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Electrometer preamplifier for measurement of voltage, current, and resistance on high resistivity materials

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An electrometer preamplifier for the measurement of dc voltage, current, and resistance in high resistivity materials has been developed. The ranges of measurement for voltage, current, and resistance are from 30 μV to 10 V, 10^{-2} to 10^{-13} A and 10^3 to 10^{13} Ω, respectively. Charge measurements can also be made by connecting a suitable capacitor in the feedback loop. It uses commerically available operational amplifiers. The preamplifier is small in size and is used in conjunction with a commerical voltmeter or recorder. It is ideally suited for *in situ* measurement of electrical properties of amorphous semiconductor films.

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INTRODUCTION

An electrometer is required for the measurement of electrical properties of high resistivity materials such as insulators, amorphous semiconductors, etc. It is necessary to exercise extreme care in connecting the electrometer to the sample under test because very high input resistances are involved. Difficulties arise in the reliability of measurements[1-4] due to leakage currents, connecting cables, and pick up disturbances from electrical apparatus nearby and also due to charges being developed by mechanical motion of the coaxial cables. It has been found[5] that many commercially available shielded cables have shielding effectiveness of only 70% to 80% and tens of microvolts may be picked up from moderate magnetic fields of the order of 10 Gauss found near motors, power transformers, etc. Electrostatic shielding can be improved by providing an additional shield, but magnetic shielding is much more difficult. Since longer cables pick up more disturbances, reducing the cable length greatly improves the stability of measurements.

Commercially available instruments have normally limited measurement ranges and modes of operation and are difficult to adapt for a particular experiment. Also, since they are usually combined input–output instruments, their size is large and hence they have to be connected to the sample by fairly long cables; besides, they are expensive.

We have constructed an electrometer preamplifier for dc voltage, current, and resistance measurements on high resistivity materials in general, and for *in situ* measurements of electrical properties of amorphous semiconductor films. It is fairly inexpensive, simple, and so small in size that it can be placed very near to the sample. It can also be mounted inside a vacuum system or a cryostat.

The preamplifier consists of a commercially available operational amplifier (opamp) No. ICH 8500A made by Intersil U.S.A. and an LM 725 instrumentation amplifier. The minimum input current of the amplifier is $\sim 10^{-14}$ A. It can be put to different modes of operation (e.g., voltage, current, and resistance) by a mode switch and various ranges of current and resistance can be selected by a range switch. For readout purposes the output of the preamplifier is connected to a voltmeter or recorder.

I. CIRCUIT DESCRIPTION

Figure 1 gives the schematic circuit diagram of the amplifier. S_1 is a single pole multiway switch of shorting type (make before break type) and is used for range switching. The wafer of S_1 is made of ceramic or Teflon as it forms a high impedance terminal. The first opamp A_1 is mounted on a Teflon sheet and fixed near the switch, S_1. S_2 is a read/standby switch. When connected to the 'read' position (1), it connects the input range switch S_1 to A_1, in the 'standby' position (2) it shorts A_1 to ground, and the whole system works as an amplifier with a gain of 10. Zero of the amplifier is also adjusted with S_2 by 'standby' position. This switch again is a high impedance switch and can be fabricated easily using Teflon. J_1 is a Teflon BNC connector for input terminals. A_1 is mounted on Teflon sheet and fixed near S_1, whereas A_2 and associated components can be mounted on an ordinary printed circuit board. S_3 is a 4-pole 4-way switch (of nonshorting type) and is used as a mode (voltage, current, and resistance) selector switch. The output of

