Quantum Design

The Newsletter from Quantum Design — *Spring 1998, Issue No.* 7

Quantum

STATES

QUANTUM DESIGN:

GREETING FROM THE CEO

Welcome to the newest issue of *Quantum States.* When we first introduced this newsletter as an experiment in communication, we thought we were creating a one-way ticket of sorts for sending out information about our company, its products, and the world of superconductivity in general. What happened surprised us all. Thanks to our readers, *Quantum States* quickly became a round-trip ticket. Not only did we begin receiving an amazing amount of information in direct response to each issue, but our not-so-regular publishing schedule prompted many readers to contact us to see if they had missed an issue. For your response and your continuing interest in Quantum Design, I want to offer a heartfelt “Thank you!”

In addition to keeping us in touch with our customers, *Quantum States* has also become a source of information for making decisions about new product development. As many of you know, we introduced one of the most exciting new options yet developed for our Physical Property Measurement System (PPMS) – the Heat Capacity option. This is a good example of Quantum Design responding to your requests: you asked for it and we developed it. Acceptance of the Heat Capacity option has been enthusiastic, and we offer a tempting taste of some early research results from it in this issue of *Quantum States.* Even better news is that several more revolutionary new capabilities for the PPMS are presently being developed or are on the drawing board.

Quantum Design reached another milestone this past July with the launch of Quantum Design Japan (QDJ), a joint venture between Quantum Design and Photonics Corporation. Headquartered in Tokyo, QDJ is dedicated to bringing to our Japanese customers the same high standard of sales and service we strive for here in the United States. John McArthur, a long-time Quantum Design employee, has been assigned to lead the technical staff at QDJ, and as I write this letter I am myself in Japan visiting some of our long-standing and highly regarded customers. I have been particularly gratified by their warm welcome and by their unanimous enthusiastic response to the establishment of QDJ.

As you can perhaps guess from my new title, during the last year I have moved out of the research lab (under great protest, I must add) into a position in which I will be dealing with longer-term issues. I expect to be traveling much more frequently in support of the many new projects we are undertaking, and I hope this will offer the opportunity to visit some of you. I enjoy sharing Quantum Design’s unique vision for the future with many of my old friends, and I’m looking forward to making many new acquaintances among our readers. I invite all of you to visit our display at the March APS meeting in Los Angeles (where we will have some surprises for you), and I hope you enjoy this issue of *Quantum States.*

Sincerely,

Ronald E. Sager, Ph.D.
CEO & Vice President of Engineering

IN THIS ISSUE

Measurement of Electrical Resistivity without Contacts Using the ACMS

L. Brinker, M. Baenitz
Fachbereich Physik, Freie Universität Berlin, D-14195 Berlin, Germany

This article will show that contactless resistivity measurements of non ferromagnetic materials can be made using the ACMS without any change of the PPMS setup.

CROSSTALK

Introduction

The resistivity of a sample can be deduced from a change in mutual inductance between two coils when the sample is inserted into them. This has been described by a number of authors. For non ferromagnetic substances the insertion causes a reduction of the mutual inductance M. This reduction δM can be expressed in the form $\delta M = \delta M' + i\,\delta M''$ whereby the imaginary part $\delta M''$ is derived from losses due to induced eddy currents. By measuring M' and M'' or, like in our case, the real and imaginary part of the AC susceptibility m' and m'', the specific resistivity can be determined. The main advantage of this inductive method to get resistivity data is that no direct electrical connections to the sample are required. Creating contacts can cause difficulties if the sample is a liquid or a pressed powder. An additional advantage is the time saving factor of this method. Concerning the potential errors, the inductive method is less sensitive since only the radius r of the specimen occurs in the calculation; whereas in the case of the direct measured resistance, errors in the radius and in the length can influence the resistivity values.

Theory

Starting from the Maxwell equations for an alternating field

$$\vec{H}(r,\varphi,t) = \vec{H}(r,\varphi)\cdot e^{i\omega t}$$

inside a material of isotropic resistivity, the response satisfies the equation

$$\nabla^2\vec{H} = \frac{4\pi\cdot i\cdot\mu\cdot f}{c^2\cdot\rho}\cdot\vec{H} = \frac{2i}{\delta^2}\vec{H} \qquad (1)$$

where δ is the skin depth of the material,

$$\delta = \sqrt{\frac{c^2\cdot\rho}{4\pi\cdot f}} \quad .$$

Here ρ is measured in μΩcm, f in kHz and δ in cm.

