Optical Switch of Polarization Based on High-T_C Films

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Abstract. It was discovered that a laser pulse could significantly redistribute sheet currents of the superconductor films in a remanent state without the change of the total number of current vortices in the film. This effect can be used to switch or to change the polarization of the optical signal on the base of the magneto-optics.

I. Introduction. Investigations of 2-D sheet current distributions based on measurements of magnetic field above the type-II high-temperature superconductor (HTSC) YBaCuO films in a remanent magnetization state have been carried out. Using the Biot-Savart's law and continuity equation, integral equations (of 2-D convolution type) for two components of current have been obtained. These equations have been solved on the basis of Tychonoff method of generalized discrepancy, and sheet currents pattern in superconductors has been retrieved as well as the magnetic field distribution on the film surface. The current peculiarities related to laser pulse effect have been retrieved from measurements. Redistribution of currents after the laser pulse impact without the change of the total vortices number has been observed. This effect gives the possibility to change (and, may be, to form) currents distributions and magnetization in the HTSC films using the laser emission. We propose to apply the magneto-optical coating of the film (see, for example [1]) to switch or to change the polarization of optical signal reflected from the film by this same signal. The magneto-optical method is known as a powerful tool for investigations of currents and magnetization of HTSC films. In this method the Faraday effect in magneto-optical active material (such as the ferromagnetic EuSe or the iron-garnet) is in use to visualize the magnetic field distribution. This distribution could be changed by optical emission and, hence, could be changed the rotation of the polarization plane when linearly polarized light passes a magneto-optically-active layer (with the depth 3-5 μm) exposed to the magnetic field of the underlying superconductor. To visualize the magnetic field distribution it is possible to use an analyzer, which is set in a cross-position with respect to polarizer.

II. Measurements. The method for measuring the perpendicular component of magnetic field $H_z(x,y)$ at arbitrary height level z above the film surface uses a Hall scanning probe (see, [2,3]). The perpendicular external magnetic field was generated by a solenoid coil, which is cooled with liquid nitrogen and produces a maximum field of 500 gauss. The magnetic field increases linearly up to its maximum value during 20 seconds and, then, decreases in the same way down to zero value. The thin film (about 0.1μm with a diameter of 20 mm was chosen for measurements. A Hall probe with the sizes 100 and 50 μm in the x-y

plane and 10 μm in the z-direction was applied in experiments. The noise level was about 0.1 gauss. The height z of measurements was chosen in 200-300 μm interval to ensure non-invasive conditions. The lateral resolution of measurements (pixel size) was chosen 250 μm (comparable with the Hall probe size).

III. Inverse problem. The integral equations (of the 2-D convolution type) for two components of current for the inverse problem formulation have been obtained in [3] using the Biot-Savart's law and the continuity equation:

$$H_z(x,y,z) = \frac{1}{c}\iint j_x(x',y')\,\frac{Y\left[z^2(X^2+Y^2+2z^2) - X^2(X^2+Y^2)\right]}{(X^2+Y^2+z^2)^{3/2}\left(X^2+z^2\right)^2}dx'dy', \tag{1}$$

$$H_z(x,y,z) = -\frac{1}{c}\iint j_y(x',y')\,\frac{X\left[z^2(X^2+Y^2+2z^2) - Y^2(X^2+Y^2)\right]}{(X^2+Y^2+z^2)^{3/2}\left(Y^2+z^2\right)^2}dx'dy', \tag{2}$$

where j_x, j_y are the components of sheet current $\vec{j}$, $X = x\text{-}x'$, $Y = y\text{-}y'$. Deconvolution of (3) and (4) yields a solution of the inverse problem of 2-D current pattern retrieval from 2-D magnetic-field distribution measured in x – y plane at some arbitrary vertical distance z. Special regularization methods should be applied in this case. Convolution equations (3) and (4) have been solved using Tikhonoff's method of generalized discrepancy [3]. Our numerical simulation gave the following results. The *rms* of random errors of retrieval related to the random "data" noise with the *rms* of 0.1 gauss changes from 0.1 A/cm for the low current values (about 2 A/cm) up to 0.5 A/cm for the strong currents (about 20 A/cm).

IV. Effect of laser pulse irradiation. In Fig.1 the initial state of the magnetic field of a circular disk film with a diameter of 20 mm after the above magnetization process is shown (height of measurements was z = 225 μm).

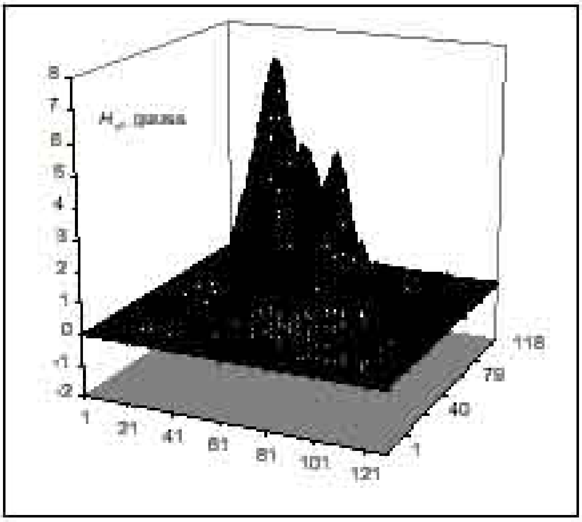

Fig.1. Initial magnetic field at z = 250 μm.

