Automated Setup for Van Der Pauw Hall Measurements

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Abstract—An automated setup for measuring electronic transport properties, i.e., the Hall coefficient and resistivity versus temperature, was developed for noninvasive characterization of different types of samples with a square shape. This setup allows characterization of thin-film samples without modifications of their shape or patterning on their surface, thus allowing further tests or practical applications. Measurements are based on the Van der Pauw method and the lock-in amplifier technique, which allow achieving quality measurements in highly noisy environments, as is the case for ceramic materials in variable temperatures. Measurements can be made in the range of temperatures from 7 up to 320 K and dc magnetic fields from 0 to 1 T. A detailed description of the setup and the discussion of the methodology of measurements are presented. This setup presents important advantages in comparison with the black-box system that is found in sophisticated equipment. Its modularity makes it transparent for a user, which is a feature that allows an operator to easily check, replace, adapt, and update parts of the system. The system has been optimized for characterization of superconducting samples. As a test of the system performance, we present measurements on Ag films and superconducting samples showing good-quality data, even for the most overdoped samples, for which we have the smallest Hall voltages.

Index Terms—Hall effect, instrumentation, lock-in amplifier, superconductors, thin films, transport properties, Van der Pauw method.

I. INTRODUCTION

Electronic transport measurements are, perhaps, the most useful and straightforward method for characterizing different conducting materials such as metals, semiconductors, and superconductors. In particular, temperature dependence of transport coefficients is of fundamental importance in the study of thermodynamical properties and transport mechanisms that help understand the physics of charge carriers. Although electronic transport measurements are, in principle, not complicated, much care has to be taken in the instrumentation to achieve enough sensitivity to detect tiny signals that are associated with some of these properties. In particular, Hall measurements in metals and overdoped superconductors require special care due to low-level voltages induced, typically in the microvolt range. On the other hand, great care has to be taken when making contacts to the sample to obtain stable and clean signals. Due to the sensitivity of Hall contacts to electromagnetic, thermal, and mechanical noise, the use of a dc measurement technique is inadequate in measurements of metals and highly doped superconductors for the sample’s currents below 100 mA. Henceforth, we decided to use the lock-in amplifier technique due to its capability of measuring tiny signals that are immersed in a large noise background [1]. In general, Hall measurements can be performed at low magnetic fields, i.e., below 1 T, which is enough to study carrier density and its temperature dependence.

Measurement of two basic electronic transport properties, i.e., ohmic resistivity $\rho_{xx}$ and Hall resistivity $\rho_{xy}$, allows computation of the most relevant transport parameters [2]–[4]: Hall coefficient $R_H = \rho_{xy}B$, Hall angle $\theta_H = \arctan(\rho_{xy}/\rho_{xx})$, mobility $\mu = (\rho_{xy}/\rho_{xx})B$ (for a single type of carriers), carrier density $n = 1/\epsilon R_H$, and carrier type (electrons or holes), where $B$ is the magnetic induction, and $\epsilon$ is the electron charge. When these parameters are measured as a function of temperature and magnetic field, they provide important information about the underlying physics of the system. A thorough discussion about the physics of the Hall effect in metals and alloys is found in [4].

Study of these parameters requires quality measurements with good temperature stability and control. Full automation of the system is required due to the long time taken by a sweep from room temperature down to a few degrees Kelvin. To seize the importance of the instrumentation techniques that are proposed for the present setup, it is necessary to realize the difficulties that are associated with the measurements of physical parameters at different temperatures. In this type of measurements, several temperature-dependent noise sources exist with more complex behaviors than those found in measurements at a fixed temperature. Therefore, a careful design of the measurement system is fundamental. In the following, we provide full details about the experimental setup and discuss the measurement methodology. The Van der Pauw measurement method was chosen instead of the more popular and easier-to-implement six-contact bridge. The main reason for this choice was the requirement of not modifying the shape of samples or making any pattern on its surface. This is due to the fact that a certain type of samples such as high-Tc superconducting films cannot be patterned without the risk of modifying some of their physical properties. For instance, they can suffer a certain
degree of chemical attack during chemical etching, or they can be exposed to heating in the case of photolithography. In both cases, changes in oxygen content with a consequent change in carrier doping may occur. In particular, we wanted to preserve the sample size and geometry to make further tests to our samples. A detailed discussion of the adequate methodology for resistivity and Hall coefficient measurements is found in [5] and [6].