For convenience we set μ as unity but it has to be pointed out that this theory fails if μ itself becomes a complex number as in the case of a magnetic phase transition.

Solving this equation for cylindrical boundary conditions as it is shown in Landau-Lifschitz (I) which describes the change of flux in the secondary coil due to a change of the magnetization m

$$m := m' + i\cdot m'' = -\frac{J_2(x\cdot i^{3/2})}{J_0(x\cdot i^{3/2})} \qquad (2).$$

Here J_2 and J_0 are Bessel functions of the first kind and the part x of the complex argument is given as

$$x = \sqrt{\frac{8\pi^2\cdot f\cdot r^2}{\rho}} \qquad (3).$$

As can be seen from the above theory the losses in the bulk material, due to the resistance, lead to a phase shift between the signal in the primary and that in the secondary coil. This means measuring the phase shift at one specific frequency is sufficient information to calculate the resistivity, since

$$\Delta\phi = \arctan\left(\frac{m''}{m'}\right) \qquad (4).$$

The main problem in obtaining exact resistivity values with this particular theory for cylindrical shaped samples lies in the complex argument of the Bessel functions in equation (2).

Data Acquisition

Some authors (II) tried to solve this problem by building their devices so that the response signal in the secondary coil is directly proportional to the resistivity of the material. This only works properly for one particular frequency since stray capacities etc. could cause non reliable data. Chambers and Park (III) used a polynomial approximation for the Bessel functions. This method only works in specific regions of resistivity so that the sample's resistivity has to be approximately known.

In order to determine the resistivity of a variety of samples in a wide range of frequencies, we wrote a program in TURBO PASCAL which calculates the Bessel functions using an algorithm from (IV) for a fixed starting value x_{start} and then using equation (4) to calculate the corresponding value $\Delta\Phi'_{start}$. After this, the program changes the x-value until the difference between the calculated value $\Delta\Phi'$ and the measured phase shift $\Delta\Phi$ is less than 10^{-4}%. Each calculation took less then 40 steps per measured data point.

To test the measured data for errors which might be derived from an artificial phase offset of -90° occurring with very weak signals (amplitude $m < 10^{-6}$ emu), the phase shift $\Delta\Phi$ can be plotted against frequency. This should, according to equation (3), result in a square root like behavior.

Experiment

The cylindrical shaped samples were inserted parallel to the axis of the alternating magnetic field. To avoid end-effect errors (which are not considered in the theory described above) we used samples with a length of approximately 12 mm and a radius of between 0.5 to 2.5 mm. While measuring the amplitude and phase of the AC-magnetization, we applied an AC magnetic field of not less than 10 oersted since the response signal becomes more stable when the field is higher. The frequency of the applied field ranged from 1 kHz to 10 kHz. For poor conductors such as indium, higher frequencies are advantageous in order to achieve stable phase signals. The measured data for the AC-magnetization (amplitude and phase) over a wide range of temperatures were later exported and written into our program for resistivity calculations.

Figure 1 and Figure 2 show our calculated values for measurements of oxygen-free copper (Fig.1) and gold (Fig. 2) in comparison with values from literature (V). In the case of copper we also performed a direct resistance measurement by applying the 4-point method (using the bridge board of our PPMS). The difference between literature and measured values for the low temperature part of the resistivity of copper is derived from impurities in our sample.

A very interesting result is shown in Figure 3. Here we measured a pressed powder sample of the super conductive material Nb_3Sn ($T_c \approx 18$ K). The graph shows the calculated resistivities from inductive measurements in comparison with those of the direct 4-point method. The difference between the absolute values is a surprising factor of 20, whereas the temperature dependence

$$k = \frac{1}{P_O}\frac{\partial\rho}{\partial T}$$

in both measurements is identical.

