Rectification of Vortex Motion in Superconducting Nb Thin Films with Spacing-graded Array of Pinning Sites

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ABSTRACT

The asymmetric potentials can provide ways to control the motion of particles in devices. The dc rectification of an ac-driven particle is known as the ratchet effect. For superconductor, we can take advantage of anisotropic pinning in the pinning sites to control the vortex motion. The rectified vortex motion in superconductor is induced by an ac applied force in an asymmetric pinning potential. In this thesis asymmetrically modulated spatial distribution of symmetric pinning sites were studied. The pinning centers are prepared by electron beam lithography with spacing-graded arrays of submicrometer-scaled holes in Nb superconducting thin films.

Two different gradient of the hole have been fabricated. The lattice-constant variation results in the change of the pinning site's density. The gradient structure breaks the symmetry of the vortex pinning potential. For small gradient, at least four matching fields are found in Magnetoresistance (MR) curves. For large gradient, it is found that the commensuration effects were eliminated by introducing graded concentration of hole distributions. MR curves show a kink around the first matching field and no higher-order matching field is observed.

The transport properties are carried out using an ac current through the Nb superconducting film along the x-axis with magnetic field perpendicular to the film plane. The dc voltage drop V_{dc} is recorded along the x-axis by a dc nanovoltmeter. The measurements revealed pronounced rectified voltage which is mainly characterized by vortex-vortex interaction. The asymmetric pinning potentials are crucial to produce the ratchet behavior. Vortex-vortex interaction changes the effective pinning landscape of vortices and asymmetric potential is formed. Vortices depin easily from high concentration to low concentration of pinning sites.

For small gradient sample, the rectified voltage is larger at matching fields than that at intermediate fields. Another remarkable situation is that vortices start to repin near the matching fields. Thus the rectified voltage varies periodically with the number of vortex per pinning center. For large gradient sample, the effects of the vortex-vortex interaction are enhanced. The rectified voltage can be found in every selected magnetic fields and the rectified voltage is about 10 times larger than the small gradient sample. In addition, a drastic change of the rectified voltages appear for magnetic field above/below the first matching field. The interstitial vortices are formed in the film above the first matching field. A reversible vortex motion is induced by the interstitial vortices for the field above the first matching field. These results demonstrated that the rectification can be characterized by the spacing-graded of pinning sites.

釘扎中心呈梯度分佈之超導鈮薄膜上
磁通運動的整流效應

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摘　　要

粒子來回運動在位能左右不對稱性的棘輪形式的位能場，粒子會呈現漂移的現象。這種因為受到交流的驅動力下運動的粒子所呈現的整流現象可稱為棘輪效應(ratchet effect).利用此原理製作不對稱的缺陷在超導體裡面，而形成不對稱的位能勢井，於是我們就可以控制磁通線的漂移方向。我們可加上交流的電流在超導裡面，那麼就會有交替的羅侖茲力推動磁通線運動，接著用精密的電壓計去測量磁通線的整流速度。超導體上的缺陷則是利用電子束顯微術來製作。本論文所作的缺陷則是在基板上定義依不用密度排列成梯度的幾何形狀的凹洞陣列，接著將超導鈮鍍在這些凹洞上所形成缺陷陣列。

在本研究有準備了三種不同的樣品，分為二個大小不同梯度的排列和一個正三角形周期排的缺陷來做對照組。實驗上確實驗証了梯度的排列會破壞磁通釘扎位能的對稱性，而且可發現磁通受到交流驅動後的漂移方向是會從高密度缺陷的位置流向低密度缺陷的位置。對於小的梯度的樣品，從磁電阻的圖形可知在匹配磁場的整數倍時仍可清楚看到周期性極值的產生。但是若加上不同方向的電流，在匹配場的情況下電

阻則是大小不同。原因是在匹配場的情況下，每個缺陷都有被磁通所佔據。這些被釘扎的磁通則因梯度排列的關係，磁通與磁通間的排斥力沒有完全抵消而是沿著低密度缺陷的方向。因此造成當力方向和此合力同相時，磁通是較易流動的。對於大的梯度的樣品，則無法從磁電阻的圖形看到相同周期性極值的產生。大的梯度的缺陷排列不再能夠緊緊釘扎住磁通。但是磁通還是易動的，若是力方向是沿著低密度方向。而且，磁電阻的產生都是發生在第一個匹配場之後。這說明當驅動力不是很大時，磁通首先會被缺陷給捕獲。但當所有的缺陷都具有一個磁通線時，多餘的磁通線本應被臨近的磁通線的排斥力所平衡，但是驅動力則是推動這些磁通線運動，同時破壞了整個釘扎的平衡，因此磁電阻很快的變的很大並且讓樣品變成正常態。

有趣的是當輸入交流的電流。一般來說在交流的電流下所量測其直流的電壓，其直流的電壓應該為 0。對梯度樣品量測到一個非 0 的峰值，這是因為缺陷的梯度排列，以致於磁通在缺陷上時，其位能並不是對稱性的，所以在交流的電流下，磁通會傾向往一邊流動。對於小梯度的樣品，因為在匹配場下磁通會因為匹配的關係會受到缺陷的吸引力，因此才有明顯的整流現象。在非匹配場時，雖有整流現象但與匹配場相較之下並不明顯。然而對於大梯度的樣品，整流的現象著重在磁通間的排斥力所造成的效應，因此比小梯度的樣品的整流現象還要明顯。然而大的梯度的樣品，因為在缺陷間會產生因排斥力所平衡的磁通線(interstitial vortices)，這些缺陷上的磁通與缺陷間的磁通，其位能的不對稱式相反的，所以量測到非 0 的峰值是顛倒的。