Report

Study on the guided flux motions in the presence of the arrays of antidots in high-T_c superconductors

Purpose of the visit

Crucial aspects which determine the applicability of high-T_c superconductors (HTS) are obtained by the critical current related properties of superconductors. The dissipation caused by vortex motion dominates among others to voltage drops in current leads, noise in active devices and an increase in the surface resistance in microwave applications. Therefore, the understanding and tailoring of the critical properties of HTS materials is a major issue in the field of HTS research. In particular, the behaviour of the critical current as a function of the magnetic field in the superconductors with several pinning distribution needs understanding [M. Laguna, C. Balseiro, D. Dominguez, and F. Nori, Phys. Rev. B64, (2001) 104505]. The vortex motion in type-II superconductors are found to be correlated in a complex way along the longitudinal and transverse to the direction of motion. Different controlling material parameters have been investigated to address several issues related to the vortex correlations [Ajay Kumar Ghosh, P. Olsson and S. Teitel, Phys.Rev. Lett. 97, (2006) 267002 and references therein]. It has also been reported that the sample dimensions along the applied magnetic field and in the transverse directions play important role in controlling the vortex motion in superconducting materials. However, such complicated field of research needs intensive experimental studies to resolve problems which will trigger the possibility of the application of superconductors consisting of intrinsic Josephson junctions. In addition, recently the inclusion of the nanosized particles including the quantum dots are found to be responsible for controlling the critical current density.

Applications have been considered with the help of the thin film of high-T_c superconductors in several areas. However, considering the complicated nature of the problem it was not possible to establish the mechanism to minimise the dissipation. The dissipation in thin film superconductors has been studied through simulations and experimental observations. Regarding the vortex motion in the film geometry several questions remain unanswered [V. K. Thorsmolle et al, Phys. Rev. Lett., 97, (2006) 237001]. Magneto-optical observations show that the vortex phase diagram of the existing HTS film consists of interesting vortex motions which needs detailed understanding to explore the possibilities of the reduction of the dissipation associated with the transport and other phenomena. Critical phenomena associated with the guided motion of vortices in the presence of the arrays of quantum dots are in the premature state of the establishment. Several experiments as well as simulations have been performed to study motion of the vortices in superconducting samples. In the thin film geometry, there are signatures of vortex dynamics induced effects in the form of nonlinear microwave absorption and disordered states measured by the magneto-optical imaging. The motion of vortices between artificial defects has become an important study to resolve the problems related to the vortex dynamics. The interaction between vortices and antidotes (artificially introduced) affects the microwave absorption in complicated way. A few studies have been done to settle several aspects associated with the reduction of low frequency noise in the SQUID [R. Woerdenweber et al, Phys. Rev. B69 (2004) 184504].

The aim of the proposed project is to study the vortex matter and vortex mobility and its impact on several physical properties of specially patterned HTS thin films. By utilizing the experimental methods the purpose of the present visit is as follows.

1. Preparation and characterisation of superconducting YBCO thin films (and, for comparison, conventional superconducting films with smaller intrinsic pinning properties)

2. Development of adequate photolithographic designs and masks (based on antidot lattices with variations of antidote size and distribution of antidots) for manipulation of vortex pinning and vortex mobility

3. Patterning of the superconducting thin films

4. Analysis of the impact of the micro- and nanostructures on the critical current density and vortex mobility via dc, rf-transport, and relaxation experiments.

Due to the limited time (in the original plan we asked for a 6 month project) not all aims could be completely solved. Nevertheless, we did succeed in the first 3 items. First measurements (item 4) were successful.

Description of the work carried out during the visit

Several superconducting YBCO thin films on $LaAlO_3$ (LAO) have been prepared by the pulsed laser deposition (PLD) technique. The typical thickness of the films used for the experiments is 60nm. The thickness measurements were done by the Rutherford Back Scattering (RBS) method. All the steps towards the preparation of the mask which has been used for optical lithography with several antidot lattice on the same mask has been developed. Films have been patterned by using optical lithography and ion beam etching. We have prepared the mask for several antidot lattices and structures and the circular antidots have radius of 100nm and 65nm. The typical lattice constant is about 600nm. So far we have studied YBCO and MoGe films having patterns of two types (i) two inclined rows of antidots and the third row is missing as shown in the optical micrograph of YBCO film.

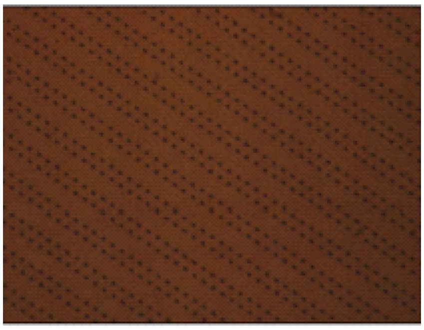

Fig.1 Optical micrograph of YBCO film of 60nm thickness with inclined rows of antidotes of radius 100nm.

and (ii) Kagome lattice. We will discuss the preparation of patterned samples and measurements as follows.

