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Epics Based Software for Electrical Resistivity Measurement of Alloys and Thin Films

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ABSTRACT: Ubiquitously, electrical resistivity measurements provide characteristics of the nature of material, study of film thickness and all the properties of semiconductor materials at scientific laboratories. The resistivity measurement is performed by the measurement of current and voltage, using four-point probe method. These parameters are controlled by the software efficiently and it delineates the characteristics of resistivity of material linearly. The Software is developed using Experimental Physics and Industrial Control System (EPICS) over Linux operating system. Linux is an open source and real time operating system.

KEYWORDS: EPICS, Linux, real time operating system, four-point probe method, electrical resistivity.

I. INTRODUCTION

EPICS has become a popular open source software framework in scientific industry, used for developing software for distributed control systems and scientific experiments. It is a collection of software tools which provide reliability, scalability and flexibility to the system. It provides various libraries and driver support to create a soft real time distributed system.
The purpose of this software is to perform resistance measurement for alloys, metals, non-metals and semiconductor materials so that user can calculate the resistivity of material. The resistivity is a measurement of electrical and optical properties of all types of materials which opposes the flow of current. The software has provision to measure the resistivity at different intervals of current value (ranging from *nA* to *mA*) according to the requirement of the user's experiment. There is an option for scanning at every value of current in the specified interval for nullifying the generated heat during the experiment. With the help of SourceMeter and Nanovoltmeter the software performs the measurement efficiently.

II. LITERATURE SURVEY

The resistance [2] can be determined from measured voltage when a current is transmitted across the sample. There are two methods available for measuring the resistance of sample. They are two-point probe and four-point probe.
The two-point probes are used to pass the current through sample and measure the corresponding voltage. This process is called as "two-point probe" method. This method provides the resistance of sample but it produces wrong result because the resultant resistance is generated by combination of probe resistance, contact resistance and sample resistance. The major drawback of this method is that an error is generated due to electrical contacts [3].
The four-point probe method completely removes the drawback of two-point probe method. This method provides an accurate resulting resistance of sample because two outer probes are used to flow the current and two inner probes are used for measuring the potential drop across the sample. In this method, probes have been used independently for current and voltage which eliminates the generated errors in two-probe method due to electrical contacts [2].

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In the resistivity measurement, the thermoelectric voltage i.e. V_{emf} is arising across the samples at low temperature. Hence the measured voltage is sum of sample voltage and $V_{emf,}$ which generates an error in resistance measurement. So the user performs current reversal method manually, for removing V_{emf} from sample voltage. In the first step current is transmitted in forward direction and then corresponding voltage is measured. In the next step voltage is measured with current, passed in reverse direction. In both the stages temperature remains same. In the last stage of measurement, average voltage is calculated by taking absolute values of voltages which is measured in forward and backward stage [3].

All the above processes are done by users manually, which is a very time consuming process. The process requires a lot of time for performing an experiment. So for automated measurement, software is developed in EPICS. It takes less time and also the development cost is reduced.

For the measurement, various devices are interfaced to EPICS [1] software on the dedicated Input Output Controller (IOC). An IOC is a database which is turn in a collection of records. There are different types of supports are available in EPICS for processing a record. They are: device support and driver support. The device support acts as a middleware for EPICS records which are independent from hardware, whereas the driver support is used for performing the interaction with hardware and it provides low level details to the software. There are various records (asyn, stream-devices) available in EPICS to communicate with devices via Ethernet, RS-232 or GPIB. In our case, the device support is used for performing logic for flow of current in forward as well as reverse direction continuously via analog record. It has been written in C language. There are various records available for performing a closed loop such as Compress record, sseq record, acalcout record [5] but all these ways do not fulfill the requirements of resistivity software. The device support is written in C to accomplish the requirements for the experiment.

