Physica C 235-240 (1994) 2099-2100
North-Holland

PHYSICA C

Current induced optical birefringence in superconducting YBaCuO (123) and BiSrCaCuO (2212) thin films.

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We have observed that the flow of an electric current through superconducting YBCO and BiSrCaCuO thin films induces an increase in the optical birefringence, characteristic of a change in the crystal symmetry. This symmetry breaking is confirmed by Raman spectroscopy and is tentatively explained by ionic displacement within the CuO2 planes and lattice distorsion.

Four years ago, one of us (G. H.) trying to study a magnetic surface effect in unperfect BiSrCaCuO (2212) superconducting thin films submitted to high current density had observed the formation of preferencial electrical paths. The phenomenon was detected by a strong increase in birefringence as shown by optical microscopy in polarized light [1]. We report here the first attempt of studying this optical effect using phase modulated polarization microscopy and Raman spectroscopy.

YBaCuO thin films were prepared *in situ* by pulsed laser deposition and BiSrCaCuO layers had been grown by rf sputtering either on {100} MgO or SrTiO3 [2,3]. The birefringenge measurements have been carried out at 20K on patterned YBaCuO and BiSrCaCuO thin films using a phase modulated polarization microscope working in the reflexion mode with a spot size of 10 μm [4]. The Raman spectroscopy set up had been previously described in detail elsewhere [5]. The films are oriented with the *c* axis perpendicular to the substrate surface and present sharp superconducting transitions between 85 and 90K for YBaCuO(123) on MgO and SrTiO3, and at 78K for BiSrCaCuO(2212) on MgO. The change in birefringence during the flow of high current density is given in Fig.1. The observed effect which corresponds to an increase in birefringence, as determined by measuring the reflected signal from a mirror located on the layer surface, is strongly different for YBCO and BSCCO. In the case of YBCO, birefringence is first slowly increasing with the current density up to the critical current Jc (Fig.1a), then it increases drastically after a short plateau in the range of Jc. Above Jc the birefringence increases as the intensity to the square (*i. e.* as the dissipated power P) up to the breaking point of the film (Fig.1b). In this high current density range, birefringence may also become strongly remanent if the current is applied during a sufficiently long time, typically a few minutes, then disappearing notably above the superconducting transition during the warming up of the sample. In the case of BSCCO, the birefringence signal which is only recorded when the critical current is reached is independent on the current density (Fig.1b), the breaking point of the film is not reached and no remanent birefringence is detected. It has been verified previously that the birefringence increase cannot be attributed to the temperature increase of the layer by recording the effect of cooling down and warming up of the sample on the birefringence signal: increasing the temperature induces a signal into the opposite way of the one recorded during the flowing of the electrical current.

Raman spectra of YBaCuO recorded at 10K while the current is flowing with J = 0, Jc/3 and Jc/2 are reported in Fig.2. As J increases the normal mode at 338 cm-1, related to O2-O3 oxygen atoms vibrating in opposite phase along the *c* axis, is splitting into two modes at 326 and 340 cm-1, the effect being reversible with J. This splitting has already been observed with YBaCuO defficient in oxygen and when oxygen disorder appears in the CuO chains [8]. These two new modes correspond to the motion of the oxygen in the CuO2 planes, they are induced by a local broken symmetry in the CuO chains

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SSDI 0921-4534(94)01615-1

promoted by the high current density flowing through YBaCuO in the superconducting state.

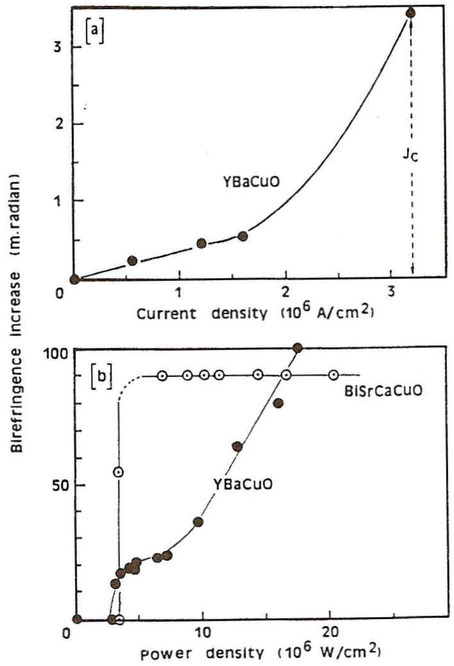

Figure 1: Out phasing as a function of current density: a) YBaCuO below Jc; b) YBaCuO and BiSrCaCuO above Jc.

We have tried to explain the phenomenon by ionic displacement within the CuO2 planes and lattice distorsion assuming that birefringence is the expression of the anisotropy in the *a-b* plane. According to the works of Meingast *et al* on the anomaly of the expansivity [6] and of Welp *et al* on the effect of uniaxial stress in YBaCuO [7], it can be supposed that the critical current inducing the transition from the superconducting to the normal state starts up an increase of the orthorhombic splitting. The *a-b* orthorhombic strain being larger in YBaCuO than in BiSrCaCuO, the lattice distorsion which is higher in YBaCuO than in BiSrCaCuO may induce a long remanent effect that disappears when the CuO2 plane recovers its orthorhombic equilibrium phase. It can also be supposed that the larger strain along the *a* and *b* axis in the case of YBaCuO induces a larger increase in birefringence together with a slower kinetic in the establishment of the effect: the birefringence plateau in YBaCuO cannot be achieved before the breaking of the microbridge.

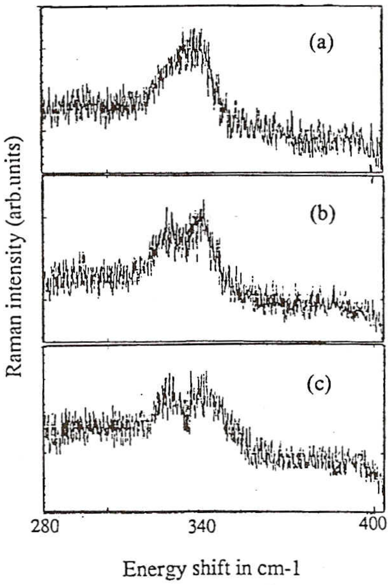

Figure 2: Raman spectra recorded from YBaCuO thin film on {100} SrTiO3 submitted to increasing supercurrent: a) J = 0; b) J = Jc/3; c) J = Jc/2.

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