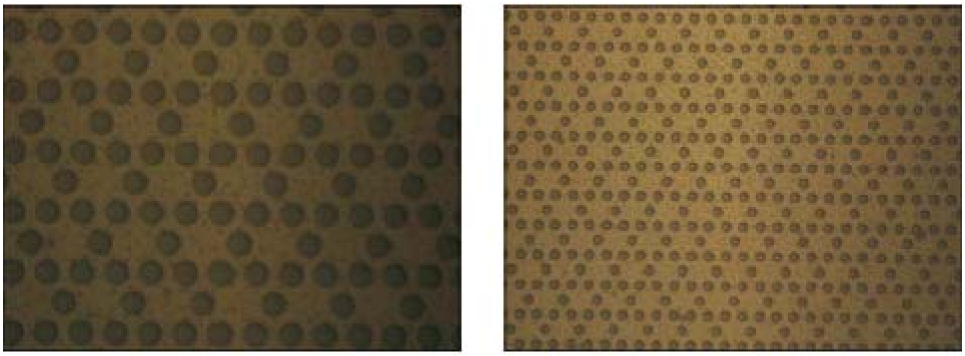

Fig.2 Top views of YBCO film of 60nm thickness with Kagome antidot lattice. The left panel shows dots of radius 100nm and the radius of the antidotes in the right panel is 65nm.

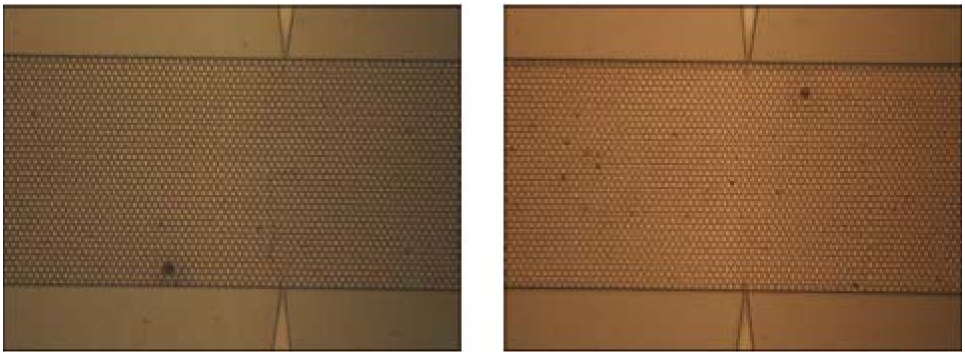

Fig.2 Gold contacts in the patterned YBCO film for the Hall voltage measurements. The left panel shows YBCO with Kagome antidot lattice with dots of radius 100nm and the radius of the antidots in the right panel is 65nm

Firstly, we have used a chip (CHIP I) which consists of three regions of YBCO film: one region of the film has antidotes structure of Kagome lattice with antidote size of 100nm (region I), the middle of the film has no dot (region II) and the third region has Kagome lattice antidots of radius 65nm (region III). Six gold contacts have been used for the longitudinal voltage measurements of each regions. Two currents contacts have been used which can be used for the rf-measurements as well. The dc resistivity measurements for three regions have been done using currents of 10μA and 100μA. We have performed both the magnetic field sweep and temperature sweep measurements.

Secondly, we have prepared a sample chip (CHIP II) consisting of YBCO film and Kagome antidot lattice like CHIP I. However, it has two pairs of Hall contacts for the measurement of transverse voltage in addition to the longitudinal voltage.

Thirdly, we have used another chip (CHIP III) on which the YBCO film has been patterned in the two regions: one region has a antidotes distribution of triangular lattice of which each third row of dots is missing and the antidots have radius of 1μ (region I), another region has the same antidotes having a different orientation (region II). We have two pairs of contacts in two regions for the hall voltage measurements. We have two contacts for the simultaneous measurements of the longitudinal voltage. Currents of 0.1mA, 1mA and 10mA have been used for the measurements. Magnetic field sweep of 0 through 0.5T has been used for all dc measurements.

We have another sample (CHIP IV) where we have used MoGe superconductors patterned with antidot distribution of CHIP III (see Fig. 1 for the typical pattern).

Description of the main result obtained

We have mesured the resistance as a function of temperature of the YBCO film with Kagome antidot lattice (CHIP II).

