Cryogenic probe and apparatus for contactless measurement of transition characteristics of HT_c superconductors

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Abstract

Cryogenic probe and automatic apparatus for study of transition properties of HT_c superconductors was developed using the inductive measurement method. The superconducting sample is sandwiched between the primary and secondary coils. Transition of the sample into the superconducting state results to significant changes of mutual inductance and that way to the changes of the output voltage of secondary coil. Comparison of the results of the four point transport and the contactless inductive method of the measurement of transition curves of the $YBa_2Cu_3O_{7-\delta}$-(Sc) samples is presented. It is shown, that these two methods can lead to consistent or complementary results in T_c measurements. It depends on such characteristics of HT_c compounds as are composition, content of superconducting phase or homogenity.

1. Introduction

The transition of the HT_c material sample from the normal state to the superconducting state is accompanied with a "jump" change of several physical quantities values. A study of the transition processes contributes new information on superconductivity.

The standard method of determination of the superconductor critical temperature T_c comprises a conventional four point technique of measurement of R vs. T dependency, where R is the electrical resistivity and T is the temperature of the sample. This method requires a making of electrical contacts on the sample surface by soldering, vacuum deposition, pressuring etc. Generally, contacting is a large disadvantage of this technique. Various detailed aspects of this problem are analysed in [1]. In some cases, the electrical contacting can cause a change of the chemical properties of the samples, mainly in the vicinity of the electrodes. It is significant particularly for the thin film superconducting samples.

Several contacless measuring methods using the change of the self inductance, of a coil located in the vicinity of measured sample [2] or the change of mutual inductance of two coils separated by the sample have been developed [3, 4]. The automatic laboratory apparatus for measurement of transition characteristics HT_c superconductors, which is described in the paper, uses mutual inductance method based on the Meissner-Ochsenfeld effect, expelling the magnetic field from the interior of the bulk superconductor in the superconducting state, even if the magnetic field was already within the sample before cooling.

We compared the results of measurement of transition dependencies of the induced voltage and resistivity voltage vs. temperature in melt textured samples $YBa_2Cu_3O_{7-\delta}$ and $YBa_2Cu_{3-x}Sc_xO_{7-\delta}$ prepared by standard techniques.

2. Apparatus description

2.1 The cryogenic probe design

The cryogenic probe design with sample, coils and temperature sensor is in Figure 1.

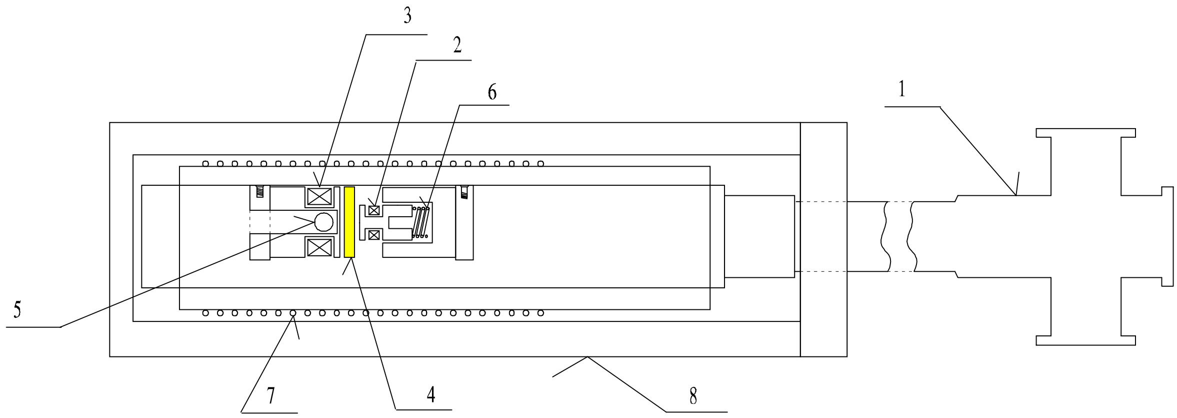

Fig.1. Schematic view of cryogenic probe design. (1) stainless cryogenic hinge with cable connectors; (2) primary coil; (3) secondary coil; (4) the sample; (5) temperature sensor; (6) phosphorus-bronze spiral for pressing the coils to the sample; (7) heating wire spiral; (8) housing.

