Magnetic Field Dependent Critical Temperature of $YBa_2Cu_3O_{7-x}$ Superconductor

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Resistance measurements for non-optimally doped $YBa_2Cu_3O_{7-x}$ were taken in a randomly oriented orthonormal applied magnetic field range of 0 T to 4 T using a Physical Properties Measurement System. At each step increase of the magnetic field, the machine down stepped the temperature from 105 K all the way down to 65 K. Normalized resistance graphs were obtained using Igor Pro. From the graphs, the critical temperature range was analyzed to be about 80 K to 90 K for this magnetic field range. The critical temperature range determines what refrigerant is needed to transition the material into a superconducting state. This range shows that $YBa_2Cu_3O_{7-x}$ can be cooled with the less expensive liquid nitrogen method, rather than liquid hydrogen or helium even under all natural earthly magnetic interference and common man made causes of magnetic interference.

I. INTRODUCTION

The current U.S. power grid generates 4.061 petawatts of power [3]. Roughly 6 % to 8 % of this power is lost using conventional transmission lines. Most of this loss is due to the electron resistance of the conductive material in the power lines. High temperature superconductors (HTS) experience zero DC electron-electron scattering and do not use electrons to carry entropy below a critical temperature (T_c). Many HTS including $YBa_2Cu_3O_{7-x}$ have a critical temperature above the boiling point of liquid nitrogen making it a feasible material to replace current transmission lines by coating tape with the YBCO material [4].

Transmission lines are often bombarded with arbitrary magnetic interference. This interference can lower the critical temperature. Possibly below the boiling point of liquid nitrogen. The Physical Properties Measurement System (PPMS) performs resistance measurements at varying temperatures and magnetic field strengths to determine the materials range of critical temperatures.

II. THEORY

HTS have transition temperatures above 30 K, 93 K for optimally doped zero field cooled $YBa_2Cu_3O_{7-x}$ [7]. Below these critical temperatures, a bound cooper paired state of the electrons have a lower energy than the Fermi energy. For $YBa_2Cu_3O_{7-x}$, these cooper pairs flow across the Copper(II) Hyposulfite layer or ab plane [9]. Cooper pairing is backed up by claims that the fundamental charge of the charge carriers for the superconductive state is twice that of an electron [5]. This attraction between electrons was thought to be due to electron-phonon interaction mechanisms similar to conventional superconductors, but may be caused by genuine electronic mechanisms instead [8]. Further indicating that the BCS theory, which explains traditional superconductors, fails to explain modern and post-modern superconductors.

Even though there is no adequate theory to explain these superconductors, rigorous experimental analysis will be able to help elucidate characteristics of specific families of HTS and generalized relationships between all superconductors. A key relationship is that HTS below its critical temperature expend a certain amount of energy to form a screening current to cancel any external field attempting to penetrate the interior of the specimen. Between a low and high critical field it is energetically advantageous for the condensed matter to allow a small amount of magnetic flux to penetrate, typically on the order of 100 nm [10]. Above the high critical field magnitude it is energetically advantageous for the matter to revert back into its normal state and allow full penetration by the magnetic field. There is a clear relationship between the critical field and the critical temperature, and therefore that the critical field depends on the temperature of the substance and that the critical temperature depends on the superposition of any external magnetic fields.

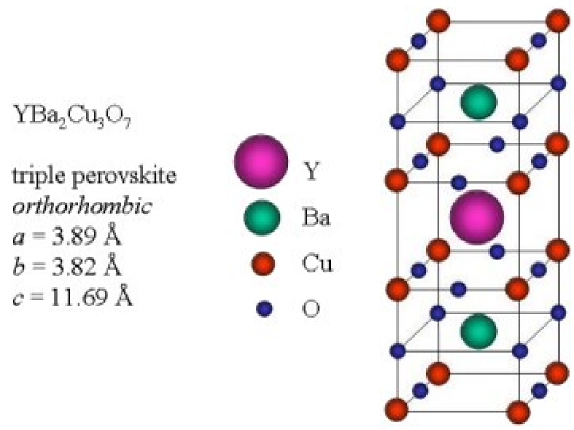

FIG. 1: Crystal Structure of $YBa_2Cu_3O_{7-x}$

III. EXPERIMENT

A 1 cm diameter $YBa_2Cu_3O_{7-x}$ conductor disk was obtained from Colorado Superconductor, Inc. The disk was split in half using cutting pliers. The thickness of the sample is about 8 mm. The sample was mounted to the resistivity puck of the PPMS, wire contacts were attached between the sample and puck using indium, and the sample was inserted into the sample chamber. Quantum Design Physical Properties Measurement System (PPMS) and 6000 Microprocessor performed resistance measurements at 100.000μA excitation currents. Resistance measurements were taken at an applied magnetic field range of 0 T to 1 T in 11 steps, then 1 T to 4 T in 4 steps. At each step of the applied field, the temperature ranged from 105 K to 65 K in 80 steps. The MultiVu software created the data file and Igor Pro analyzed and graphed the data.