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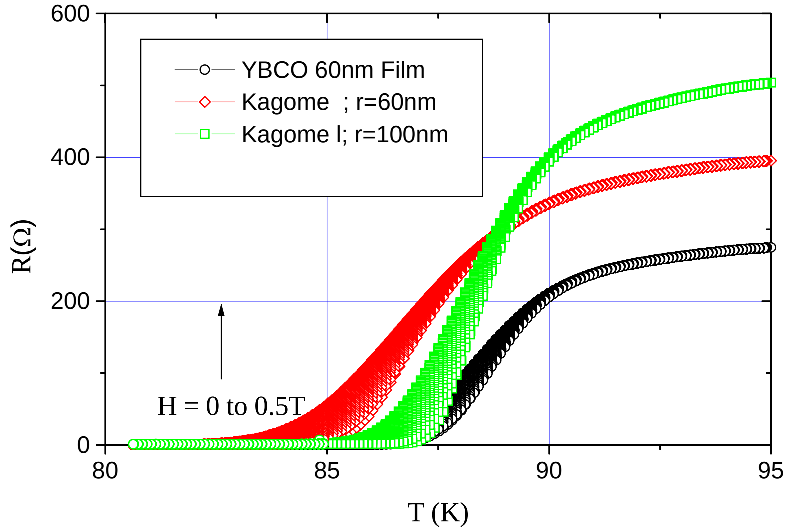

Fig. 3 Resistance as a function of temperature in three cases of YBCO film. The magnetic field sweep at all temperature has been used in all cases. The upper most symbols correspond to the magnetic field of 0.5T as shown by the arrow.

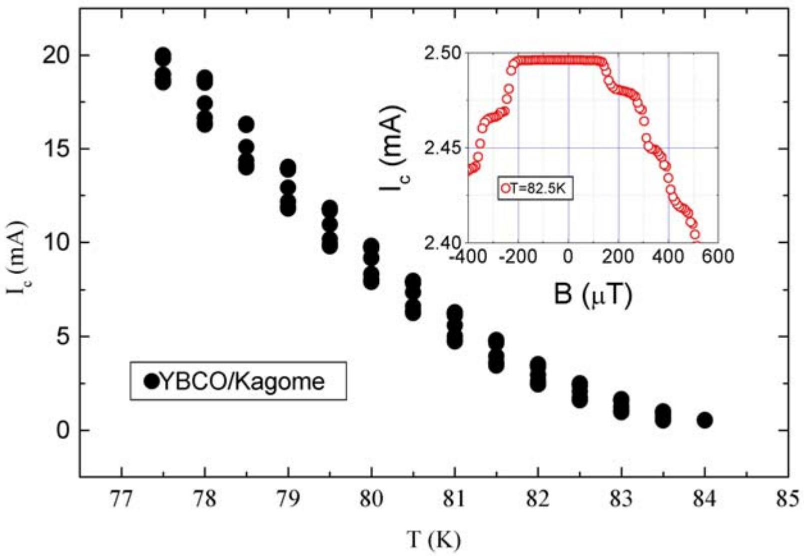

Fig. 4 Critical current as a function of temperature in YBCO film with Kagome antidot lattice. Inset shows a typical variation of I_c as a function of the applied magnetic field at T=82.5K. We superimposed an (frequency 1.1kHz) ac field with dc current for I_c measurements.

The resistive transition shows that the nature of the superconducting transition has been affected by the presence of the antidots distribution. The magnetic filed sweep of 0 to 0.5T has been used at all temperature. The dc current used is 10μA the data of which is given in Fig. 3. The nano thickness of the film may have an impact on the superconducting transition. However, the impact of the Kagome lattice of holes is clearly visible. An exact determination of the size dependence needs several other measurments of samples with controlled smaller size of dots. Analysing the flux flow resistivity data, we have concluded the vortex dynamics in presence of AC signal of frequency 1.1kHz and above superimposed with the dc current would be an important investigation to study the critical current, I_c, with the magnetic field in the low magnetic field region. We have measured I_c of YBCO with 65nm antidot lattice at several temperatures. A typical variation has been shown in Fig. 4. The vortex guidance have reasonable impact in controlling longitudinal I_c in patterned film. Detail results will be published in international journals.

Future collaboration with host institution

The measurements already done are currently being analysed which will make clear the impact of vortex guidance in patterned films. The research activities under the present program will not be restricted only to the period of the project. The field of manipulating the critical properties of superconducting thin films via patterning is of interest for both partners, (Dr. Roger Woerdenweber, Germany and Dr. Ajay Kumar Ghosh, India). The project will lead to a strengthening of collaborative activities in the field of the basic understanding of vortex matter in patterned films and their application in the field of fault current limiters, SQUID diagnostic and microwave application for communication. We have planned to continue the investigation in future including the electron beam lithography for the pattering of the films with antidots even smaller sizes.

Projected publications/articles resulting or to result from the grant

Several publications will be possible out of the analysis of the obtained data. We have planned to submit our result in conferences such as (i) organised by ESF to held in Germany, in September, 2008 and (ii) LT conference, 2008 to be held in Leiden. We have also planned for publication of our results in several international journals in near future after further refinements of the present measurements.

Other comments

The collaborative works on the inclusion of the arrays of nanosized antidots in superconducting film will be important in developing the new ideas related to the quantum jump in the several parameters which are essential to understand several basic phenomena as well as the possibility of the applications.