The evidence of phase transitions of the vortex lattice in YBaCuO HTc superconductors

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The investigation of the vortex matter in high critical temperature superconductors is very powerful tool to understand the dissipation mechanism in such materials in the mixed state. Generally speaking, the vortex lattice exhibits a various and undefined phases in the (H-T) phase diagram [1]. In this work, the voltage noise measurements will be used to study the vortex phase transitions in $YBa_2Cu_3O_{7-\delta}$ high Tc superconductors. The measurements were performed for a high external magnetic field so that the vortices will be densely packed in order to manifest a collective behavior. Our sample is carrying a dc transport current of 1nA. The important findings in this article are: (1) an excess noise is registered for three values of frequency (2) the results of the voltage noise power spectral density show a three signatures of the vortex matter transitions. (3) The exponent α was found to be depending on the external magnetic field.

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1. Introduction

The scientists have paid a lot of attention to the dynamic of the vortices in order to comprehend to mixed state of a HTc superconductors. Since the discovery of those materials in 1986, their investigation becomes the centre of interest of several works. The experimental [2,3,4], theoretical [5,6] investigations show that the vortex matter exhibits diverse properties and a various phase transitions in the mixed state.

It is obvious that whenever a HTc superconductor carries a transport current, the vortices are induced to move along the sample. Thus, a flux flow dissipation mechanism is generated in the superconductor. The study of this mechanism is very important to understand how to avoid, as much as possible, the dissipation in superconductors. One of the most useful tools to investigate the dynamic of vortices in type II superconductors is the voltage noise measurements. Van gurp and Von Ooijen were the first researchers to use this technique for this purpose [7].

In high Tc superconductors, as they are known to be very pure materials, the phase transitions of the vortex matter transitions can be described from the measurements of the voltage noise as well as from the magnetic filed measurements [3]. The phase transitions of the vortices can be exhibited as an excess of noise in the curves of the power spectral density $S_V(f)$. In the works of many authors, one or two peaks were detected in the voltage noise measurements. For instance, Scola and al. [8] in his works found that the voltage noise dependence on frequency exhibits multiple peaks. He interpreted the presence of such multiple peaks by multiple phase transition in the vortex lattice.

In our case, the results found for the $YBa_2Cu_3O_{7-\delta}$ high Tc superconductor show the existence of three peaks in the power spectral density $S_V(f)$ curves at three different frequencies. For every peak, an excess noise in observed and thus for the interpretation of those results, we agree with J. Scola in his thoughts and conjecture that three phase transitions occurred for every single frequency. Therefore the presence of the peaks in the noise measurements is obviously noisy signatures of phase transitions.

2. Experiments

The thin film of single crystal $YBa_2Cu_3O_{7-\delta}$ studied was developed in the laboratory of Siemens in Germany by the research group of Professor Roas. C-axis oriented epitaxial $YBa_2Cu_3O_{7-\delta}$ films with a thickness of 400 nm, and a width of 7.53 (figure 1) µm are deposited by the laser ablation method on the surface (100) of $SrTiO_3$ substrate. The resistance vanished, in zero magnetic field, at $T_c=90\ K$.

Electrodes of measurement are in gold and deposited on the surface of the sample in situ by evaporation. The distance between electrodes of power measurement is 135 µm. Contact resistances were less than 1Ω. A direct current, perpendicular to the magnetic field, is applied on edges of the sample. The sample central region voltage signal goes through a low-noise transformer of report n = 100, then in a preamplifier of gain equal to 100 and finally in a RC filter (figure 2). The signal is visualized on a programmable oscilloscope then recorded and analyzed by computer [10].

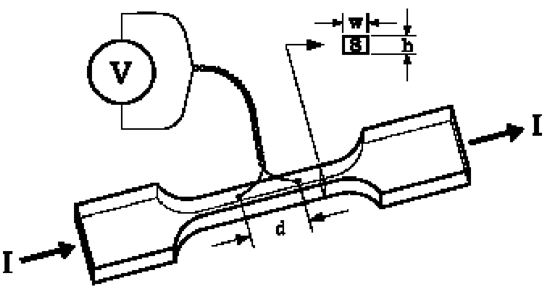

Fig. 1. Schematic representation of the sample with the electrical contacts of transport measurements d =135 µm, h=400 nm, w=7.53 µm.

