Vortex Lattice Anisotropy in the Conducting Plane of Organic Superconductors

L. Ya. Vinnikov [a,1], T. L. Barkov [a], M. V. Kartsovnik [b], N. D. Kushch [c]

[a] *Institute of Solid State Physics, RAS, 142432 Chernogolovka, Moscow district, Russia*

[b] *Walther-Meissner-Institute, Walther-Meissner-Str. 8, D-85748, Garching, Germany*

[c] *Institute of Problems of Chemical Physics, RAS, 142432 Chernogolovka, Moscow district, Russia*

Abstract

Vortex structure in organic superconductors κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ and κ-(BEDT-TTF)$_2$CuN(CN)$_2$Br has been studied by use of the decoration technique at magnetic fields up to 23 Oe directed perpendicular to the two-dimensional superconducting *bc*-plane. A quantitative analysis of high quality vortex lattice images reveals an anisotropy of the vortex lattice which can be attributed to a penetration depth anisotropy.

Key words: vortex lattice; anisotropy; organic superconductors

Layered organic superconductors with relatively high critical temperatures ($T_c \sim 10$ K) are well established strong type II superconductors whose magnetic and resistive properties below T_c are mainly determined by the vortex structure [1]. First experiments on a direct observation of the Abrikosov vortices in the superconductor κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ [2] have revealed an anisotropy of the vortex lattice (VL) in the plane of superconducting molecular layers (i.e. crystallographic *bc*-plane) which could be attributed to a penetration depth λ anisotropy. In the present work we report the results of a quantitative analysis of this anisotropy.

Since our previous studies [2], we improved the experimental conditions by optimizing the initial helium pressure and minimizing the sample heating during the decoration process that resulted in a much higher quality of the vortex structure images. An information about VL parameters has been obtained by digitalizing and FTT (fast Fourier transformation) processing of the scanning electron microscopy (SEM) images. An X-ray analysis has been used to provide an information about the in-plane crystal orientation.

We have succeeded in imaging the Abrikosov vortices on 4 different samples κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ at magnetic fields up to 23 Oe applied perpendicular to the *bc*-plane.

Fig. 1a shows an example of a SEM image of a decorated sample surface obtained in the secondary electron emission mode. The sample was decorated at the magnetic field of 23 Oe. The bright spots correspond to a higher concentration of magnetic particles, i.e. to the vortex areas where the magnetic field penetrates into the sample. The high quality of the sample results in a well ordered VL. This is reflected in the sharp maxima in the FFT pattern shown in Fig.1b.

If the VL was an ideal hexagonal 60 degree one, the first order FFT maxima would form a regular hexagon. In the present case of a slightly distorted lattice this hexagon is not a regular one and it cannot be inscribed into a circle. Instead, an ellipse is required; it corresponds to a Fourier transformation of a circle circumscribed around the primary vortex triangle in real space. Such an ellipse constructed on the FFT maxima as the base points is also shown (Fig. 1c). The ratio between the main axes of the ellipse is 1.06. It should

[1] Corresponding author. Present address: Institute of Solid State Physics, RAS, 142432 Chernogolovka, Moscow district, Russia. E-mail: vinnik@issp.ac.ru

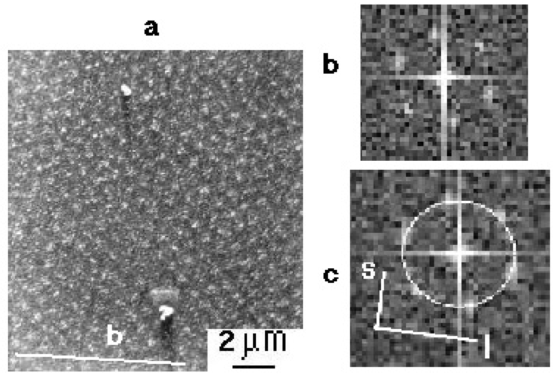

Fig. 1. a) Vortex lattice in the superconductor κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ at the magnetic field of 23 Oe. The direction of the crystallogrpahic b-axis obtained from X-ray data is also shown; b) FFT pattern of the vortex lattice in an arbitrary scale; c) ellipse circumscribed around FFT maxima, l and s mark the directions of its main axes.

