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Small angle Neutron Diffraction Studies of Vortex Structures in High Temperature Superconductors.

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ABSTRACT
We have used neutron scattering to provide direct information about flux structures in the bulk of crystals of the superconductor $Bi_2Sr_2CaCu_2O_8$. Its extremely high effective mass anisotropy, makes the flux lattice susceptable to melting and also to decomposition into 'pancake' vortices, which would give a more two-dimensional vortex structure. At low temperatures and fields the scattered intensity is consistent with a three dimensional flux-line structure. At higher fields and temperatures, the scattering from the flux lattice dissapears well below T_c. We can associate this dissappearance with the above changes in the vortex structure. We compare the neutron scattering results with macroscopic measurements of magnetisation.

INTRODUCTION
Microscopic techniques, such as μSR [1] and neutron diffraction[2], are the most direct methods for measuring the magnetic quantum vortex structure in the bulk of superconductors. Such measurements provide quantitative information on the distribution of the local magnetic field which depends on the microscopic structure of the quantised vortex state.

NEUTRON DIFFRACTION
Small angle neutron scattering measurements immediately revealed the anticipated triangular Abrikosov flux line lattice (Fig.1), pinned to the b-axis of the crystal.

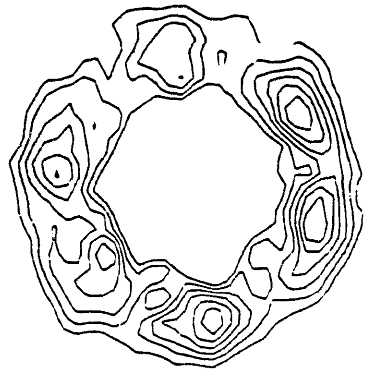

Fig.1 Flux lattice diffraction pattern from 2212-BSCCO at 4.2K and 50mT.

On cooling the sample to low temperatures in increasing fields, the neutron diffraction signal disappeared, as expected for a decomposition of the flux line lattice into uncorrelated 2D arrays of flux pancakes. The diffraction signal from the low field flux lattice also disappeared above the irreversibility line, with no evidence for a ring of diffracted intensity, as would have been expected for a simple flux line lattice melting transition. This implies an absence of any long range correlation of the flux line or pancake structure along the field direction, consistent with melting into either a liquid of highly curved flux lines or a liquid of 2D flux pancakes within planes.

MAGNETIC MEASUREMENTS
Features of the characteristic magnetic hysteresis of 2212-crystals (fig. 2) provide indirect supporting evidence for the magnetic phase diagram published

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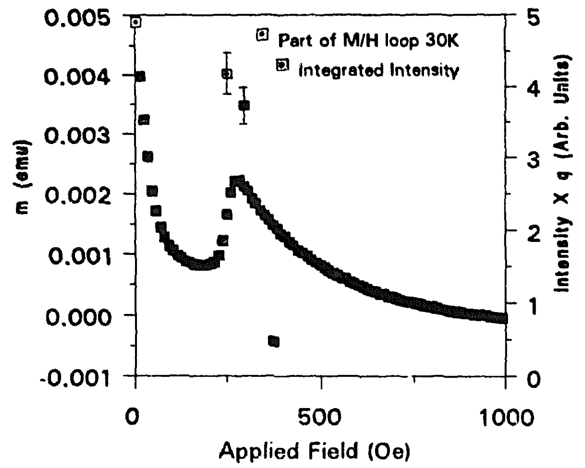
elsewhere[3]. The field at which the "arrowhead" anomaly occurs coincides with the decomposition field into 2D layers of pancakes deduced from neutron and μSR[1] measurements. On decomposition, the observed *increase* in pinning may result from flux pancakes redistributing themselves within individual CuO_2 planes to take maximum advantage of pinning by the highly regular planar dislocation networks present in such crystals[4].

a) As grown BSCCO 2212



b) O_2 treated at 500°C

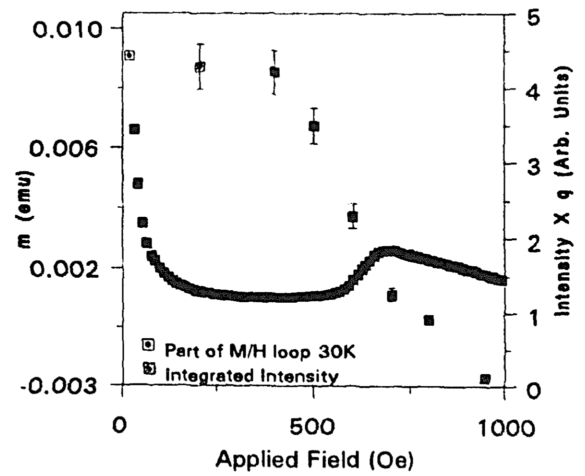


Fig.2 Magnetisation and neutron scattering measurements showing the dimensional crossover.

The 3D to 2D decomposition is predicted to occur at a field, $B_{2D} \sim \Phi_0/(\gamma s)^2$ (ref.5), which depends on the interlayer spacing s and the anisotropy factor $\gamma^2 = m_c/m_{ab}$. γ is a strong function of coupling between the planes and can be varied by changes in oxygen stoichiometry on annealing in oxygen or vacuum. The as grown sample shows the loss of scattered intensity and rise in magnetisation both occuring at 300 Oe, which when associated with a dimensional crossover yields an anisotropy factor γ of 175 (fig. 2a). Similarly the sample treated in 1atm oxygen at 500°C shows a higher crossover field of 470 Oe, consistent with a reduction of γ to 140 (fig. 2b). For vacuum annealed or insufficiently oxygenated as-grown samples, there was no evidence for a magnetic arrowhead anomaly.

SUMMARY

In 2212-BSCCO and almost certainly all other highly anisotropic cuprate high temperature superconductors, the Abrikosov flux lattice only exists over a very limited range of temperatures and fields. At most fields of practical importance the flux lattice will already have decomposed into a layered flux pancake structure, where planar pinning defects may be effective in increasing critical currents. The decomposition field and irreversibility line for 2212-BSCCO crystals are strongly dependent on oxygen stoichiometry, which is likely to be important for optimisation of critical currents in BSCCO wires and tapes.

ACKNOWLEDGEMENTS

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