We interpret this difference in absolute values as a result of non homogenous potential distributions within the powder specimen where the 4-point method is applied. In order to get the same resistivity values, one should use an effective cross section and length of the specimen.

A considerable advantage of the inductive method for measuring the resistivity of metals is the smaller geometrical error since one has to know only the radius r of the sample, whereas in the

CONTINUED ON PAGE 7

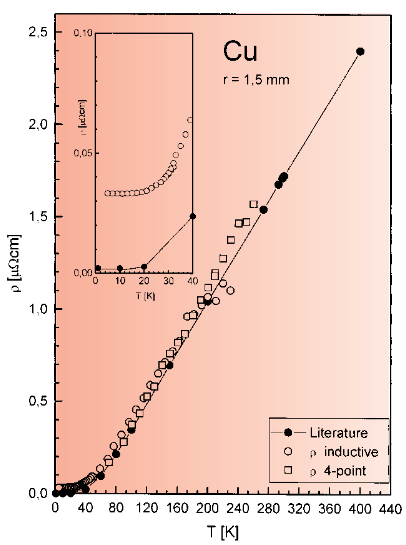


Figure 1: Resistivities of oxygen-free copper determined with the inductive method (open circles) and those determined with the 4-point method (open squares), in comparison with data from literature (V).

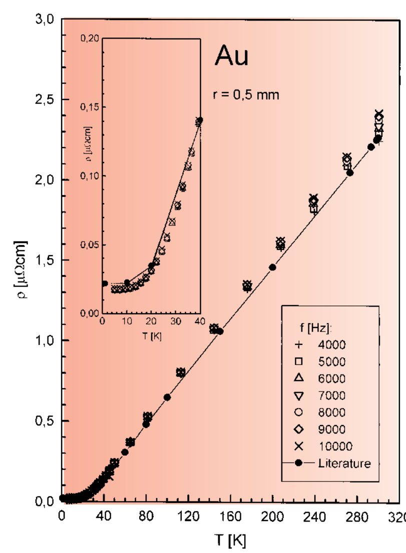
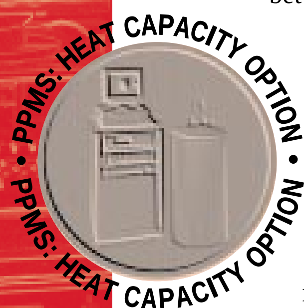


Figure 2: Resistivities of gold plotted versus temperature. The full circles are derived from literature (V). Other symbols are calculated values from inductive measurements with different frequencies of the applied AC magnetic field.

Quantum Design Releases Heat Capacity Option for PPMS



Heat capacity measurements reveal a wealth of quantitative information about the intrinsic behavior of a material including magnetic, electronic, and structural transitions, energy levels, and lattice dynamics, allowing comparisons not possible otherwise between theory and experiment. Now, thanks to the long awaited Heat Capacity option for the Quantum Design Physical Property Measurement System (PPMS) product line, this measurement can be made easily and reliably. The introduction of the Heat Capacity option marks a significant step into microcalorimetry for Quantum Design.

The focus of this option is to perform quality heat capacity measurements on a wide variety of samples with a unique user-friendly architecture. Dr. Randy Black, principle designer of the Heat Capacity option, states that "Our goal in developing the Heat Capacity option was to provide PPMS users with a fully automated technique for performing a difficult but physically important measurement. We have focused on combining state-of-the-art instrumentation, hardware, and intelligent software with a flexible microcalorimeter sample stage design. This product is geared for scientists who could benefit from heat capacity measurements but who are neither specialists nor have the time for designing and building such an apparatus."

The Heat Capacity option combined with the PPMS base platform provides users with a fully automated instrument capable of measuring heat capacity on small solid samples of about 1 to 500 mg in a temperature range from 1.9 K to 350 K and magnetic fields up to 14 tesla. The Heat Capacity option provides users with a very convenient sample mounting station, modular plug-in sample holders, a fully automated high-vacuum system, and a full-featured software package to assist the users throughout their experiments. The option uses a relaxation technique that combines the best measurement accuracy with robust analysis techniques. During each measurement cycle, the Heat Capacity application software fits the temperature response of the sample platform to a model that accounts for both the thermal relaxation of the sample platform to the chamber temperature and the relaxation between the platform and the sample itself. "This is the closest any commercial product has come to offering a turn-key capability for the difficult field of heat capacity," states Dr. Mike Simmonds, Vice President of Research & Development and co-founder of Quantum Design.

