Dynamic vortex regimes in Mo/Si multilayers: magneto-transport measurements

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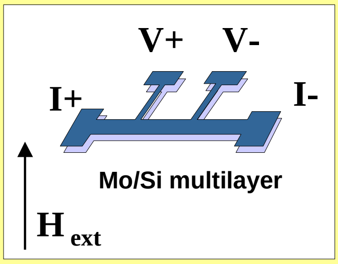
Abstract:

Superconducting superlattices are taken as a model for the study of fundamental properties of layered superconductors (1). In these systems, the interlayer Josephson coupling strength has a great influence on its behaviour. We study how this coupling can be varied in different conditions of magnetic field and temperature.

We have performed transport measurements (V-I characteristic curves) in a Mo/Si multilayer sample with fixed layer spacing. The analysis of the *dV/dI vs I* curves shows that different dynamic regimes of the flux line lattice are achieved as a function of the vortex driving force (i.e., the applied current). At a fixed temperature, this dynamic regimes can be varied by means of an external magnetic field, leading to an evolution of the *dV/dI vs I* curves that suggests a transition from a 3D to a 2D behaviour. This transition is studied at different temperatures.

A comparison with several theoretical simulations allows to relate the effect of temperature and magnetic field with the interlayer Josephson coupling.

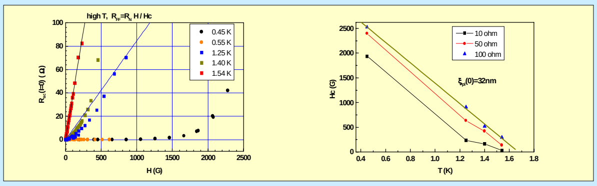


Sample characteristics:
50 Mo/Si bilayers :
Mo (7 nm) / Si (6 nm)
$T_C(H=0) = 1.65$ K,
(T_C Mo = 0.9 K)
$R_N = 94\Omega$
The magnetic field is applied perpendicular to the layers.

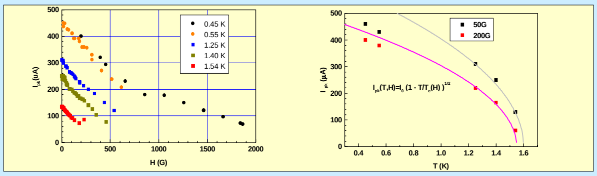
Measurements in a ^{3}He cryostat:
Temperature range: 0.4 -- 2 K
Magnetic field range: 0 -- 3000 G

From the analisys of the I-V curves we can extract information about the dynamic vortex phases in the multilayer:

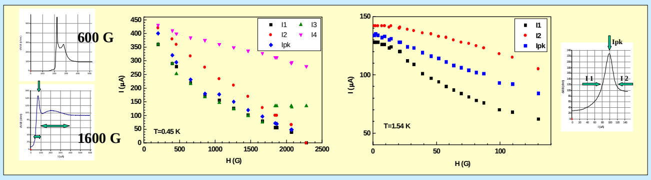
- •Plots of the differential resistance at I=0 as a function of the magnetic field shows that close to Tc the system is always in the Flux Flow regime. At the lower temperatures, this flux flow regime will be reached only at high field, before the transition to normal state.
- •The critical field, H_{c2}, can be obtained with different resistance criteria. Only the criterium of the highest resistance gives a linear behaviour for Hc(T). The criteria of 50% and 10% of R_N give deviations close to Tc.



- •The current at which dV/dI presents a peak decreases linearly with H. At all temperatures the slope of Ipk-H is similar, but at the lowest temperature this slope changes at about 800 G.
- •The position of the peak at a given field goes as $(1\text{-}T/Tc)^{1/2}$ close to Tc. At low temperature it clearly deviates form this behaviour.



- •The positions and widths of the peaks in the *dV/dI vs I* curves are used to determine the different dynamical regimes that the vortex system presents at a given field, as the current (i.e., the driving force) is increased.
- •At low temperature (0.45K, 0.55K) we find the richest structure. It is specially interesting the broad "background" bump that appears more clearly at the highest fields. This feature, and its evolution with field and temperature, has been observed both in theoretical and experimental works on 2D vortex systems **(2)**.