be noted that the orientations of the main axes of the ellipse are very sensitive to the initial data on the FFT maxima positions since the ellipse does not strongly differ from a circle. This is the reason why we could not perform reliably such a procedure until the well ordered lattices with sharp FFT maxima were obtained. To achieve a higher accuracy, the results for each sample have been averaged over several (5-10) SEM microphotographs taken from different parts of the sample (it is to be mentioned that these results are in a good agreement with each other, otherwise this averaging would make no sense). The ellipse orientation has been compared with the crystal orientation obtained from X-ray data.

The main result of such a processing is that for all 4 samples we have the same configuration of the ellipse: the long axis in Fourier space coincides with the direction corresponding to c-axis in real space, to an accuracy of $\pm 7^{\circ}$. The ratio between the main axes of the ellipse varies from 1.05 to 1.08. In other words, the distance between vortex rows in real space is minimum in the c-direction and maximum in the perpendicular b-direction and the ratio between these maximum and minimum distances is 1.05-1.08.

It is well known [3] that in the case of an isotropic type II superconductor the most preferable VL configuration is a regular hexagonal one. In real superconductors, however, there are many factors which may lead to a distortion of a VL. When it is not forbidden by the symmetry of the problem considered, the simplest reason for the anisotropy of a VL is a difference of intervortex interactions in different directions. In the local London model such a situation is realized when a projection of the inverse-mass tensor on the plane perpendicular to the magnetic field is not a scalar. In this case, the screening Meissner currents flowing around

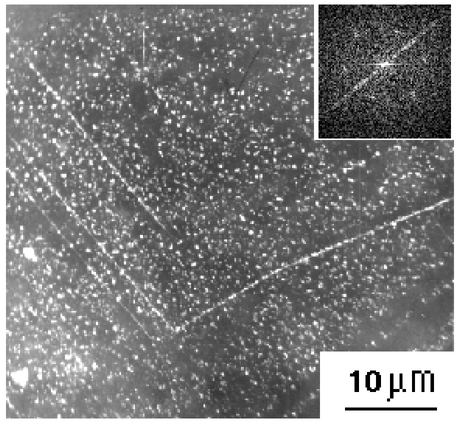

Fig. 2. Vortex structure in the superconductor κ-(BEDT-TTF)$_2$CuN(CN)$_2$Br at the magnetic field 17 Oe. Inset: FFT pattern in an arbitrary scale.

the vortex core have the form of an ellipse instead of a circle; thus, the interaction between them is anisotropic that leads to a formation of a distorted VL. Taking into account the monoclinic symmetry of κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ we do not see principal objections to attributing the observed VL anisotropy to the inverse-mass tensor anisotropy (as it would be in the case of cubic or tetragonal superconductors). The corresponding mass ratio m_b/m_c should be 1.10-1.16.

One more interesting result of the present work is an observation of a VL in another organic superconductor, κ-(BEDT-TTF)$_2$CuN(CN)$_2$Br. An example of the VL image for the magnetic field of 17 Oe as well as its FFT are shown in Fig. 2. To our knowledge it is the first direct observation of the Abrikosov vortices in this material. A preliminary analysis shows that there is an anisotropy in the VL of the same order, $\simeq 5-10\%$. Studies of the mutual orientations of the VL and crystal lattice are in progress.

Acknowledgements

This work was supported by the RFBR grant 00-02-04019a (DFG-RFBR grant No. 436 RUS 113/592) and NWO grant FN 4359.

References

[1] M. Lang, Superconduct. Rev. **2** 1 (1996).

[2] L.Ya. Vinnikov, T.L. Barkov, M.V. Kartsovnik, and N.D. Kushch, Phys. Rev. B **61** 14358 (2000)

[3] A.L. Fetter, P.C. Hohenberg in "Superconductivity" by R.D. Parks, Marcel Dekker, Inc., New York, 1969, Chapter 14, p.836