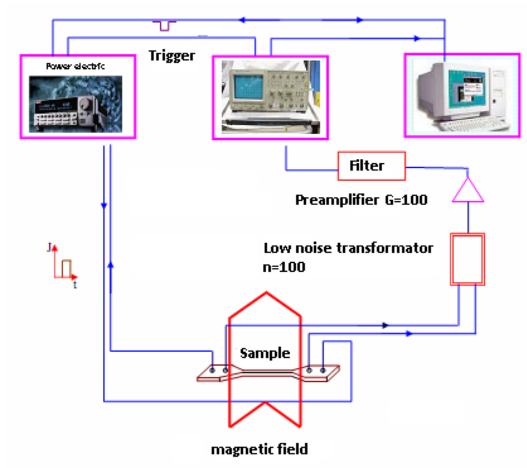

Fig. 2: Schematic diagram of transport measures to pulsed current.

3. Results and discussions

The voltage noise measurements of the $YBa_2Cu_3O_{7-\delta}$ HTc superconductor were performed for a range of temperature that comprises between 78K and 90K. The sample undergoes an external magnetic field of 2.4T, 5T and 14T parallel to *ab* plan, and carries a transport current of 1nA.

3.1 The power spectral density $S_V(f)$ in $YBa_2Cu_3O_{7-\delta}$ HTc superconductor

In the Fig. 3, we present an example of the voltage noise power spectral density $S_V(\boldsymbol{f})$ as a function of frequency for an external magnetic field of 5T parallel to *ab* plan, and carries a transport current of 1nA, the value of temperature is 86K which belongs to the mixed state of the sample.

In this curve, one can conclude that the power spectral density $S_V(f)$ exhibits at high frequencies a $1/f^{\alpha}$ behavior, where α is the exponent that was calculated using the Lorentzienne shape $A[(1+\pi f/f_0)^B]^C$.

The values of α ($\alpha= -B\times C$) were determined for three values of the external magnetic field 2.4T, 5T and 14T. The figure 4 shows the variation of the exponent α versus the temperature.

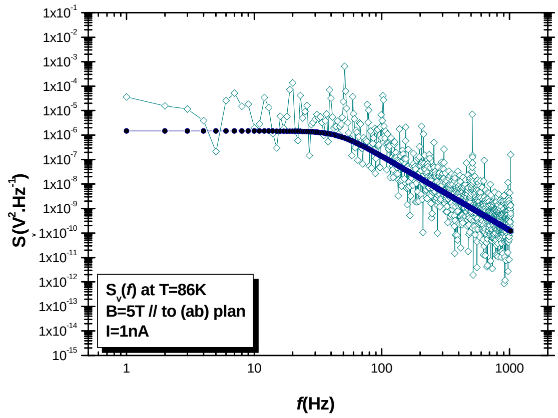

Fig. 3. (◇) curve of the power spectral density $S_V(f)$ of the $YBa_2Cu_3O_{7-\delta}$ HTc superconductor and (o) the curve of the fit with the Lorentzienne shape $A[(1+\pi f/f_0)^B]^C$. the external magnetic field is 5T parallel to ab plan and the transport current is 1nA.

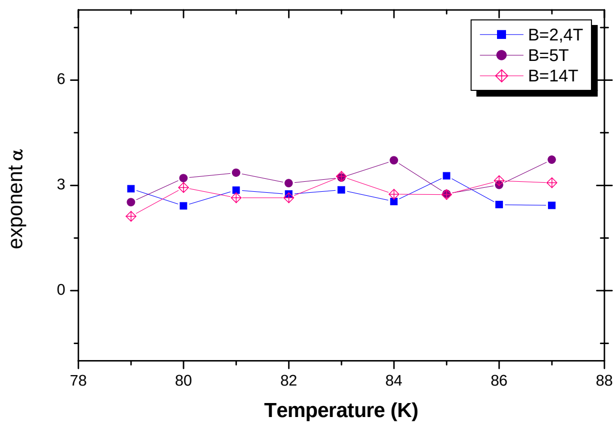

Fig. 4. variation of the exponent α versus temperature for three values of the external magnetic field 2.4T, 5T and 14T parallel to ab plan and the transport current is 1nA.

Some recent works prove that this parameter exhibits a strong correlation with the external magnetic field. In fact, α in $NbSe_2$ samples [11,12] et MgB_2 samples [13] increases when the magnetic field increases. In the case of our materials, one can conclude that this parameter varies from 2.4 to 3.6 when the magnetic field varies from 2.4T to 5T. However, continuing to increase the external magnetic field till 15T leads to decreasing of α to 2.8.

The mean value of the determined exponent for a large range of temperature (78 to 88) and for the three mentioned values of the external magnetic field leads to the value 3.1.

Paltiel et al. [13] found in this researches a value of 4, while Eggenhöffner et *al*. obtained α comprised between 1 and 2 [13].

Scola and al. determined that this exponent varies from 2 and 4.5 [9]. For several other works this parameter is calculated to be fairly equal to 2 [14,15].