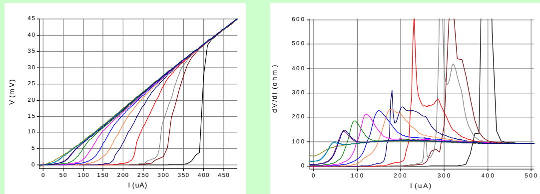


- • These V-I curves, and their evolution with magnetic field and temperature, are very similar to those obtained in experiments and simulations on layered systems **(3)**.
- • 3D molecular dynamics simulations allow a direct correlation between the features observed in the V-I curves (in that case, vortex velocity vs driving force) and the dynamical configurations of the vortex lattice.
- • Those results **(3)** show that the system undergoes a series of transitions as the driving force is increased (with fixed magnetic field (i.e.:vortex density):
  - •for strong interlayer coupling the phases are:
    - • 3D pinned --- 3D plastic --- 3D smectic --- 3D reordered
  - •for low interlayer coupling the phases are:
    - • 2D pinned --- 2D plastic --- 3D reordered

Transport measurements:

V vs I and *dV/dI vs I* plots show peaks and inflections corresponding to transitions between different dynamic vortex phases.

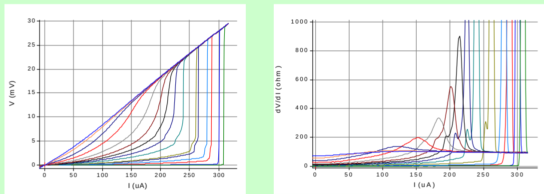
Low T: 0.45 K



As H is increased we observe a series of different behaviours:

- • at very low H there is a sharp jump in the *V-I* curve as the critical current is reached, leading the system directly to its normal state. This shows as a sharp peak in *dV/dI vs I*.
- • as H increases another peak appears prior to the sharp jump to normal state.
- • for intermadiate fields these two peaks still remain, but now a bump in dV/dI (which broadens a H increases) denotes the transition to the normal state.
- • at high magnetic fields a single broad bump marks the tansition to the normal state.

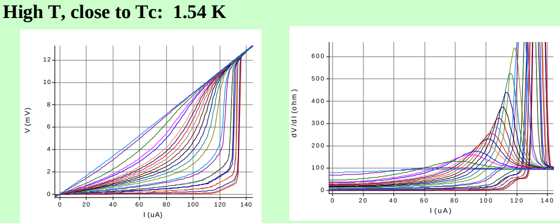
Intermediate T: 1.25 K



At this temperature we also detect different regimes:

- • at very low H a single sharp peak in *dV/dI vs I* indicates the transition to the normal state.
- • for intermadiate fields another peak appears prior to the sharp jump to normal state. Both peaks broaden as H is increased
- • finally, at high magnetic fields, a single broad bump marks the tansition to the normal state.

High T, close to Tc: 1.54 K



Close to Tc, *V-I* curves also show different vortex regimes as the magnetic field is increased:

- • at low H, the jump to normal state is always preceded by a linear increase of V once the critical current is reached. This feature appears as a step in the *dV/dI* curves, which is smothed out and finally disappears as H increases.
- • at high magnetic fields, like for the previous temperatures, a single broad bump marks the tansition to the normal state.

In our case, the interlayer coupling strength will depend mainly on temperature via the coherence length perpendicular to the layers, giving maximum coupling at high temperatures.
But at a fixed temperature, as H is increased the vortex-vortex interaction increases, and then the system presents an enhanced 2D behaviour respect to the interlayer 3D coupling. This situation may be the origin of the "second bump" in the dV/dI curves at low temperature and high fields.
At high temperatures the dV/dI curves present basically the same behaviour at all fields. The higher interlayer coupling in these cases prevents the decoupling of the layers due to the magnetic field.

In the near future, the evolution of V-I curves vs H, at different temperatures, will be studied in detail in order to determine the H-T phase diagram in different dynamic conditins (i.e.: different driving currents). With this study we will obtain information about the pinning and coupling mechanisms responsible of the different features observed in the V-I curves. We will try also to identificate clearly the dynamical vortex configuration corresponding to each of those fearures.

References:

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