

## Study of the birefringence by optical reflectivity in $\text{YBa}_2\text{Cu}_3\text{O}_7$ and its variation with a superconducting current.

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The birefringence of *c*-axis thin films of  $\text{YBa}_2\text{Cu}_3\text{O}_7$  has been evaluated by the change in polarization of reflected light. It has been observed that the flow of an electric current through superconducting YBCO thin film induces an increase in the optical birefringence. That is tentatively explained by a the shift of the oxygens in the chains. The polarization and the complex refractive index have been computed as a function of the shift of the O atoms: the result is in good agreement with the experimental relative phase difference.

The birefringence measurements have been carried out at 20K using a phase modulated polarization microscope working in the reflection mode with a spot size  $< 2 \mu\text{m}$  at a wavelength of 660 nm on micro-bridges patterned on YBCO thin films grown by pulsed laser deposition on {100}  $\text{SrTiO}_3$  ( $T_c \geq 90 \text{ K}$ ). The detector measures the phase difference  $\delta\theta$  between the *x* and *y* components of the light polarization;  $\delta\theta$  is then measured as a function of the current density along the (100) and (010) axes of the substrate [1]. We have previously observed that the flow of an electric current through YBCO (123),  $\text{BiSrCaCuO}$  (2212) and  $\text{TlBaCaCuO}$  (2212) micro-bridges induces above  $J_c$  a strong increase in the optical birefringence, which was tentatively explained in terms of a change in the crystal symmetry [2,3]. However in the case of YBCO, birefringence is first slowly increasing with the current density below the critical current in the superconducting state. In this paper, a model is developed to explain how that can result in a variation of the optical index assuming that this current induced birefringence is due to the shift of oxygen atoms in the CuO chains.

If the complex values of the refractive indices along the *a* and *b* axes, *i.e.*  $\tilde{n}_a$  and  $\tilde{n}_b$ , are known it is possible to calculate the expected phase difference in the reflected beam. If the surrounding medium is air, the complex reflection coefficient from a surface of complex index  $\tilde{n}$  is given by:

$$\tilde{r} = \left| \frac{1 - \tilde{n}}{1 + \tilde{n}} \right| = |r| e^{i\theta} \quad (1)$$

with  $\tilde{n} = n - ik$ , *n* is the real reflection index, and *k* the extinction index [4]. If the layer is sufficiently thick, reflection from deeper boundaries can be neglected; the phase factor  $\theta$  will be then given by:

$$\tan \theta_i = \frac{-2k_i}{(1 - n_i^2) - k_i^2}, \quad i=a,b \quad (2)$$

So the dephasing between the two axes, *a* and *b*, can be calculated:

$$\delta\theta = \theta_a - \theta_b \quad (3)$$

The index values at  $\lambda = 660 \text{ nm}$  have been taken from Humlicek *et al.* ( $n_a = 1.755$ ,  $k_a = 0.456$ ,  $n_b = 1.378$  and  $k_b = 0.780$ )[5]. At this wavelength, we do not probe the free carriers moving in the CuO planes. Hence a dielectric crystal lattice consisting of CuO chains will be considered and an optical theory developed for conventional perovskites will be applied. The outline of the calculation is therefore to calculate the real index  $n_b$  for a certain shift of the oxygen atom, the real index  $n_a$  and the imaginary indexes  $k_b$  and  $k_a$  staying constant ( $n_b = 1.38$ )[5]. Considering a crystal consisting of copper and oxygen atoms respectively at the (0,0,0) and (0,0,1/2) site, we use the method proposed by Kinase *et al.* [6] for a distorted perovskite by modelling each ion as a dipole under the influence of the field applied along the *b* axis. The starting point of the index calculation is:

$$n_b = \sqrt{1 + \frac{4\pi\bar{P}^>}{\bar{E}^>}} \quad (4)$$

where  $\bar{E}^>$  is the incident electric field and  $\bar{P}^>$  the electronic polarisation. The effective electric field on a point in the lattice is then given by:

$$E'_{cu} = \frac{P_{cu}}{\alpha_{cu}} = E + \frac{1}{V} \{ y_1 P_{cu} + y_2 P_o \} \quad (5)$$

$$E'_o = \frac{P_o}{\alpha_o} = E + \frac{1}{V} \{ y_1 P_o + y_2 P_{cu} \} \quad (6)$$

where  $V$  is the volume of the unit cell,  $E'_{cu}$ ,  $E'_o$  and  $P_{cu}$ ,  $P_o$  are respectively the effective electric field and the electronic polarisation along the  $b$  axis at the Cu and O sites,  $\alpha_{cu}$  and  $\alpha_o$  are the respective polarisabilities,  $\Delta$  the relative displacement of the oxygen along the  $b$  axis and  $y_1$ ,  $y_2$  the Lorentz coefficients, which are here :

$$y_1 = 4\pi/3 + q_{cu} + A_{cu}\Delta$$

$$y_2 = 4\pi/3 + q_o + A_o\Delta$$

with  $q_{cu} = 0.0442$ ,  $A_{cu} = -0.259$  and  $q_o = 0.553$ ,  $A_o = -1.715$ ,  $V = 178.83 \text{ \AA}^3$ . Combining (5) and (6), this give:

$$\frac{P}{E} = \frac{(P_{cu} + P_o)}{EV(1 + \Delta)} \quad (7)$$

The index  $n_b$  versus  $\Delta$  is then obtained by equation (4), and therefore the relative phase difference by equations (2) and (3). The unknown parameters in these formulae are the values of the polarisabilities for oxygen and copper. These must be chosen so as to give  $n_b = 1.38$  for  $\Delta=0$ . Assuming that the polarisability of the oxygen should be of the order of a few  $\text{\AA}^3$  [6] and knowing the optical index,  $\alpha_{cu}$  is calculated from the above relationships.

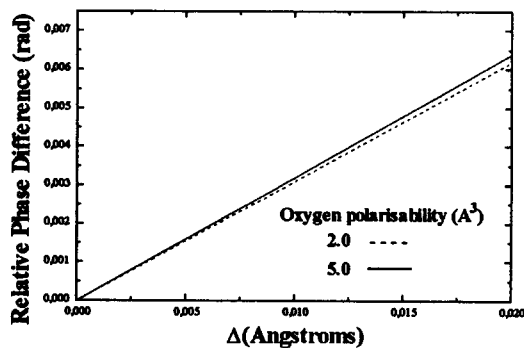


Figure 1: Calculated relative phase difference versus shift of the oxygen atoms in the chain

The result of the numerical calculations which is reported in Fig.1 indicates that the displacement

necessary to produce the observed birefringence requires a movement of the oxygen atom of a few hundredths of an Angstrom. Fig. 2 compares the induced relative phase difference with the variation of  $\Delta$  as a function of the current density obtained by combining the model with the experimental results. It is concluded that these results tend to support the hypothesis of oxygen displacement in the chain in so far as the calculated oxygen displacement appears reasonable. A large oxygen displacement would be likely to distort the entire structure, evidence for this has not been seen in the superconducting state [2].

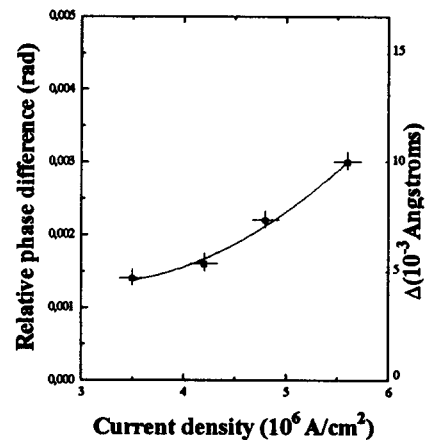


Figure 2: Induced relative phase difference and shift of the oxygen atom of the CuO chain versus the applied current density.

#### REFERENCES:

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