A last comment about our measuring system is the justification for developing a new setup given the already existing compact multipurpose measurement systems that are commercially available that can measure several physical properties. The reason is that, in addition to its high prices, the problem with the equipment arises when the user wants to check the system to solve any failure, customize the system for specific measurements, or improve the system somehow. At that moment, the expensive machine is a black box that cannot be understood from inside, thus preventing the user from making any of these activities. The best choice for an experimentalist that wants to be confident and to interact closely with his measurement system is to build a modular setup that he can understand, fix, or update part by part easily.

This paper is organized as follows: In Section II, we present the experimental aspects, beginning (Section II-A) with a brief review of the Van der Pauw method and the basic definitions for square samples. Sections II-B and C respectively present details about resistivity and Hall coefficient measurements. Section II-D contains a short description of the lock-in amplifier technique and how it is applied in the present setup. In Section II-E, we present details on a homemade current supply for feeding the sample. In Section II-F, the complete assembly of the experimental setup is presented. Section II-G discusses the measurement methodology. Section III presents some measurements: comparative results for Hall voltage versus magnetic field for Ag thin films with the standard six-leg dc technique and the Van der Pauw method plus the lock-in technique. Then, we present measurements of the resistivity and the Hall coefficient in superconducting YBCO samples. Finally, Section IV contains the conclusions. Appendices A and B respectively contain details about the methodology of measurements of the resistivity and the Hall coefficient. Appendix C presents a detailed list of instruments in the setup. Appendix D presents the technical specifications of the measurement system.

II. EXPERIMENTAL

A. Van der Pauw Method

Van der Pauw [7] presented an elegant mathematical demonstration of a method for measuring the resistivity and the Hall coefficient in semiconducting samples of an arbitrary shape. His method consists of making four contacts at the edge of the sample, located at arbitrary distances around its periphery. By commuting them for sending current and measuring voltages in different configurations, he was able to compute Hall and ohmic resistivities. A general discussion of measurement methodology for different geometries can be found in [5] and [6]. In this paper, we specialize the Van der Pauw method to the case of square samples. The definition of contact positions and numbering is indicated in Fig. 1(b), where \( B \) is the magnetic induction that is perpendicular to the plane of the sample, with positive polarity going out of the sheet. To eliminate magnetoresistance contributions, each measurement is made twice with opposite polarities of the magnetic field and then subtracted. Reversing the polarity of the current flowing through the sample allows the removal of offset and thermoelectrical voltages. The advantage of using the lock-in technique is twofold: in addition to its remarkable property of noise removal, at the same time, the polarity of the sample’s current alternates without the need of commuting the corresponding electrical contacts. To get the different configurations of contacts for the current supply and voltage measurement required by the Van der Pauw method, a switch matrix device was used, as detailed in Appendix C.

B. Resistivity

Fig. 1(a) illustrates one configuration for resistivity measurements. A second configuration used is obtained by rotating the contacts by 90°, as indicated in Appendix A.

Bulk ohmic resistivity of the sample, which we will call, hereafter, simply as \( \rho \), disregarding the \( xx \) subindex that is mentioned in Section I, can be obtained by inverting the Van der Pauw equation, i.e.,

\[
e^{-\pi t R_A/\rho} + e^{-\pi t R_B/\rho} = 1
\]

where \( R_A \) and \( R_B \) are the two side resistances, as defined in Appendix A, and \( t \) is the sample’s thickness. The numerical solution of this equation is provided by a subroutine in the measurement software (LabView). This way, we get a value of \( \rho \) for each set of resistance measurements.

C. Hall Coefficient Measurement

Fig. 1(b) illustrates one configuration for Hall measurements. A second configuration used is obtained by exchanging current and voltage contacts. With the magnetic field switched on, the current is applied along one diagonal, while the voltage is
measured along the other diagonal. Then, the magnetic field’s polarity is inverted, and a second measurement is made. The same procedure is followed for the second configuration of connections, as explained in Appendix B.

The Hall coefficient is given by

$$R_H = \frac{t V_H}{B I}$$

(2)

where $V_H$ is the averaged Hall voltage as computed in Appendix B, and $I$ is the magnitude of the applied current. Both $V_H$ and $I$ are RMS values.