With the introduction of the Heat Capacity option, Quantum Design brings integrity of measurement – provided with an unprecedented level of automation – to this field. While electronic transport measurements, such as resistivity, are substantially more common, the link between experiment and theory is not always as clear as it is in a heat capacity measurement. When statistical theory of matter involves computing the density of states and energy levels, these computations naturally lead to predictions of heat capacity numbers. From a practical point of view, materials used in the construction of thermal devices, such as refrigerators and cryostats, must be characterized thermally; knowledge of the heat capacity of construction materials is important to any successful thermal design. And users will find three distinct advantages not available in any other commercial system.

Unprecedented ease of use which has become a Quantum Design trademark, is the first feature of this option that customers will enjoy. An intelligent, user-friendly software package includes built in background subtraction to correct for the contribution of heat capacity from the sample holder. Following a simple sample mounting procedure, the sample mount is inserted into the sample chamber. The heat capacity measurement parameters are then entered into the software. Now the easy part begins: the system performs all necessary temperature, field, and vacuum settings; data acquisition and analysis; and data plotting *automatically.*

A high degree of accuracy is provided through our sophisticated fitting model for relaxation measurements, called the *two-tau*™ *model*, enabling the system to accurately simulate the effect of heat flow between the sample and the calorimeter components. Even with less than perfect thermal contact between the sample and sample holder, the system can accurately compute sample heat capacity values and estimate errors based on the fit quality. Our software screen shows the power of this advanced analysis. It provides a wide range of valuable data and diagnostics *automatically.*

Our users find **extraordinary functionality** with this option. The sample may be mounted safely on the microcalorimeter platform and easily introduced into the integrated high vacuum system. Unique in this industry, the Quantum Design Heat Capacity system also automatically calculates the Debye temperature at each measurement point. Measurements can be performed over a very broad temperature range – 1.9 to 350 K – *automatically.*

For additional information on this exciting new product, call Quantum Design (1-800-289-6996) or visit us on the internet (www.quandsn.com).

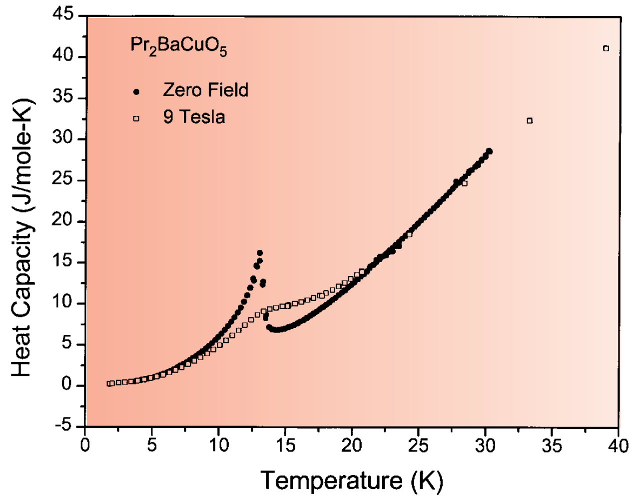


Figure 1: *Pr_2BaCuO_5. This system is related to the “green phases” for High T_C superconductors, but orders ferromagnetically at low temperature.*

