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Contactless resistivity measurements on small platelets

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Abstract. A combination and modification of recently proposed techniques for contactless resistivity measurements were found to be well suited for the investigation of flat samples much smaller (surface area $\geqslant 0.5$ mm^2) than reported so far. The described experimental set-up is applicable for samples with $\sigma t \gtrsim 1\ \Omega^{-1}$ (σ is the conductivity, t the thickness of the sample) and thus covers a conductivity regime complementary to the microwave cavity perturbation method.

Electrical conduction properties can give useful information on chemical bonding in new compounds. For this purpose, it is usually sufficient to know the order of magnitude of the conductivity and its temperature dependence. However, when dealing with new materials, one often has to consider small air-sensitive single crystals. In this case, the contactless microwave cavity perturbation method is most appropriate (Buranov and Shchegolev 1971, Bauhofer 1981). The high conductivity limit for this technique is around 10^3 $(\Omega\text{cm})^{-1}$.

For materials with higher conductivity several methods based on the same principle, i.e. the perturbation of a MHz resonant circuit, have been developed. The perturbation produced by inserting a conducting sample into the time varying magnetic field of the circuit inductance is measured by either detecting the change in resonance frequency (Zeller *et al* 1979, McRae *et al* 1979) or by monitoring the current necessary to maintain the level of oscillation constant (Miller *et al* 1976). Miller *et al* have shown that the power absorption in flat samples which are large compared with the coil cross section is proportional to σt (the thickness t of the sample is always assumed to be much smaller than the skin depth). Thereby, the drive current I_T keeping the amplitude of the oscillation constant is also a linear function of σt.

In our measurements, we use the amplitude stabilisation circuit described by Miller *et al* together with a similar coil design (see figure 1) where the magnetic flux is guided within a ferrite cup core (Siemens, Siferrit K1, central hole filled up with a ferrite rod). However, we apply this method to samples which are much smaller (order of magnitude 1 mm^2) than the cross section of the inner ferrite rod (similar to Zeller *et al* 1979) whose diameter is 5 mm. The sample is inserted through a rectangular hole in the ferrite core within a thin walled and flattened quartz capillary (1.5 x 0.5 x 0.01 mm). With 14 turns of 0.2 mm copper wire the inductance has a quality factor of 70; together with a capacitance of 2.2 nF the resonance frequency amounts to 1.2 MHz. One can easily show that the power absorption P of a disc-shaped sample situated perpendicular to the direction of a uniform oscillating magnetic field is in first order proportional to $s^2\sigma t$ where s is the sample surface area:

$$P \propto s^2 \sigma t. \tag{1}$$

This relation (already used by Bartlett *et al* 1979) is the main assumption of the method. We have examined the range of its validity with a variety of arbitrary shaped samples ($0.5\ \text{mm}^2 \leqslant s \leqslant 2.5\ \text{mm}^2$) with known conductivity. The results are plotted in figure 2, which shows the change of the drive current (normalised to a sample surface area of 1 mm^2) as a

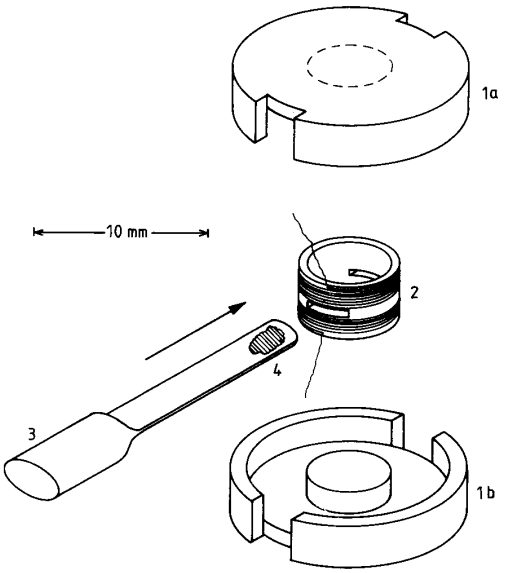

Figure 1. Exploded view of inductance and sample holder arrangement consisting of ferrite cup core (1a, b), coil on teflon cylinder (2), thin walled quartz capillary (3) and sample (4). During the measurement the sample is placed in the middle of the central ferrite rod.

