ESRF

Experiment title: **High resolution x-ray diffraction investigation of the interaction between the vortex and crystal lattices in high T_c superconductors**	**Experiment number:** HS-836

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Report:

Unusually large magnetostriction effects have been detected for high T_c cuprate superconductors by dilatometric measurements [1,2,3,4]: a relative sample length change of 10^{-4} along the ab plane has been detected at 4.8 K for a magnetic field of 6 T applied along the c axis of $Bi_2Sr_2CaCu_2O_8$ [1]. The same effects have been observed for other high T_c superconductors [2,3,4]. It has been noticed that the magnetostriction is strongly anisotropic: it is approximately two orders of magnitude smaller if the sample length is measured along the field direction. These effects have been attributed to flux-pinning in the sample but such a model still does not show quantitative agreement with the data.

It has also been suggested that the results of the dilatometric measurements are strongly influenced by the sample shape [5]. Therefore we proposed to measure the magnetostriction of the high T_c superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) by x-ray diffraction which is independent of such geometric considerations.

These measurements were performed on a crystal fabricated at the University of Geneva. It has been shown that flux-pinning in ultra-pure crystals of $YBa_2Cu_3O_{7-\delta}$ is due to oxygen vacancy clusters [6]. We used in a first step a sample with $\delta \simeq 0.05$ (superconducting temperature 92 K). Untwinned samples were used as the detwinning process is known to introduce strain in the sample, which would be detrimental to our experiments: the relative change of the lattice parameter is expected to be small. The lattice parameters of the orthorhombic crystallographic structure are a = 3.82 Å, b = 3.88 Å and c = 11.68 Å.

The field produced by the cryomagnet lent by the Nuclear Scattering Group was applied along the c crystallographic axis and the Bragg reflection [200] was studied. Because of the presence of twins, the reflection [020] was also observed in our longitudinal scans, in the vicinity of [200] and it exhibited similar behaviour to the [200].

Since we needed high longitudinal resolution, ideal silicon monochromator and analyzer crystals were used. In addition we worked as close to the non dispersive mode as possible so that the scattering vectors (G) of monochromator, sample and analyzer match. In these ideal conditions the mosaic spread of the non ideal sample is totally decoupled from the longitudinal resolution. In practice we chose the Si [220] reflection

(G = 3.25 Å^{-1}) for the monochromator and the analyser. They match nicely the $YBa_2Cu_3O_{6.95}$ [200] (G = 3.28 Å^{-1}) and [020] (G = 3.26 Å^{-1}) reflections.
To compensate for a drift of the triple axis diffractometer which we noticed in a previous similar experiment (HS-552), we used an extra Si crystal which was fixed on the cryomagnet. Each measurement on the $YBa_2Cu_3O_{6.95}$ sample was therefore followed by a measurement on this Si crystal. The actual value of the variation of G for $YBa_2Cu_3O_{6.95}$ was obtained by a difference of the results of these two measurements. We assumed the Si magnetostriction to be negligible. The Si was moreover submitted only to the stray field of the cryomagnet which corresponds at the Si location to $\lesssim$ 20 % of the field applied to the sample.
In Fig. 1 we present the results obtained for the variation of the lattice parameter a measured with an X-ray energy of $\sim$ 200 keV. The thermo-magnetic history for the measurement is described in the figure caption. The variation of the lattice parameter amounts to $\sim 2 \times 10^{-4}$ for a field of 5 T and surprisingly it is positive.
Macroscopic (dilatometric) measurements have been subsequently performed on the *same sample* at the University of Frankfurt. Preliminary experiments showed an effect much larger and of the same sign as the one obtained by X-rays. However it turned out that these macroscopic measurements were flawed. The large anisotropy of the compound leads to large magnetic torque which affected the measurements. New measurements designed to overcome these artifacts finally gave negative values for the magnetostriction in accord with the natural expectation that the lattice should contract as the density of flux lines increases.
Therefore we suspect our X-ray data to be wrong. The effect of the magnetic torque could be an explanation although it seems not to be relevant in the case of a microscopic measurement. However, during our experiments we noticed that the intensity of the Bragg reflection dramatically decreased as the field was increased and came back to its initial value as the field was reduced. It was unfortunately impossible to line up the sample to restore the full intensity of the Bragg peak as the field was increased. The goniometer is indeed not strong enough to allow for a tilt of a relatively large mass such as the cryomagnet. Therefore the crystal was not optimally aligned when a field was applied and this misalignment may be at the origin of a incorrect estimate for the interplanar spacing.

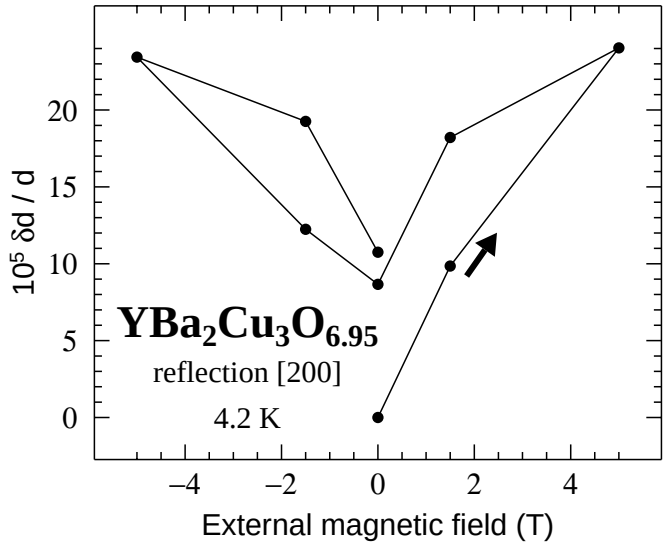

Figure 1: Relative variation of the interplanar spacing measured on the [200] Bragg reflection (corresponding therefore to the a lattice parameter) as a function of the field applied on $YBa_2Cu_3O_{6.95}$. The sample was cooled to 4.2 K in zero field. Then the field was cycled in the following sequence: 0, 1.5, 5, 1.5, 0, −1.5, −5, −1.5 and 0 T. The presented results are the average of several measurements.

Reference

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