### D. Lock-in Amplifier Technique

The synchronous detection principle is applied in a lock-in amplifier to track an ac signal and extract it from a noisy background [1]. This technique allows measurement of tiny voltage signals in the range of nanovolts without difficulty. The only condition is that the sample excitation be an ac signal at a stable and accurate frequency. We can stimulate the sample either by sending an ac current and a transverse dc magnetic field or, on the contrary, by applying a dc current and a transverse ac magnetic field. In the present case, due to the strength of magnetic fields required and the inductance of 1-T electromagnets or superconducting coils, it is preferable to use the first scheme, i.e., an ac current and a dc magnetic field. The operating frequency has to be chosen such that it is not a harmonic or a subharmonic of the electrical network frequency. It is also important that the frequency should be not too high to avoid inductive effects in the wires connecting the sample and eddy currents in metallic sample holders, which are usually made of copper. An additional point that has to be taken into account is the possible frequency dependence of the properties that will be measured. In particular, in superconducting films, it is well known that magnetic susceptibility and flux-flow resistivity depend on the frequency [8], [9]. We chose a frequency of 1 Hz, which produces large-enough signals in typical superconductive samples and fulfills the above conditions. A very useful feature that is found in modern digital lock-in amplifiers is the zeroing function. This function enables the removal of the annoying and unavoidable residual ohmic voltage appearing in Hall measurements due mainly to contact misalignment. This function is of great help because the offset may be of the order of millivolts, whereas Hall voltages may lie in the microvolt range (in metals and superconductors). If the offset voltage is not removed before the amplification of the signal, it would saturate the amplifiers before the Hall voltage can be raised to an acceptable level.

### E. Current Source

Supplying a stable and constant ac current to the sample requires a current supply with certain characteristics. In metallic or superconducting samples, the load resistance is lower than 1 $\Omega$ and, at low temperatures, can practically become zero. The level of current that is needed to achieve a good resolution can be as high as 1 A (RMS), which is a value that is out of range in most electronic current supplies. In addition, it is required that the ac be in phase with the synchronization signal from the lock-in amplifier or from a signal generator. To fulfill these requirements, we have built a transconductance amplifier whose input is fed by the sine output of the lock-in amplifier. This device delivers a current to the sample that is proportional to the input voltage, which is independent of the load impedance. Fig. 2 shows the electronic scheme of this device.

Fig. 2. Electronic scheme of the transconductance amplifier and its power supply made to supply a constant ac to the sample synchronized with the sine output of the lock-in amplifier.

### F. Measurement Setup

Fig. 3 presents a scheme of the measurement setup. A detailed description of the instruments can be found in Appendix C, and technical specifications of the overall performance of the system can be found in Appendix D. Fig. 4 shows the details of the electrical connections to the sample for one configuration of the Hall coefficient measurement. Voltages are measured in a differential mode to avoid grounding the sample. The 1-$\Omega$ resistor, which is in series with the sample and the current supply, allows the measurement of the current flowing through the sample by means of the oscilloscope (due to the nonstandard frequency).

### G. Measurement Procedure

A crucial point during sample fabrication is contact preparation. Good-quality contacts are fundamental for Hall measurements. We have obtained good contacts by evaporating metallic pads in situ after sample growth. Conventional contacts that are made of silver paint or indium wire pressed onto the sample’s surface may work for resistance measurements, but not for Hall coefficient measurements. We have evaporated silver contacts of about 1-mm diameter on the sample’s corners. Gold pads are also a good choice because of lower oxidation. However, we choose silver pads because of compatibility with the silver paint that is used to bond copper wires to the sample.

Cooling down samples must be carried out at a slow rate to allow for thermal equilibrium between the different
Fig. 3. Schematic of the measurement setup. See Appendix C for details on the instruments.

Fig. 4. Illustration of current and voltage connections to the sample for Hall coefficient measurements. AC excitation is supplied by the transconductance amplifier, which converts the sine output signal of the lock-in amplifier to a regulated current. The 1-Ω resistor in series with the sample and current supply allows monitoring of the sample’s current on the oscilloscope. The sample’s voltage is measured in a differential way by the lock-in amplifier.

elements. Otherwise, thermoelectrical voltages, remaining gas turbulence, and temperature gradients may cause noisy and erratic instrument readings. A cooling rate of 0.03 K/s was found to be a good compromise. The measurement of the Hall voltage versus temperature requires some care due to the residual ohmic voltage already mentioned, which depends on temperature and, by an unknown mechanism, on magnetic field. A single measurement of the Hall voltage at a fixed magnetic field, for each temperature point, was found to be not enough, producing a curve $R_H(T)$ with important fluctuations. We have improved the quality of these measurements by making, for each temperature point, between five to ten measurements (depending on the sample and contact quality) at different values of the magnetic field, from $-1.0$ to $+1.0$ T. Then, from a linear fit, the slope gives the ratio $V_H/B$, which enters in the definition of $R_H$ [see (2)].