The sample is sandwiched between the coils. The phosphorus-bronze spiral presses the coils and sample together to provide a good mutual magnetic coupling. The temperature (silicon diode) sensor is inserted into a hole in the coil holder. The sample's temperature control is made with the help of the power control of heating spiral. The probe with the primary and secondary coils, the sample, the temperature sensor and the heating wire are closed in thermaly isolated and placed in the inner atmosphere housing. The probe is immersed in the liquid Nitrogen.

2.2. The measuring apparatus

The measuring apparatus consists of the cryogenic probe, the source of the AC current, the electronically controlled power source, the electronic switch, the digital voltmeter and PC, see Figure 2.

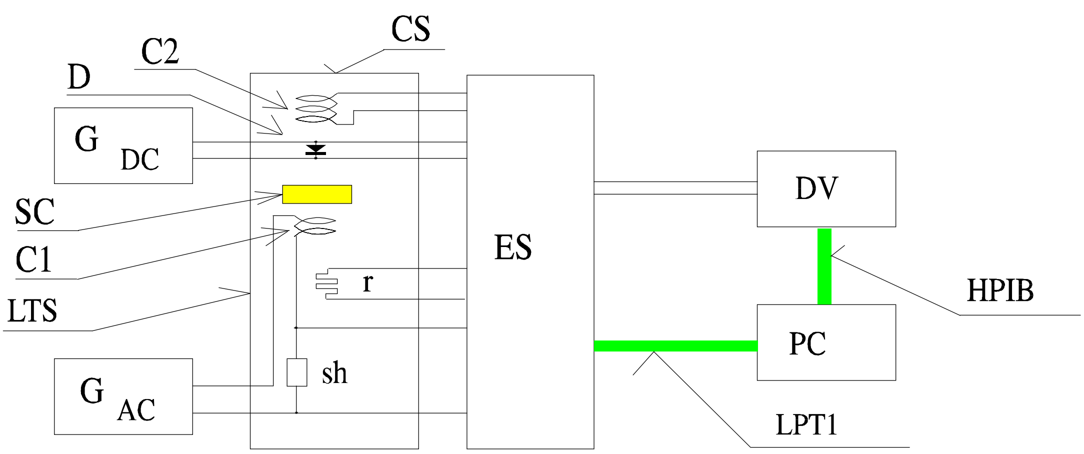

Fig. 2. Schematic view of the apparatus for measurement of the transition characteristics. (G_{DC}) The current source for the temperature sensor driving, (G_{AC}) the AC current source for the primary coil driving, (CS) the cryogenic probe, (D) the temperature sensor, (SC) the superconducting sample, (C2) the secondary coil, (C1) the primary coil, (r) the heating resistor, (sh) the shunt for measuring the primary coil current, (ES) the electronic switch and heating source, (PC) the personal computer, (DV) the digital voltmeter with GPIB bus.

The software function allows to connect the voltmeter terminal with the terminal of the temperature sensor, with the secondary coil and the shunt using the electronic switch (ES). The comparison of measured and calculated values with the specified limit levels initiates the selection of the appropriate subprogram, e.g. the data recording, the control of the electrical heating of wire spiral and etc. The digital voltmeter SOLATRON SCHLUMBERGER 7081 was used for measurement of the voltage. The communication between PC and the voltmeter is performed by GPIB bus via Quick Basic program.