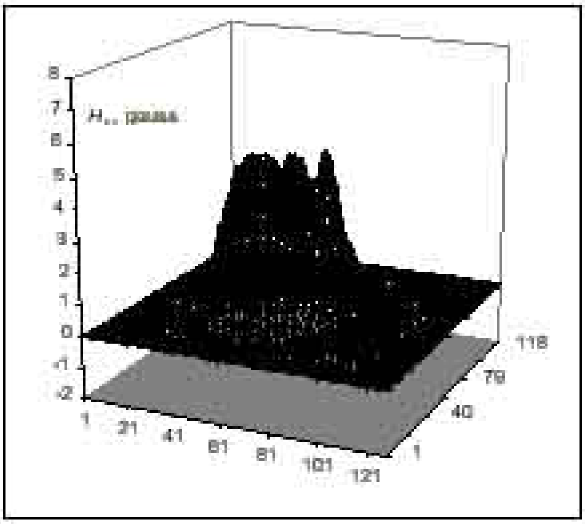

Fig.2. After a laser pulse.

The current perturbation due to the laser pulse (with the beam footprint of 2 mm) leads to a new distribution of currents and, hence, to new magnetic field distribution shown in Fig.2.

The pulse duration was $\tau = 10^{-7}$ s, chosen comparable to the time of film-substrate heat exchange. The time of thermal relaxation of the whole system is about 10^{-4} s. The retrieved current patterns before and after laser pulse are presented in Figs.3, Fig.4, and their difference is shown in Fig.5. One can see that the strong counterclockwise current rotation region near the center of the film (Fig.3) is disappeared and this region could be well seen in the same place (but clockwise) in Fig.5. The regions of current enhancement (mainly in the form of the vortices, seen as rotating counterclockwise in Fig.5) appeared in the region around the beam footprint. So, the laser pulse leads to currents shift to surroundings. It is a very interesting result.

The magnetic field distributions before and after the laser pulse have been calculated. The most unexpected result is that the mean (over the film surface) value of the change of the surface magnetic field is equal to zero inside the limits of measurements accuracy. It means that in the considered case the laser pulse redistributes currents significantly without the change of the total number of current vortices in the film.

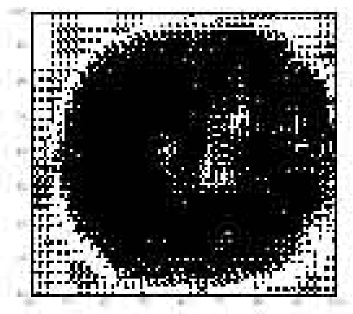

Fig.3. Initial currents.

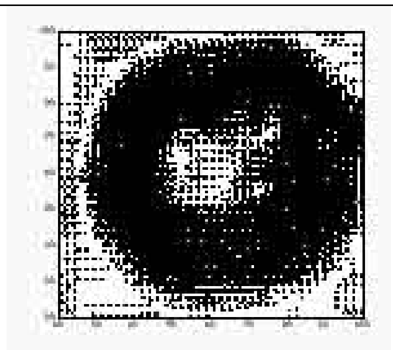

Fig.4. After a laser pulse.

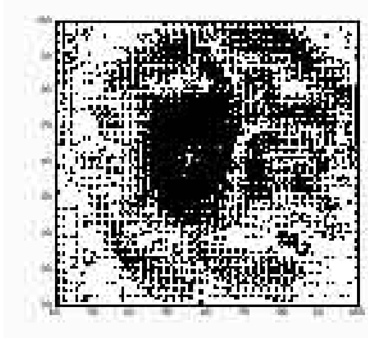

Fig.5. Currents difference.

Thus, this effect gives the possibility to change the magnetization in the HTSC films using the optical emission and to switch or to change the polarization of the optical signal reflected from the film (and it makes the same transmitted signal) using magneto-optical coating of the film.

References

1. Th.Schuster, H.Kuhn, E.H.Brandt, M.V.Indenbom, M.Klaser, G.Muller-Vogt, H.-U.Habermeier, H.Kronmuller, A.Forkl. Current and field pattern in rectangular and inhomogeneous superconductors. Phys. Rev. B., 52, 10375 (1995).
2. A.Chang, H.D.Hallen, L.Harriot, H.F.Hess, H.L.Kao, J.Kwo, R.E.Miller, R.Wolfe, J.van der Ziel. Scanning Hall probe microscopy. Appl.Phys.Lett, vol.61, No.16, pp.1974-1976, 1992.
3. Gaikovich K.P., Nozdrin Yu.N., Reznik A.N., Zhilin A.V. Determination of sheet current patterns of HTSC films fixed in a magnetic field by measurements of magnetic field. XII German–Russian–Ukrainian Seminar on High Temperature Superconductivity (25-29 October, 1999, Kiev, Ukraine), 1999, Kiev: V.N.Bakul Institut for Superhard Materials of National Academy of the Ukraine, p.86.