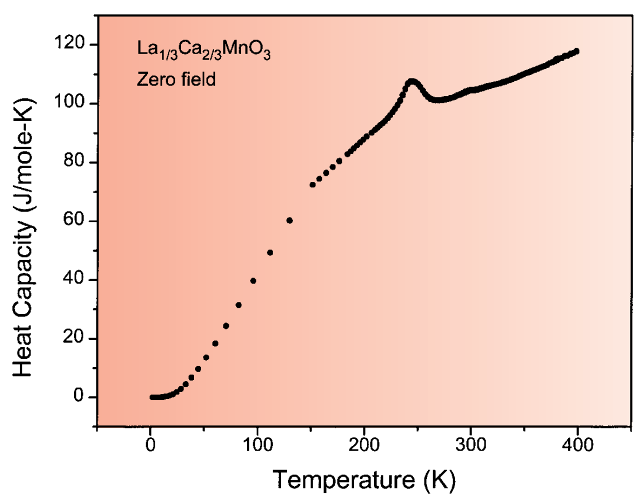
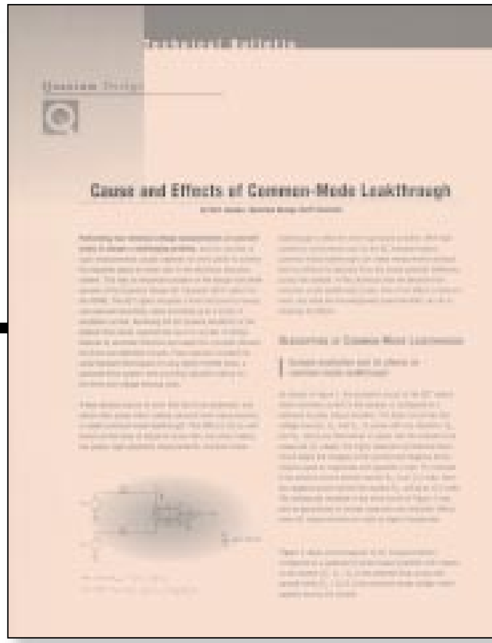


Figure 2: *$La_{1/3}Ca_{2/3}MnO_3$. This is a manganese perovskite, which presents the Colossal Magnetoresistance effect for $La_{1-x}Ca_xMnO_3$. For this high Ca concentration there is a charge ordering transition (T=240K) and an antiferromagnetic ordering (T_n=145K). Also an extra weak peak observed at T=300K is probably related to the polaron formation.*

Data courtesy of Dr. José L. Martinez, ICMM-CSIS. Madrid, Spain.


Technical Bulletin
Quantum Design
Cause and Effects of Common-Mode Leakthrough

Cause and Effect of Common-Mode Leakthrough

A TECHNICAL BULLETIN

Staff physicists at Quantum Design have collaborated on a technical note written to assist anyone wanting to identify and avoid spurious signals caused by contact resistance and impedance imbalance in a four-terminal voltage measurement. When performing four terminal voltage measurements at nanovolt levels, background signals can potentially smear out the actual physical signal and ruin the measurement. Contact resistance and impedance imbalance in the current leads are known to be a common source of background signals, but what is less often discussed is the reason why contact resistance can introduce such spurious voltage signals. The newly released technical note entitled "Cause and Effect of Common-Mode Leakthrough" describes why impedance imbalances can result in artificial signals from the measurement instrument and how one can identify their existence. The technical note also covers some steps experimentalists can take to minimize effects of common-mode leakthrough.

TECHNICAL • BULLETIN

Copies of this technical note may be obtained free of charge from the sales department at Quantum Design. Please contact us by email, phone, fax or on the World Wide Web as indicated on the back page of this issue of *Quantum States.* Also, watch *Quantum States* for information on the future publication of technical notes dealing with both magnetic and electro-transport measurements.

NOTICE TO ALL MPMS USERS

MPMS-7 users will be pleased to know that they can upgrade their systems with AC Susceptibility and/or Ultra Low Field capabilities! Call for more details.

Premounted palladium sample holders (Model C210) are now available from Quantum Design. Offering ease and accuracy with which to calibrate the MPMS, this new high purity palladium sample is conveniently mounted in its own quartz sample holder and will reduce problems associated with mounting a reference sample properly. For more information, please contact your local sales representative.

