Controlling the motion of tiny particles and magnetic flux quanta

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Summary: Initially inspired by biological motors, new types of nanodevices have recently been proposed for particle motion control, including particle separation, smoothing atomic surfaces, and superconducting vortex manipulation. If small particles are driven by an ac external force (or by a fluctuating force) on an asymmetric substrate, their ac motion can be rectified, thus providing useful work. Some of these devices have been realized experimentally to manipulate vortices, particles in asymmetric silicon pores, as well as charged particles through artificial pores and arrays of optical tweezers. We have proposed several novel approaches to control motion of small particles. Moreover, we also have studied motion control without any spatially asymmetric potential (i.e., no ratchet).

How to control vortex motion using asymmetric pinning traps

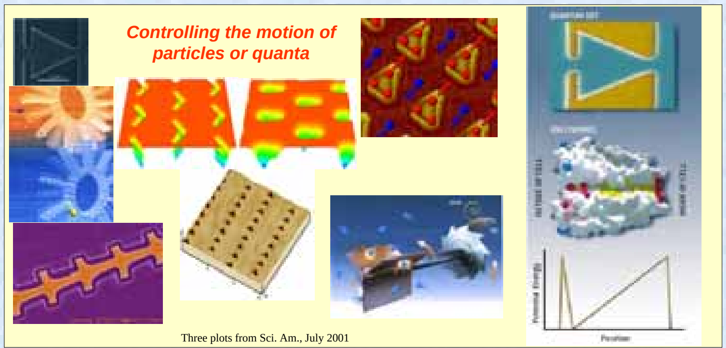

Fig. 1 Spatially asymmetric structures to control the motion of electrons, colloidal particles, ions, magnetic flux quanta (vortices) etc.

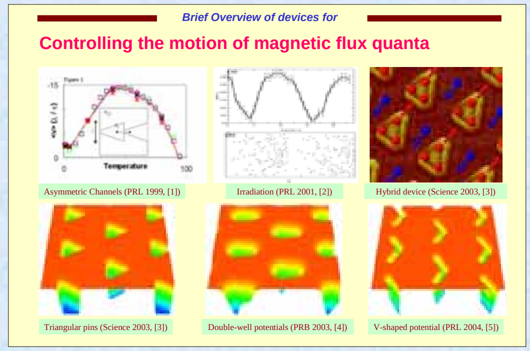

Fig. 2 A few of our proposals to control the motion of vortices in superconductors.

We studied the collective stochastic rectification of ac-driven vortices due to the "ratchet effect" produced by asymmetric pinning sites [1-5]. The regular structure studied in [5] produces a dc voltage from ac driven vortices for any value of the magnetic field. Moreover, using two interpenetrating square pinning sublattices [4] allows a precise control of the collective motion of the vortices, including stepmotors. We numerically obtained, for the first time, magnetic "lensing" of fluxons.

Reversible rectifier that controls the motion of magnetic flux quanta

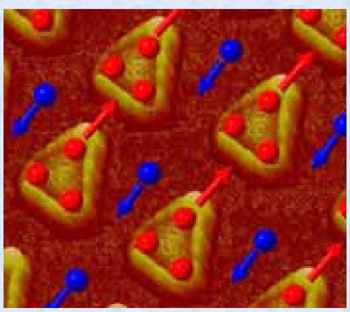

Fig. 3 3D schematic diagram of vortex motion for the fourth matching field.

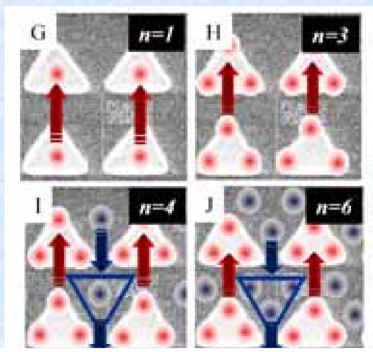

Fig. 4 Sketch of the positions of the vortices for several matching fields. Vortices pinned on the triangles are shown in red and interstitial vortices in blue. Red and blue arrows show the direction of the net flow of these vortices.

We describe [3] a device that controls the motion of flux quanta in a Niobium superconducting film grown on an array of nanoscale triangular pinning potentials. The controllable rectification of the vortex motion is due to the asymmetry of the fabricated magnetic pinning centers. The reversal in the direction of the vortex flow is explained by the interaction between the vortices trapped on the magnetic nanostructures and the interstitial vortices.

Ratchet without spatial asymmetry: Controlling the motion of vortices using time-asymmetric drives

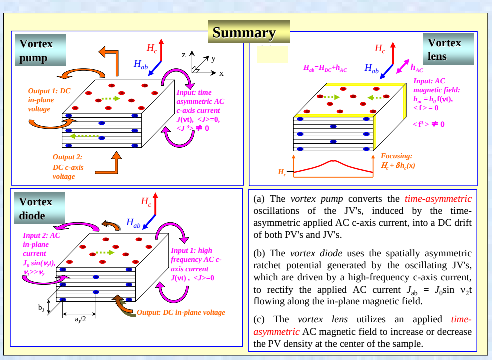

Fig. 5 Summary of devices for vortex motion control using temporal-asymmetry instead of spatial-asymmetry.

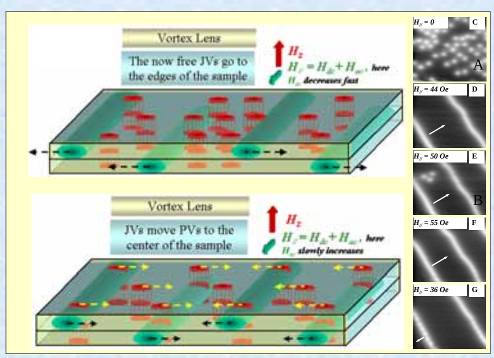

Fig. 6 "Crossing lattice" "vortex lenses" rectifying time-asymmetric drive (A,B); (C-G) experimental images of Josephson vortices (shown in green in A,B) transporting PVs (shown in red in A,B) through the sampole.

We propose [6,7] completely new types of ratchet-like systems that do not require spatially asymmetric potentials in the samples. Magnetic fields penetrate superconductors as vortex lattices of flux quanta. In extremely anisotropic layered superconductors placed in a tilted magnetic field, there are two interpenetrating vortex lattices consisting of Josephson vortices (JV's), aligned parallel to the CuO_2 planes, and pancake vortices (PV's), oriented perpendicular to those planes. We show that, due to the JV-PV mutual interaction and asymmetric driving, the AC motion of JV's and/or PV's can provide a net DC vortex current. This controllable vortex motion can be used for vortex pumps, diodes and lenses [8].

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