Transverse threshold for sliding conduction in a magnetically induced Wigner solid

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Abstract

The Hall voltage–current relationship in the sliding conduction régime of the magnetically induced quantum Wigner solid at a low disorder GaAs/GaAlAs heterojunction shows a non-linearity which would be expected if motion perpendicular to established sliding conduction channels were inhibited up to a threshold perpendicular force. This force is roughly a tenth of that required to establish the initial sliding. © 2000 Published by Elsevier Science B.V. All rights reserved.

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A periodic elastic system in a random field acquires a finite correlation length as it strains to take advantage of the random fluctuations [1,2]. Sufficient force induces sliding and possibly channeling [3], has been suggested [4,5] the channels have “depth” in the sense that it requires a finite force perpendicular to the flow lines to change their direction.

We test this idea in an experiment on a 2-D Wigner solid which measures at what applied perpendicular force the particles leave the channels.

Valence band holes at an epitaxial [3 1 1] interface between GaAs and GaAlAs constitute an isotropic 2-D system of particles in interaction in a weakly disordered environment. At low temperature and in the presence of a strong magnetic field to neutralise the quantum fluctuations it undergoes a quantum liquid to solid transition. The disorder induces collective pinning which curtails the long-range periodicity. In a sufficiently strong in-plane electric field the system depins and slides globally along the field direction, possibly in channels not always locally parallel. A small perpendicular force to test the rigidity of the pattern can be applied by the Lorentz force and an electric field.

Measurements were made on an \( l = 2.2 \times w = \) 0.8 mm\(^2\) sample of interface hole density \( n = 5.6 \times 10^{10} \) cm\(^{-2}\)(\( r_s \approx 10 \)) and mobility \( \mu \approx 8 \times 10^5 \) cm\(^2\) V\(^{-1}\) s\(^{-1}\) in the magnetically induced Wigner solid portion of the phase diagram (magnetic fields \( B > 8.5 \) T and temperatures \( T < 400 \) mK) [6]. Fig. 1 shows longitudinal \( V_L \) and Hall \( V_H \) voltages as a function of the current driven along the sample. These were obtained by appropriate symmetrization with respect to oppositely oriented magnetic fields.

The Hall voltage is characterized by a small current, pre-sliding linear segment passing through the origin with slope \( R_H = B/\Delta EC \) and, in the high current sliding régime, by parallel but offset asymptotes which cut the \( V \)-axis at \( V_{LH}^o \).

Focusing on the sliding régime, we note that a threshold force of \( f = f_{th} = eV_{th}/l \) per particle must be reached before the sliding current \( I_s \) is established. It is only then that a Lorentz force \( f_{LH} = eB \times v/c \), where \( v \approx I_s/\Delta EC \) is the velocity along the streamline, becomes appreciable. It adds, perpendicularly to the streamline, to the much larger initial force necessary to start the sliding. The Hall voltage corresponds to the external force that must be applied to ensure zero transverse current. The difference between it and the Lorentz force, represented by the continuation of the low current segment, gives the internal force exerted by the disorder. The offset indicates

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Fig. 1. Hall (antisymmetric to field reversal) and longitudinal voltages versus current. \( n_s = 5.85 \times 10^{10} \text{ cm}^{-2} \); \( B = 14 \) Tesla; \( T = 105 \) mK.

Fig. 2. Internal asymptotic transverse force versus longitudinal threshold force for sliding for different fields at fixed temperature.

that this internal force saturates at the value \( f_{\text{th}} = eV_{\text{th}}/w \) and is the threshold beyond which the conduction paths change appreciably. It can be viewed as the maximum confining force that the conduction channel can exert.

The longitudinal threshold field increases with lower temperature or higher magnetic field. Fig. 2 shows that at fixed temperature the measured transverse threshold follows the same trend and is about a tenth of the magnitude.

This work is strong experimental support for the idea of a transverse threshold force in sliding conduction of a periodic elastic system in a globally isotropic weak random field. Although the original theoretical ideas were developed for vortex motion driven by a transport current for the low-temperature vortex glass phase of high-temperature superconductors, the basic physics carries over directly to the 2D Wigner solid. In return, the present experiment raises the question of whether the same effect is responsible for the lack of a Hall effect from vortex motion in the vortex glass phase.

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References