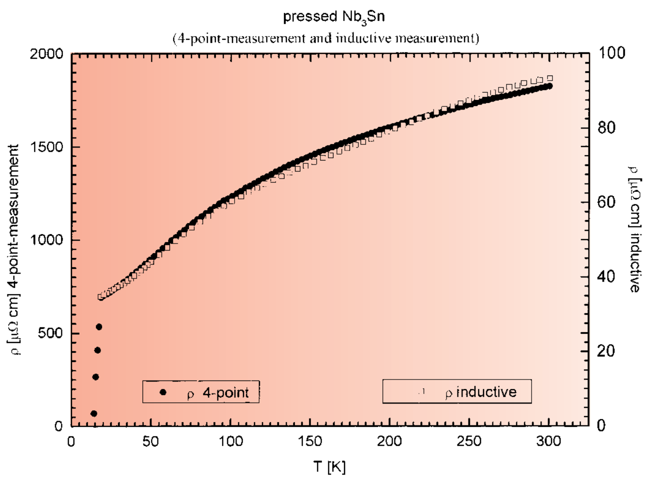


Figure 3: Calculated resistivities deduced with the inductive method (right axis) and those deduced from measurements using the 4-point method.

MEASUREMENT OF ELECTRICAL RESISTIVITY CONTINUED...

case of the direct 4-point method, errors in the cross section and the length can occur.

Acknowledgement

The investigation of this method was performed in the research group of Prof. K. Lüders, Fachbereich Physik, Freie Universität Berlin, Germany and supported by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologien (BMBF Project No. 13 N 6660/3).

The authors are obliged to Prof. Lüders and the members of his group for the helpful discussions and to R. Pues who started the investigation of the contactless resistivity method.

Literature:

[I] L. D. Landau & E. M. Lifschitz, *Elektrodynamik der Kontinua*, Bd. 7, 3. Aufl., Akademie-Verlag Berlin, 1974

[II] Ya. A. Kraftmakher, *Meas. Sci. Technol.* 2 (253) 1991

[III] R. G. Chambers, J. G. Park, *British Journal of Applied Physics*, 12 (507) 1961

[IV] W. H. Press, B. P. Flannery, S. A. Teukolsky, W. T. Vetterling, *Numerical Recipes in C*, 2nd Edition, Cambridge University Press 1992

[V] *CRC Handbook of Chemistry and Physics*, 75th Edition, CRC Press London, 199

SERVICE SUGGESTIONS CONTINUED...

Voice Mail!

We are happy to announce that Quantum Design, San Diego now has voice mail. When calling for service, we are not always able to get to your call. To minimize "on hold" time, if the service engineers are busy, your call can be placed directly through to voice mail. Leave a message with as much detail as you'd like, and please remember to leave your name, fax and phone numbers. We'll call you back as soon as we can.

Be sure to stop by Booth 521 at the American Physical Society Conference, which will be held March 17-19. Quantum Design will be introducing the latest advancements for the MPMS and PPMS. Many surprises await you.

SERVICE

Service Suggestions

BY CAROL LIVINGSTON,
TECHNICAL SUPPORT MANAGER

Powdered Samples

Do you measure powdered samples with the MPMS? Have you had problems with light samples being moved around or disturbed in the airlock during the purge cycle? We've developed a small adapter that can be easily installed into the MPMS airlock hardware to minimized airflow turbulence during the purge cycle. The device, which is a thin sheet of stainless steel with a small hole in it, can be inserted into the airlock and easily removed when not needed. With this constrictor in place, the purge cycle is slowed somewhat, but samples experience significantly less motion during the purge cycle. If you'd like one of these airlock flow restrictors, we are providing them at no charge. Just contact us by telephone, fax, email, or through our website, and we'll send one to you.

European Service Center Expands

Our European Service Center has extended their coverage to include Israel. This expansion took place as L.O.T. – Oriel, our Sales Representative in Germany recently increased their representation to include Israel. The European Service Center includes a working MPMS system that may be used to evaluate equipment, perform repairs, and improve service technician training.

Credit Cards

A note for our domestic customers, Quantum now accepts credit cards! Visa and Mastercard credit cards are an acceptable form of payment for sales and service items.

CONTINUED ON PAGE 7

CONTACT QUANTUM DESIGN

We welcome article contributions and comments from our readers. Contact editor Joyce Bathrick. To request a subscription please contact the Marketing Department at (619) 481-4400, Fax: (619) 481-7410, e-mail: info@quandsn.com, or internet: http://www.quandsn.com.

Quantum Design

11578 Sorrento Valley Road

San Diego, California 92121