3. Results and discussion

The transition characteristics of the sintered or melt textured samples $YBa_2Cu_3O_{7-\delta}$ and $YBa_2Cu_{3-x}Sc_xO_{7-\delta}$ are shown in Figures 3 and 4. Dependencies of the electrical resistance *R* vs. the temperature *T* (measured by the standard four point transport technique) and also the induced voltage U^* vs. *T* (measured by the mutual inductance method) using our apparatus are shown in Fig. 3. The values of *R* and *U** are normalised on corresponding values of R_0 and U_0 at 200 K. In Fig. 3 the normalised U/U_0 vs. *T* dependence of single cryogenic probe is shown. The * symbol is used for quantities corrected by the effect of *U* vs. *T* dependence of single cryogenic probe.

The critical temperature can by used for a comparison of two methods. Using the standard criterion for determination of T_c value, we obtained $T_c(R=0)$ = 91.7 K by the transport method and T_c(onset) = 91.4 K by the inductive method. This can be considerd as good agreement (for the homogeneous superconducting samples). It is in the range of estimated error of measured temperature (~0.5 K). However, in the case of significant difference between the surface and the volume (or intergrain and intragrain) superconducting properties of the samples, the inductive criterion T_c(onset) used for estimation of $T_c(R=0)$ fails**.** As an example, we show normalised (R/R_0)-*T* and (U/U_0)-*T* transition curves for the sample $YBa_2Cu_{2.75}Sc_{0.15}O_{7-\delta}$ in Fig. 4. The substitution of Sc^{3+} for Cu^{2+} results in materials with paramagnetic phases and with low content of superconducting phase, as was determined by the diffraction and EPR methods [5]. In this case T_c(onset) = 78.2 K and $T_c(R=0)$ = 86.2 K**.**

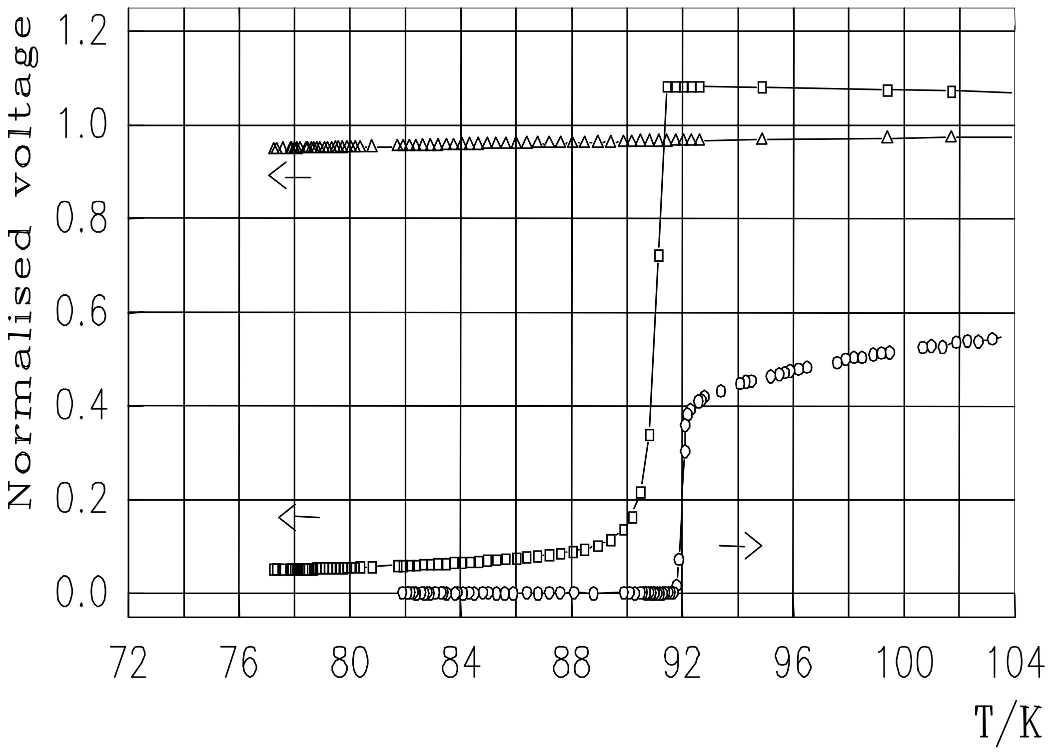

Fig. 3. Normalised R/R_0 vs. *T* dependence(o) measured by the four point transport method and U^*/U_0^* vs. *T* dependence ( ) of the melt textured sample $YBa_2Cu_3O_{7-\delta}$. U/U_0 vs. *T* of the alone cryogenic probe without the sample is denoted by (Δ). The symbol * designates the corrected (on the effect of single probe) quantities of U/U_0.