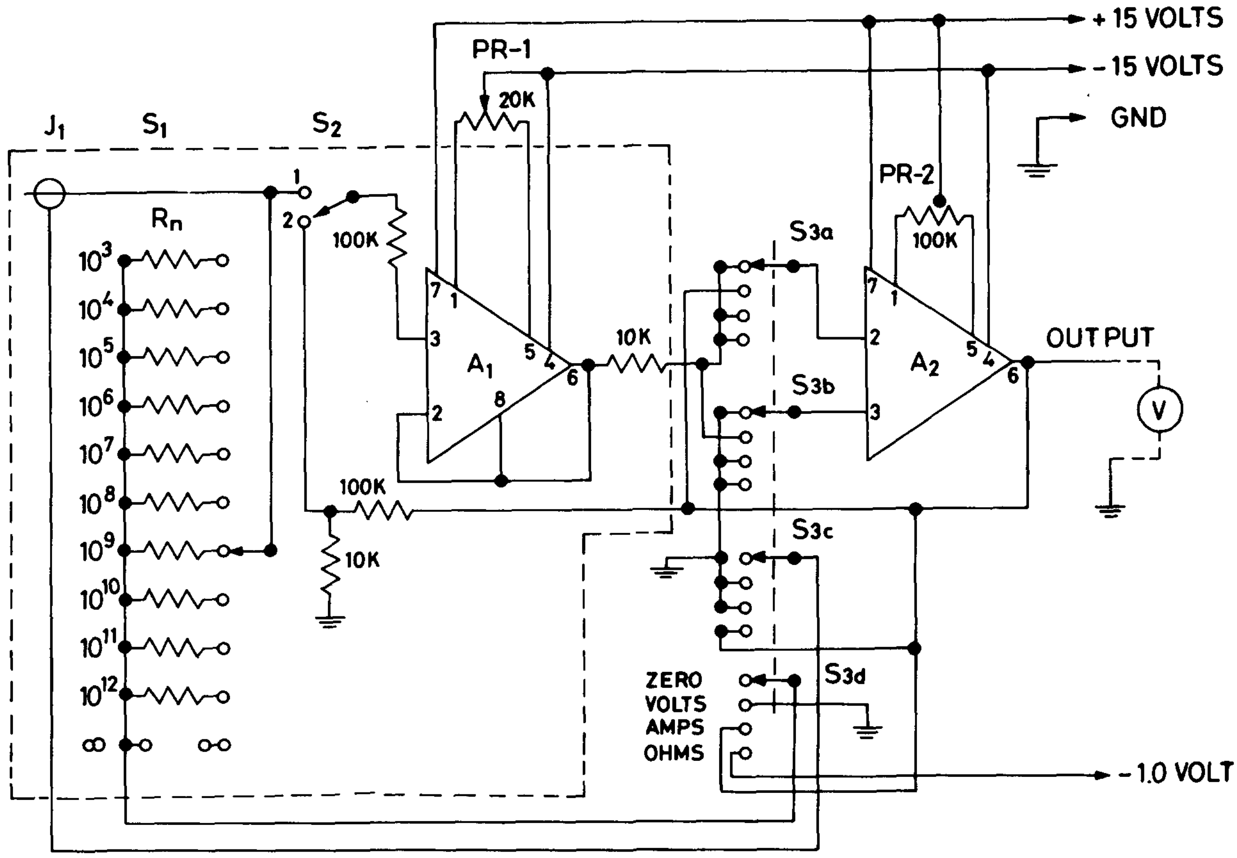

FIG. 1. Circuit diagram of the preamplifier. A_1 is ICH 8500 A operational amplifier and A_2 is LM 725 instrumentation operational amplifier compensated for unit gain. All resistances are in ohms unless otherwise specified.

A_2 is connected to any voltmeter or recorder. All the measurements are referred to the output voltage of A_2.

The preamplifier acts as voltage follower with a gain of nearly 1 in the voltage mode. Measurement of current can be done in two ways. First, the unknown current I_{in}, is made to flow through the appropriate range resistor R_n and the resultant voltage drop in R_n can be measured by the output voltmeter. The mode switch S_3 in this case is kept in voltage mode. It should, however, be made sure that R_n is smaller than the source resistance, otherwise it leads to loading errors. Second, the range resistor R_n can be connected in feedback loop by switching S_3 in current mode. The output of A_2 is again equal to $I_{in}R_n$. The second method improves the time response considerably and there are no loading errors. The value of R_n can be chosen from range switch S_1, from 10^{12} to 10^3 Ω in steps of 10 (the actual number of range resistors depends upon the number of ways in S_1).

For resistance mode, the preamplifier acts as an amplifier whose gain depends on the value of unknown resistor, R_x. In this mode R_x is connected in feed back loop by selecting the mode switch position marked 'OHMS.'

