurs for currents exceeding a certain threshold value. The phenomenon is related to the presence of pinning structures at matching fields.

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PACS: 74.60.Ge; 74.60.Jg

Keywords: Matching effect; Pinning force; Critical current density; Superconducting thin film

Flux pinning effect by artificial pinning arrays in a superconducting thin film has been widely studied over the past decade because of fundamental as well as technological importance [1–5]. However, the nature of the pinning mechanisms for the artificial pinning dots, such as magnetic dots, metal dots, hole, etc. is still not understood. The pinning properties in superconducting thin films with an array of pinning centers are complicated by the competition between random and ordered pinning centers, and the existence of many possible vortex lattice configurations.

Electron beam lithography is a powerful technique which allows the fabrication of arrays of small dots with controlled geometry. A triangular pinning array of defects due to the structural corrugation of the Nb thin films was prepared as described elsewhere [4]. The layer structure is silicon/Si<sub>3</sub>N<sub>4</sub>/Nb(100 nm), as shown in Fig. 1. The circular holes form a triangle lattice with spacing of 500 nm and hole diameter of around 200 nm

in the Si<sub>3</sub>N<sub>4</sub> layer with Nb thin films covered on it. The depth of holes measured by the AFM is around 75 nm. Based on the corrugation of the Nb film causing a lower  $T_c$  superconductor than other region with the only Nb film, the defects can serve as an array of pinning centers.

Fig. 2 shows the magnetoresistance curves for a Nb film with a triangle array of pinning centers in a limited current range 10–300 mA at  $T = 8.73$  K ( $T_{c, \text{onset}} \sim 8.89$  K). As can be seen, these curves show a set of minima of magnetoresistance at specific value of external field called matching field, i.e.,  $B_n = nB_1$ , where  $n$  is an integer and  $B_1 = 89.6 \pm 0.8$  Oe is the first matching field. This implies that the artificial regular array of defects in the Nb thin film act as strong pinning centers. At matching fields the vortices are highly ordered and form some geometric configurations, resulting in the interaction between the artificial pinning centers and vortex lines.

Fig. 3 shows  $I$ – $V$  curves at integer and half-integer matching fields. At higher driving force an ordinary monotonic behavior can be observed, that is, the voltage drop increases with magnetic field. However, at lower driving force a distinct crossover is observed in that the

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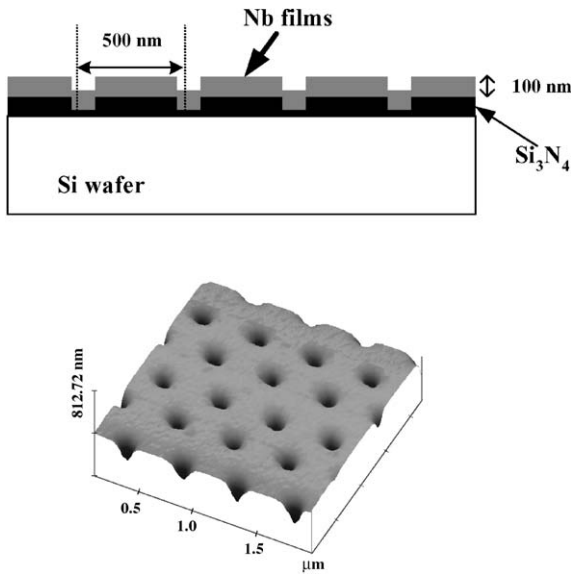


Fig. 1. (a) Cross-sectional view of fabricated layer structure, silicon/Si<sub>3</sub>N<sub>4</sub>/Nb(100 nm), and (b) AFM 3-D image of the patterned sample.

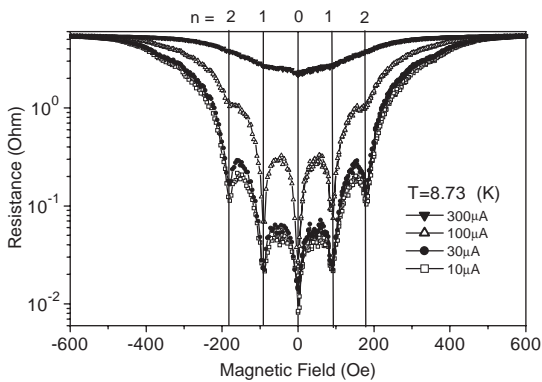


Fig. 2. Magnetoresistance curves taken at  $T = 8.73$  K for different currents for this sample.  $n$  indicates the number of vortices per unit cell of hole array under matching condition.

voltage drop at integer matching fields becomes smaller than that at half-integer ones. A crossover occurs for currents exceeding a certain threshold value. In the low current density region, the flux vortices tend to form a triangle lattice easily at matching field that the vortex

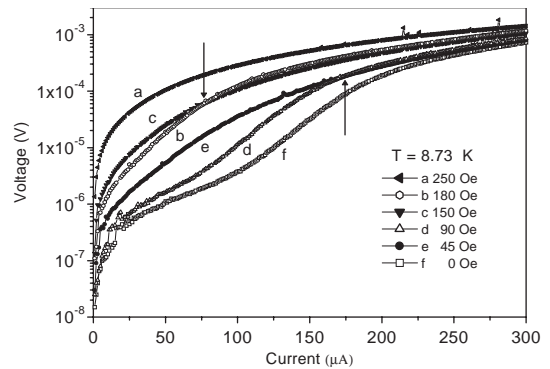


Fig. 3.  $I$ - $V$  characteristics for a triangle lattice at  $T = 8.73$  K under various magnetic fields applied perpendicular to the film plane. The arrows represent the crossover currents between integer and half-integer matching fields.

lattice configuration can sustain the driving force with less energy loss. In the high current density region, however, the vortex lattice configuration cannot hold in the higher driving force.

Artificial periodic flux pinning centers on niobium thin films with two-dimensional triangle array of submicrometer holes causing the structural corrugation have been fabricated. A strong pinning effect and matching effect can be found in our sample in which the artificial pinning centers are neither magnetic nor nonmagnetic dots.

This work was supported by the National Science Council of the Republic of China under the Grant No. NSC 91-2112-M-018-012.

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