This measuring procedure requires much longer time but is an effective way of reducing intrinsic thermal fluctuations of the Hall coefficient and minimizes different errors, which depend, in a complex way, on temperature and the magnetic field.

III. MEASUREMENTS

A first test performed to check the functionality of this setup was a measurement of the Hall voltage in thin silver films. We prepared two square samples $1 \text{ cm} \times 1 \text{ cm} \times 100 \text{ nm}$ by thermal evaporation. One sample was patterned into a six-leg bridge, whereas the other was kept squared with four wires connected to the corners. In both cases, we used copper wires and silver paint. The six-leg bridge sample was measured with a dc current of 10 mA, whereas the square sample was measured with an ac current of 10 mA (RMS), with the Van der Pauw method and the lock-in technique. Fig. 5 presents the corresponding measurements of the Hall voltage versus the magnetic field at room temperature. A linear fit to both sets of data, from which we compute the Hall coefficient, gives the following errors for the slope: 2.2% for the bridge structure [Fig. 5(a)] and 0.33% for the square sample [Fig. 5(b)]. An improvement of almost one order of magnitude was obtained with the Van der Pauw method and the lock-in technique. Computed electron densities are $7.82 \times 10^{22} \text{ cm}^{-3}$ in the bridge sample and $1.0 \times 10^{23} \text{ cm}^{-3}$ in the square sample. These values are compatible with tabulated electron densities in Ag films, confirming a good calibration of the system.

Fig. 6 presents measurements of the Hall voltage versus the inverse temperature for high-Tc superconductor YBCO samples with different doping. The doping level is proportional to the index given in arbitrary units in the inset. These data show good linear dependence with small fluctuations. Errors in the slope that are computed from linear fits are smaller than 4%. This linear dependence is a well-known behavior of high-Tc superconductors.

Figs. 7 and 8 respectively present resistivity and Hall coefficient measurements for the same superconducting samples. In both figures, we can appreciate reliable low noise data with a smooth behavior. Such good-quality data are required for the analysis of transport phenomena to minimize error propagation in derived quantities that are obtained by numerical operations between these two sets of data, as mentioned in Section I. To discuss different models of superconductivity, we often require precise fits to these data [3], [10], [12], [14]. Such fits can be confidently carried out with data of present quality. If, on the contrary, our data had low quality, computed properties
Fig. 5. Hall voltage versus magnetic field for two Ag thin films at room temperature. (a) Six-leg bridge structure measured by the standard dc technique. (b) Square sample measured by the Van der Pauw method and the lock-in technique. The slope of fitted lines is used for computation of the Hall coefficient. Corresponding errors in fitted slopes are 2.2% for the bridge (a) and 0.33% for the square, showing an enhancement in precision of almost one order of magnitude by using the Van der Pauw method and the lock-in technique.

Fig. 6. Hall voltage versus inverse temperature for thin-film samples of the high-Tc superconductor YBCO, with different doping. Hole carrier doping is indicated by an arbitrary index ranging from 0.43 (underdoped) to 1.16 (overdoped). Good linear dependence, with small fluctuations, is observed even in the most overdoped sample (bottom curve). These results agree with measurements reported by other authors.

Fig. 7. Resistivity versus temperature for thin-film samples of the high-Tc superconductor YBCO, with different doping. The smooth curve with very small noise can be used for the analysis of the curvature and the derivative of resistivity, as necessary in the computation of transport coefficients.

Fig. 8. Hall coefficient versus temperature for thin-film samples of the high-Tc superconductor YBCO, with different doping. A limited amount of points was measured in each curve due to the long time taken by each measurement. Nevertheless, we obtain reliable data with very small noise that can be used for analysis of these curves, as required in the computation of transport coefficients.

$\rho_{xx/xy} = \rho_{xx} B/R_H$, as shown in Fig. 9. These data present a good linear behavior for all samples with different doping, as observed in high-Tc superconductors by several authors. An appropriate normalization of the data made all curves coalesce into a single line. Since the purpose of this report is not to study the physics of our measurements, we refer the interested reader to a discussion of these results presented elsewhere [3], [10].