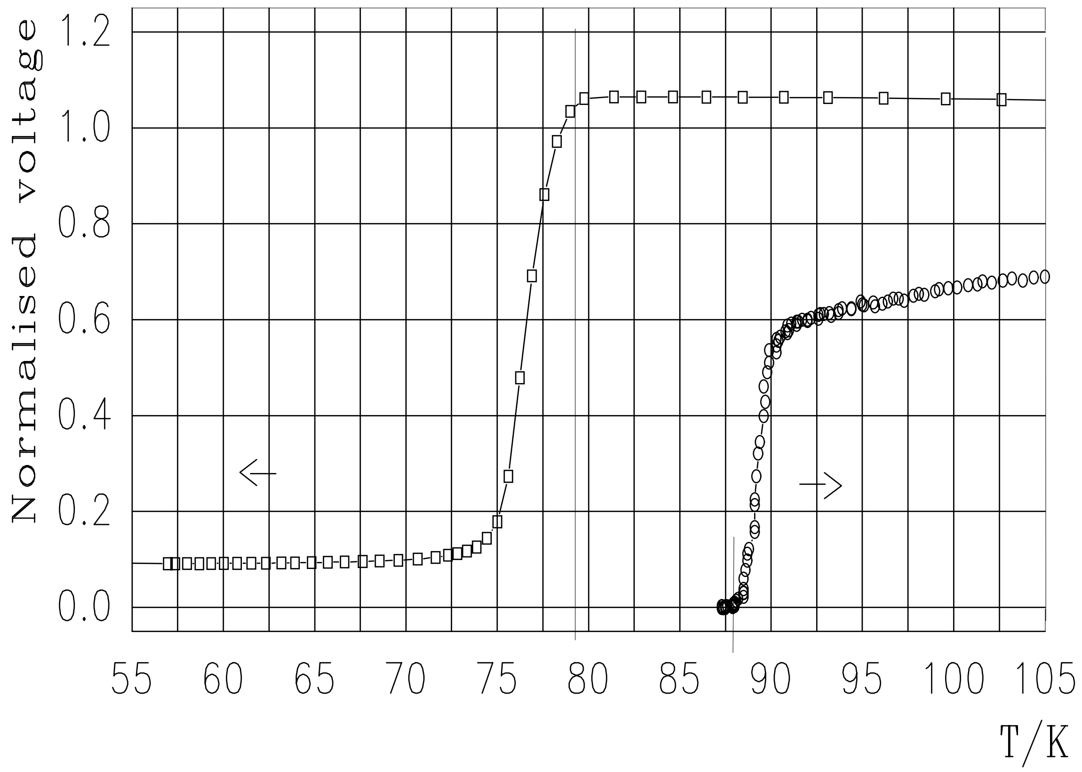

Fig. 4. Normalised R/R_0 vs. T dependence (o) measured by the four point transport method and U/U_0 vs. T dependence ( ) of the sintered sample $YBa_2Cu_{2.75}Sc_{0.15}O_{7-\delta}$ with a low content of the superconducting phase.

Conclusions

We presented the apparatus for measuring of the transition characteristics of HTc superconductors by the inductive method. The temperature of sample is determined by means of the control of energy balance between moderate electrical heating and moderate cooling by liquid Nitrogen without the moving the sample in the cryostat. The accuracy of the determination of the transition parameters is significantly affected by the rate of temperature change. In our measuring system this can be kept on required value by the electronically controlled energy balance.

Acknowledgements

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References

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