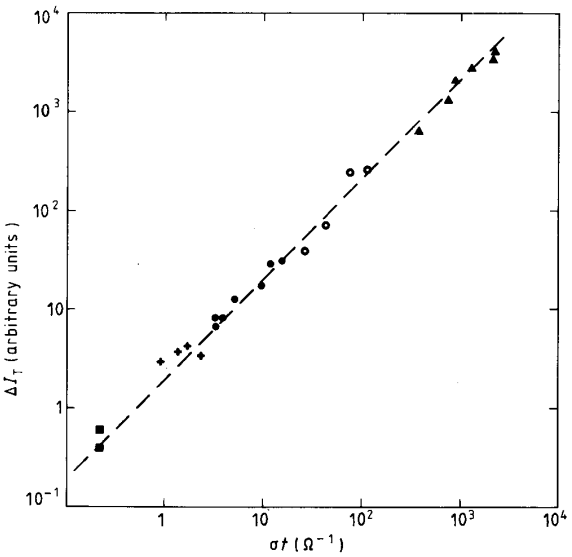

Figure 2. Change of the oscillator drive current against the product σt (σ = conductivity, t = thickness) for various gold, (▲); $EuAs_3$, (○); $SrAs_3$, (●); Si, (+, ■) samples normalised to a surface area of 1 mm^2.

Table 1. Parameters of the samples used for the calibration curve depicted in figure 2.

Material	Symbol	Resistivity	Thickness [10^{-4} cm]	Surface area [mm^2]
Au	▲	2.4×10^{-6} Ωcm	9 ... 53	0.23 ... 0.41
$EuAs_3$	○	2.0×10^{-4} Ωcm	53 ... 223	0.44 ... 2.25
$SrAs_3$	●	1.5×10^{-3} Ωcm	45 ... 234	0.52 ... 2.90
Si	+	10^{-2} Ωcm	85 ... 235	0.90 ... 2.25
Si	■	10^{-1} Ωcm	210 ... 220	2.20 ... 2.30

function of the product σt. All the experimental points lie in the log–log plot around a line with unity slope confirming the overall linear relationship. Table 1 gives a compilation of the different calibration samples. The scatter of the points in figure 2 is a measure of the accuracy of the method. We see that a conductivity in the range 10^2 to 10^6 $(\Omega cm)^{-1}$ of a sample whose thickness and surface area has been measured, can be determined with an accuracy of a factor of two. The most significant error is probably due to deviations from relation (1) caused by surface areas with no circular symmetry. The accuracy can be increased considerably using calibration samples of comparable conductivity with very similar geometries.

The relative change of conductivity due to a variation of temperature can be determined with much better accuracy. Down to 80 K there is no relevant change in the properties of the resonant circuit which is kept at the sample temperature. This stands in contrast to a recently published presumption that the ferrite magnetic material seriously affects the stability of the sensing inductor even in a small temperature range (Singhal and Kernick 1981). We use a conventional cooling system with liquid nitrogen tank, helium exchange gas, heater and temperature controller. The sample is removed and reinserted at each temperature to compensate for the temperature dependent drift of the drive current stabilising the unloaded resonant circuit. Figure 3 shows a comparison of a temperature dependent conductivity measurement of $EuAs_3$ (room-temperature resistivity $\simeq 2 \times 10^{-4}$ Ωcm) by a four point DC method with the contactless technique (using a sample with $s \simeq 1$ mm^2 and $t = 1.5 \times 10^{-1}$ mm).

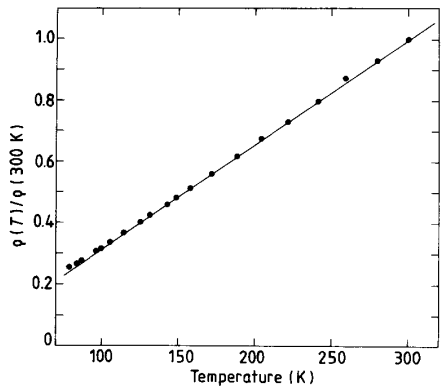

Figure 3. Comparison of the temperature dependent resistivity of $EuAs_3$ measured by a four point DC method (line) and by the presented contactless technique (points). The contactless measurement was made on a sample with $s \approx 1$ mm^2 and $t = 1.5 \times 10^{-2}$ cm.

The resistivity normal to the basal plane of disc-shaped samples can generally be measured with pressure contacts even when the samples are small. The inductive method, however, is often the only way to determine the true in-plane conductivity.

A wealth of rare earth halides with unusual stochiometry has been prepared recently (Mattausch *et al* 1980). Single crystals of the extremely air-sensitive layer compounds with the general formula LnX (Ln = lanthanide, X = halogen) have been obtained with maximum dimensions of $0.7 \times 1.0 \times 0.1$ mm^3. With the described method we were able to prove the metallic character of the in-plane conductivity ($\simeq 10^4$ $(\Omega cm)^{-1}$). Thus, in our opinion, this method enables measurements on small crystals to be made, which earlier have been considered as hopeless cases.

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