A. Final Remarks

A point worth mentioning is that our setup is able to measure with no difficulty the overdoped YBCO samples, which contain large carrier densities, similar to metals, therefore presenting very low Hall voltages. In the literature of high-Tc superconductors, we usually find Hall measurements in underdoped samples, which contain carrier densities that are at least one order-of-magnitude higher than our overdoped samples. Most
Hall measurements that are reported for these materials are made with the standard method of six-leg bridge and dc current [11]. Some variations of this method can also be found, like the six-probe method and ac current [12], the Van der Pauw technique with square samples and dc [13], and the six-point contact in a rectangular prism geometry and dc current [14]. However, a few or perhaps none of them, to our knowledge, combine the Van der Pauw method together with the lock-in technique, as proposed here. In the case of Hall measurements in metals, it is a common practice to use the standard six-leg bridge with dc currents of several tens of amperes to get measurable Hall voltages. However, this practice reduces the precision of measurements due to the inherent low resolution of high current supplies. Our technique can be useful in this type of measurements allowing good resolution by using precise electronic current supplies.

IV. Conclusion

A measurement setup for electronic transport properties, i.e., the Hall coefficient and the resistivity, has been presented. This system can achieve good-quality measurements in variable temperatures for low-level signals, as has been found in overdoped high-Tc superconductors and metals. This capability has been obtained by the appropriate combination of two well-known instrumentation techniques: the Van der Pauw measurement method and the lock-in amplifier technique. A remarkable reduction of fluctuations in Hall coefficient measurement has been obtained by computing it from a linear fit of the Hall voltage versus the magnetic field, which has been measured at 10–20 different field values, depending on the sample’s quality. Our methodology is noninvasive and nondestructive, and does not require any modification, patterning, or exposition of the sample to chemicals or risks of physical modifications due to etching processes. Our method offers the advantage of more transparent study of samples, in addition to the possibility of using them in further tests or directly for applications. From the instrumental point of view, our setup is a modular one, which can be easily upgraded by parts. Fixing instrumentation problems is made easy by allowing a follow-up of signals through each step of the system. Precision and quality measurements are guaranteed by the quality of component instruments and quality of samples. This setup can be used in industrial and scientific applications with different samples like semiconductors, metals, and superconductors. A detailed description of instruments and measurement methodology has been presented. Two such systems have already been built in different institutions and are actually being used in scientific research [3], [10].

APPENDIX A
RESISTIVITY MEASUREMENT

For the square sample and contact numbering shown in Fig. 1(b) and the following definitions for currents and voltages:

\[ I_{ij} \rightarrow \text{current flowing from contacts } i \text{ to } j \]
\[ V_{ij} \rightarrow \text{voltage measured between contacts } i \text{ and } j \]

we have the following possible configurations without magnetic field \((B = 0)\):

\[ R_{43,12} \equiv V_{43}/I_{12} \quad R_{34,21} \equiv V_{34}/I_{21} \]
\[ R_{32,41} \equiv V_{32}/I_{41} \quad R_{23,14} \equiv V_{23}/I_{14} \quad (3) \]
\[ R_{12,43} \equiv V_{12}/I_{43} \quad R_{21,34} \equiv V_{21}/I_{34} \]
\[ R_{41,32} \equiv V_{41}/I_{32} \quad R_{14,23} \equiv V_{14}/I_{23} \quad (4) \]

These values have to obey the following conditions:

\[ R_{43,12} = R_{34,21} \quad R_{32,41} = R_{23,14} \quad (5) \]
\[ R_{12,43} = R_{21,34} \quad R_{41,32} = R_{14,23} \]

The reciprocity theorem also requires

\[ R_{43,12} + R_{34,21} = R_{12,43} + R_{21,34} \quad (6) \]
\[ R_{32,41} + R_{23,14} = R_{41,32} + R_{14,23} \quad (7) \]

In practical measurements, we must require that conditions (5)–(7) be obeyed within 3%–5%. Otherwise it would indicate sample nonhomogeneity, anisotropy, problems in sample’s contacts or instrumentation problems. Once these relationships are verified, we compute resistivity in the following way. First, define the average resistances in the two perpendicular directions, i.e.,

\[ R_A \equiv (R_{43,12} + R_{34,21} + R_{12,43} + R_{21,34})/4 \]
\[ R_B \equiv (R_{32,41} + R_{23,14} + R_{41,32} + R_{14,23})/4. \]

The resistivity of the sample is computed by solving Van der Pauw equation (1), as mentioned in Section II-A.