II. CONSTRUCTION

The mount for A_1 and S_2 was made by drilling 1-mm diam. holes through 3 mm thick 4 × 2 cm Teflon sheet. Metal eyelets were then fitted in these holes. The Teflon mount, the ceramic wafer (of S_1), and S_2 were then cleaned ultrasonically in Teepol using deionized water. After rinsing thoroughly in deionized water, they were degreased by boiling in trichloroethylene. The opamp A_1 and switch S_2 were then soldered to the eyelets using a grounded tip low voltage soldering iron. It is advisable to keep the opamp pins shorted together till the assembly is completed. Switch S_1 can also be fixed on the Teflon mount with appropriate screws. Once again, the Teflon mount along with S_1 and S_2 should be boiled in trichloroethylene. Finally, they are baked at 150 °C for about half an hour in an oven. S_3 and A_2 with their associated components are mounted on an ordinary printed circuit board. The circuit is then completed by soldering all resistors and making all interconnections as shown in Fig. 1. It should, however, be noted that extreme, care should be taken to ensure that the high impedance part of the circuit (enclosed in the dotted region in Fig. 1) should not be touched with bare hands. A slight contamination of Teflon board or switches S_1 and S_2 may affect the performance drastically. The short across the pins of A_1 can now be removed.

For application where the working space is limited, it is only necessary to wire the circuit enclosed in the dotted region on a single Teflon board which can conveniently be placed inside a vacuum system, cryostat, etc. The rest of the circuit can be placed outside and the interconnections can be made via long wires.

Since offset zero is provided for A_1 only, it is assumed that the offset voltage for A_2 is zero. A_2 could be an auto zero opamp or a precision opamp with a very small input offset voltage. However, in the case of 725 the output is zeroed as follows. First, the power supply is connected to the amplifier. The output of A_1 is then disconnected and S_3 is kept at position marked 'VOLTS' and input of A_2 is shorted to the ground. Then the voltage appearing at A_2 output is zeroed by 100 KΩ preset potentiometer PR-2 (PR-2 should preferably be a high stability metal film resistor). Once the output of A_2 is zero, A_1 can be connected to A_2.

III. OPERATION AND DISCUSSION

The power supply connections are made and a voltmeter is connected across the output of A_2. About 15 minutes are allowed as the warm-up period. S_3 is kept at position marked 'ZERO' and S_2 at 'standby' position. Zero is then adjusted with the help of potentiometer PR-1. The instrument is now ready for the measurements. For voltage measurements the mode switch S_3 is kept at the position marked 'VOLTS' and the input voltage is same as the output voltage (R_n in this case should be ∞). For current measurements S_3 can be kept at 'VOLTS' or 'AMPS' position. The output voltage V_o is related to the input current, I_{in}, as $I_{in} = (V_o/R_n)$ amps. For resistance measurements, S_3 is kept at the position marked 'OHMS'. The output voltage V_o is related to the unknown resistance, R_x, as $R_x = (V_o \cdot R_n)\ \Omega$.

The maximum voltage that can be measured by the preamplifier is 10 V, this being the maximum common mode voltage of A_1. The minimum voltage is determined by the stability of the output which in turn is governed by the source resistance and stray pick-up signals. With the input shorted one can measure about 30 μV. Similarly, the minimum current and maximum resistance limits are also determined by noise and drift criteria. We could measure currents down to 10^{-13} A and resistance up to $10^{13}\ \Omega$. The maximum current and minimum resistance limit in practice is determined by the value of range resistor.

In principle a single amplifier A_1 can perform all these functions. However, in practice it is found that switching of the input terminals of A_1 causes problems in terms of drift and a zero shift. Also, since the maximum allowed differential voltage for A_1 is 0.5 V, it is better to use A_1 in the voltage follower mode to avoid any damage due to input voltage rising above 0.5 V.

Incorporation of Read/Standby switch S_2 creates a problem if the amplifier is to be used inside a vacuum system, since it requires a separate mechanical feed through attachment to the vacuum system. It is also possible to eliminate this switch by a suitable modification in the circuit diagram, but an electrically-operated read relay switch is ideal. However, there may be other problems such as interference of relay current and contact at small potentials. Also, there can be leakage of currents through the body of the read relay switch which deteriorates the performance of the preamplifier significantly. It is suggested that these problems be evaluated separately. We, however, could not investigate them due to the nonavailability of a good read relay.

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