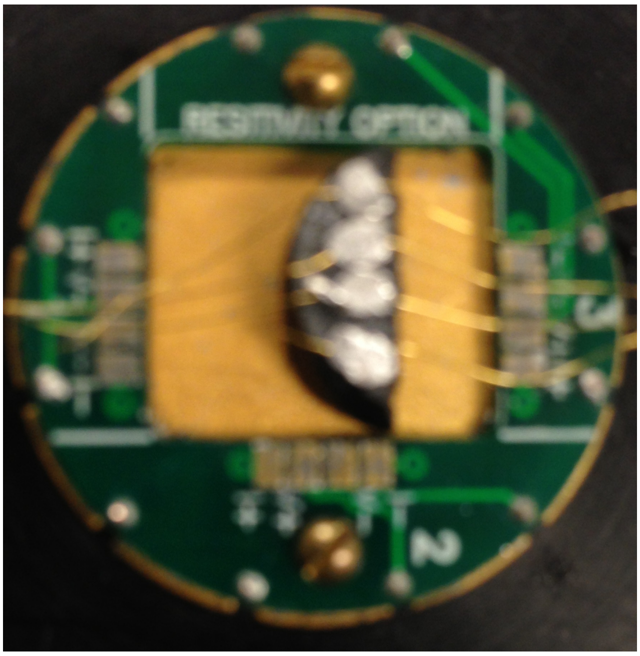

FIG. 2: $YBa_2Cu_3O_{7-x}$ sample mounted to the PPMS resistivity puck

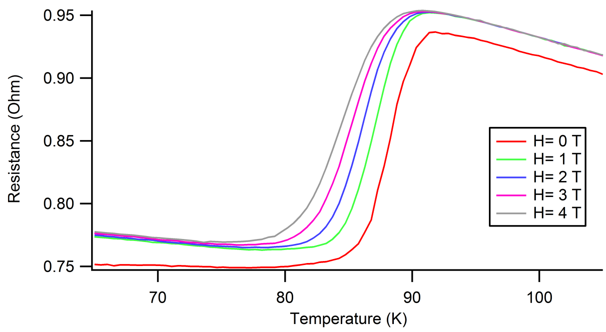

FIG. 3: Resistance taken at H=0, 1, 2, 3, and 4 T with H arbitrarily oriented either along or perpendicular to the ab plane of the $YBa_2Cu_3O_{7-x}$ lattice structure

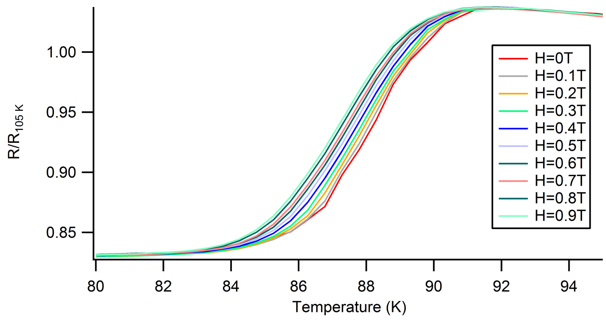

FIG. 4: R/R_{300} taken at H=0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 T with H arbitrarily oriented either along or perpendicular to the ab plane of the $YBa_2Cu_3O_{7-x}$ crystal structure.

IV. RESULTS

The resistance data for the cuprate at varying applied fields are represented in Fig. 3. The R/R_{300} data for the cuprate at varying applied magnetic fields are represented in Fig. 4 and Fig. 5. The zero field cooled transition temperature is below 93 K indicating the sample is not optimally doped. Also, as the magnetic field increases the transition temperature decreases. The critical temperature never decreases below 80 K. Between 80 K to 90 K there is a sudden but not sharp transition to a new phase, the superconducting phase. Indicating the doping concentration is $x \leq 0.7$ [9]. However, the resistance never hits zero and is offset by some resistance dependent on the strength of the magnetic field. Above the critical temperature the sample experiences a rise in resistance with decreasing temperature independent of the applied field. Below the transition temperature the sample experiences the same increase in resistance with decreasing temperature, but the slope of this change varies between H=0 and 1 T and is too small to discern between the higher fields.