![Fig. 9. Normalized Hall cotangent versus temperature squared for thin-film samples of the high-Tc superconductor YBCO, with different doping. A robust $T^2$ behavior of this function is evident for all doping levels. Appropriate normalization makes all lines coalesce into a single line. Good-quality measurements of the resistivity and the Hall coefficient are fundamental to obtain this curve computed from $\cot(\theta_H) = \rho_{xx}/\rho_{xy}$.](image)
APPENDIX B

HALL COEFFICIENT MEASUREMENT

Following contact numbering of Fig. 1(b), we have the following configurations for the Hall coefficient measurement. Superindex (+) indicates a measurement with the magnetic field with positive polarity going out of the sheet, and superindex (−) indicates a measurement with the magnetic field in the opposite direction. With the positive magnetic field, we have

\[ I_{42} \rightarrow V_{31}^+ \quad I_{24} \rightarrow V_{13}^+ \quad I_{31} \rightarrow V_{24}^+ \quad I_{13} \rightarrow V_{42}^+ \]  

where the right arrows indicate measured voltages corresponding to the given current. For the magnetic field with negative polarity, we have

\[ I_{42} \rightarrow V_{31}^- \quad I_{24} \rightarrow V_{13}^- I_{31} \rightarrow V_{24}^- \quad I_{13} \rightarrow V_{42}^- \]  

Then, we define the following voltages:

\[ V_C \equiv V_{31}^+ - V_{31}^- \quad V_D \equiv V_{13}^+ - V_{13}^-; \]
\[ V_E \equiv V_{24}^+ - V_{24}^- \quad V_F \equiv V_{42}^+ - V_{42}^-. \]  

(10)

Inversion of the magnetic field polarity and subtraction of both measurements, i.e., \( V_{ij}^+ - V_{ij}^- \), results in the cancellation of magnetoresistance effects because that contribution does not depend on the polarity of \( B \) [2]. On the other hand, inversion of the current polarity and addition of both measurements \( V_{ij}^+ + V_{ji}^+ \) eliminates offset contributions, which change sign with the current polarity. A checkout of individual measurements \( V_{ij} \) must be performed to verify the validity of (5)–(7). The averaged Hall voltage is then given by

\[ V_H = (V_C + V_D + V_E + V_F)/8. \]  

(11)

APPENDIX C

INSTRUMENT DESCRIPTION

This is a list of the instruments that are used in this setup. Some of them have been chosen because of their convenience for this application; others have been chosen simply because of availability.

- electromagnet Brucker model B-M8 and power supply Brucker model B-MN-CS;
- Hall card Keithley model 7065 and switch matrix Keithley model 7001;
- inversion and security circuit for the electromagnet, homemade;
- lock-in amplifier Stanford Research, model SR-830 (dual channel);
- closed-cycle refrigerator Jannis model CCS-300ST/202;
- temperature controller Lake Shore, model LS-332;
- digital oscilloscope Tektronix model TDS1000;
- transconductance amplifier, homemade (see Fig. 3);
- vacuum pump Edwards, model E2M40;
- PC with GPIB interface card;
- data acquisition and analysis program LabView, from National Instruments.

APPENDIX D

SPECIFICATIONS OF THE SYSTEM

The technical specifications of the setup are given as follows:

- temperature resolution: 0.01 K, measured by a Lake Shore GaAs thermometer;
- temperature stability: 0.05 K, with a heater resistor and an inner chamber of cryostat in vacuum;
- magnetic field resolution: 10 G, measured with a Bell magnetometer;
- magnetic field stability: 50 G ≈ 5%; magnetic field controlled by current with a calibration table;
- resistance resolution: 1%, typical;
- Hall voltage resolution 1 μV (the low accuracy is due to the sample and contact quality, current and magnetic field resolution; the lock-in amplifier allows the resolution of the order of 1 nV).

The limiting factor determining these specifications is not the instrumental accuracy but the setup itself, the geometry of connections, and the sample’s quality. It is possible to improve these figures by a more careful design and by improving sample preparation and connection techniques.

ACKNOWLEDGMENT

H. Castro would like to thank the Low Temperature Group, Tel-Aviv University, Tel-Aviv, Israel, for the scientific collaboration.

REFERENCES


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