3.2 The possible origins of the noise in the $YBa_2Cu_3O_{7-\delta}$ HTc superconductor

In is true that this kind of noise is common to many electronic devices such as resistors, amplifiers, semiconductors…. However, in the case of superconductors, the noise observed was found to be greater than any other noisy system. The researchers of the superconductivity domain had then made a lot of efforts to understand and get access to the mechanism responsible of the excess noise in those new materials.

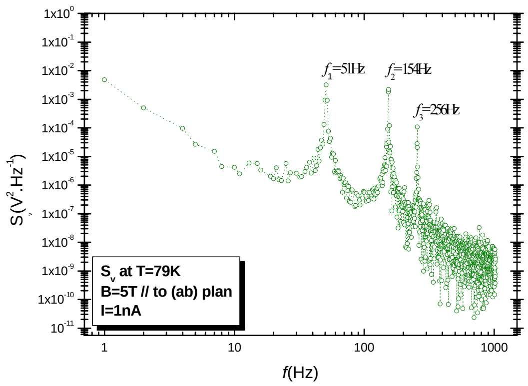

Fig. 5. curve in log-log scale of the power spectral density $S_V(f)$ of the $YBa_2Cu_3O_{7-\delta}$ HTc superconductor showing the existence of three peaks as a phase transitions in the vortex matter. The external magnetic field is 5T parallel to ab plan and the transport current is 1nA.

For this purpose, three possible sources of noise in the superconductors materials are conjectured:

- The first possible source is the thermal fluctuations [16]. However, the calculated noise basing on the thermal model was smaller than the experimental results obtained for superconductors in the mixed state;
- The second possible source is the vortices fluctuations being in the mixed state [17]. This second source in considered to be the most important one nevertheless there is no theoretical evidence to link it to the experimental results;
- The third possible source of the 1/f is the magnetic fluctuations [18,19], but according to some authors [16] the fluctuations of the magnetic field are just a consequence of the voltage noise since the voltage is related to the magnetic filed by the famous Maxwell equations.

Some experimental results emphasis the second source to be the predominant source of noise in superconductors. In fact, in some seldom cases, the power spectral density of the voltage noise $S_V(f)$ shows a certain number of peaks that separate two power laws. In our measurements, such behavior was observed in the case of $YBa_2Cu_3O_{7-\delta}$ HTc superconductor. The figure 5 above presents an example of those special curves.

The existence of two power law at the same curve is a consequence of phase transitions of the vortex matter, and thus, the noise registered in the superconducting materials is directly related to the vortices of the mixed state. One should note that the logarithmic scale reduces the importance of the excess noise at the frequencies where transitions occurred. In order to show the magnitude of the noise in $YBa_2Cu_3O_{7-\delta}$ HTc superconductor, the same curve of the Fig. 5 is plotted below in the figure 6 in a normal scale.

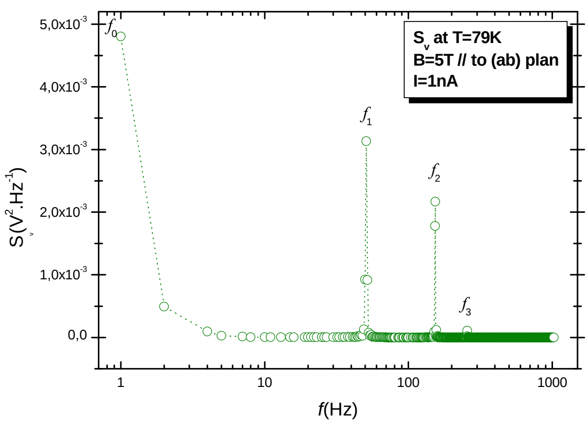

Fig. 6 curve in normal scale of the power spectral density $S_V(f)$ of the $YBa_2Cu_3O_{7-\delta}$ HTc superconductor showing the existence of three peaks as a phase transitions in the vortex matter. The external magnetic field is 5T parallel to ab plan and the transport current is 1nA.

The Fig. 6 shows also a net peak around the frequency f_0, in which the noise exhibits a very large magnitude. Unfortunately, in the literature we couldn't find any interpretation about the existence of such low frequency peak.

4. Conclusion

In this paper a voltage noise power spectral density was studied for the YBCO HTc superconductor. Those materials exhibits a $1/f^{\alpha}$ noise with α exponent strongly related to the magnetic field. The shape of the noise in our sample is common to many electronic systems even though the noise in those systems is found to be very smaller compared with that of superconductors. The major source of the noise in our sample is supposed to be the vortex fluctuations in the mixed state. Some of the obtained measurements of the power spectral density show a signature of phase transition in vortex matter. At the frequency where the signature occurred, an excess of noise is noticed and thus a peak is registered.

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