V. DISCUSSION

The transition temperature even for the 4 T field is well above the boiling point of liquid nitrogen. This is significantly higher than the realm of most natural earthly magnetic phenomena and common industrial phenomena [11]. It remains practical to transition the condensed matter to a lower resistance state. However the increase in resistance before and separately after the sample hits its critical temperature follows the relationship formed in semiconductors. This relationship is different from the $YBa_2Cu_3O_{7-x}$ conductor, which has a gradual decrease before the sharp and sudden drop in resistance as temperature lowers [7]. Additionally, the resistance at around 100 K is found to be two order of magnitudes higher than traditional $YBa_2Cu_3O_{7-x}$ doped for superconductivity [9]. However, $YBa_2Cu_3O_{7-x}$ compounds

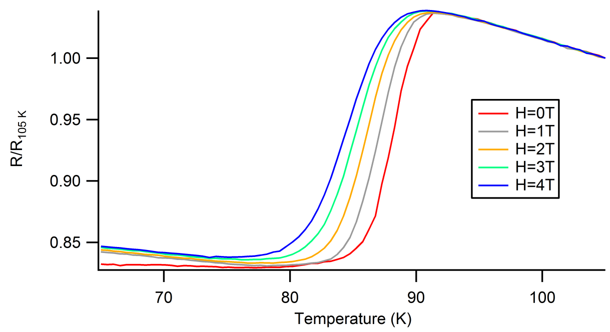

FIG. 5: R/R_{300} taken at H=0, 1, 2, 3, and 4 T with H arbitrarily oriented either along or perpendicular to the ab plane of the $YBa_2Cu_3O_{7-x}$ crystal structure.

doped to insulate do not experience a sudden drop in resistance as this sample does. This indicates that the offset resistance comes from an added layer, possibly a thin oxide skin layer deposited between the wire contacts of the resistivity puck and the wires. Since the oxide layer should have semiconductor properties, it is believed Indium(II) Oxide formed on the contacts of the puck. Indium(II) Oxide is a ferromagnetic material, so in the presence of a magnetic field it becomes magnetized and produces an induced magnetic field which acts upon the superconducting sample. Perhaps altering the critical temperature of the sample, but not by much since there is no noticeable slope change between 1 and 2 T. This indicates the Indium(II) Oxide has a saturation magnetization lower than 1 T. Additionally, the superconducting sample induces a magnetic field upon the Indium(II) Oxide. Ferromagnetic material have magnetoresistance increasing the resistance up to a field that saturates the magnetization of the oxide. This can be seen clearly from the jumps in the non-normalized resistance graphs between H=0 T and the higher fields. But, also in the pretransition temperature slope change between 0 and 1 T fields. The slope change is due to the superposition of the PPMS magnetic field and the induced magnetiic field of the superconducting sample on to the Iindium(II) Oxide layer. Above the transition temperature, the YBCO compound is antiferromagnetic at low temperatures when not superconducting and has a negligible magnetization [6]. The net magnetization from the YBCO is due to its orthorhombic crystal structure from oxygen doping. Since the magnetization is negligible the Indium(II) Oxide only experiences the field from the PPMS and a slope change is not observed in the normalized graph above the critical temperature. In the future, the resistivity puck must be cleansed with methanol and given time to dry after every attempt to attach a wire using Indium. This will provide more accurate T_c measurements.

Furthermore, these samples were bombarded with magnetic fields in one orthonormal direction to the samples lattice structure. In the real world, magnetic interference may hit the YBCO tape at any direction. But the largest impact is seen when the field is perpendicular to the ab plane, decreasing the upper critical field by more than half [9]. Analysis of the orientation of the YBCO structure must be done with diffraction experimentation or further test through varying the angle of the field to the sample must be made.

Testing between polycrystalline and single crystal samples will be beneficial to see how high a quality we need the YBCO material.

VI. CONCLUSION

The critical temperature for non-optimally doped $YBa_2Cu_3O_{7-x}$ across a range of 0 T to 4 T applied magnetic fields were acquired using a PPMS and analyzed using Igor Pro. The critical temperatures were found to be between 80 K and 90 K for a randomly oriented orthonormal field from 0 T to 4 T. The magnetic interference lowered the transition temperature, but never below the boiling point of liquid nitrogen. Future experimentation will involve, testing the quality of the sample and varying the angle of the incident fields to see if we can further save on production cost by utilizing lower grade YBCO material.

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