EPICS records are created by Visual Database Configuration Tool (VDCT) to make a .db file. VDCT [4] is a database configuration tool for EPICS which is a completely Java based graphical tool. It creates database file (.db) which contains detail of various records and this file is interfaced with database definition (dbd) file which provides specification for records. It performs conceptual modeling for applications in the form of hierarchy of records. The "asyn-4-21" record which is imported in visual database configuration tool (VDCT) is used for acquiring the data to/from devices.

III. Design and Implementation:

A. Experimental Setup:

The software measures the current and its corresponding voltage by using the four-point probe method. The four-point probe method is used for measuring the resistance of a sample. In this method, two outer probes are connected with current SourceMeter and two inner probes are connected with Nanovoltmeter for measuring voltage across the sample. In the experimental setup (see figure 1), the SourceMeter and the Nanovoltmeter are connected to personal computer (PC) respectively via Ethernet and RS-232. The setup parameters of TCP/IP and RS-232 (such as IP address, port number and baud rate of device) are mentioned in startup file. When IOC is booted the startup file executes command and establishes the connection between PC and device automatically. The functional requirements of the software are:

1. To nullify the heat generation during experiment
2. To measure the resistance for resistivity of material
3. The software should verify the V-I characteristics which ensures that the measurement is performing in right way.

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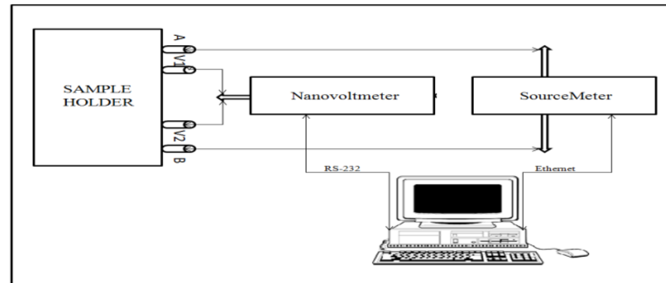

Figure 1: System Architecture of Resistivity Measurement

B. Proposed Technique:

The software performs its operations in two phases. In the first phase, software initializes all the parameters and establishes a connection for acquiring a data from device. In this phase user mentions the interval of current value along with the step size in the software. The software has no limitations for unit of current (it can measure the current sample from nA to mA or vice-versa).

In the second phase, software starts the measurement. When the resistivity measurement is performed at low temperatures then problems occur due to thermoelectric voltage [3].The solution of this problem is current reversing technique which is performed by the software for neglecting the V_{emf} at low temperatures. In this technique, the value of current is kept constant and the variations in the voltage are determined. The current reversing technique is performed by the software continuously as per the requirements of the experiment. User mentions the value of current and defines iteration for performing current reversing technique. The device support has been written for performing a loop which transfers the value in a specific record. The implemented "C" code is mentioned below:

For current reversing technique:

```
//-----------------------for forward and reverse current--------------
// support for ai record which performs flow in forward and backward direction.
// variable list:- current, loop, i, j, fixed_current
// fixed_current represents defined value of current which wants to process in SourceMeter.

static long read_ai (precord)
struct aiRecord *precord;
{
static int i=1;
if (j<(loop+1))                      //value of j is taken from event record
{
Current = fixed_current;
        if (i==1)
        {
         i=0;
        precord -> rval=current;          // positive value of current stores in the field of ai record
        }
else
        {
        i=1;
        precord -> rval= -(current);      // negative value of current stores in the field of ai record
        }
}
return (0);
}
```

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The above code snippet describes how to process flow of current in either forward or reverse direction.
The proposed technique is described in this section with the help of a flow chart which is mentioned below in the Figure 2. The flow chart describes data and control model of the system. It performs the current reversing technique and corresponding voltage measurements. The sequence of the program is as follows:
The records will be activated whenever event (val field of event is 1) is generated in program. The records initialize all the parameters which have been used in measurement and it forwards request to device support. The record provides essential features and hides the background details of mechanism. The device support act as a logical layer which processes the request performs the action and sends the response to record. The device support will be executed whenever event is changed in a program.

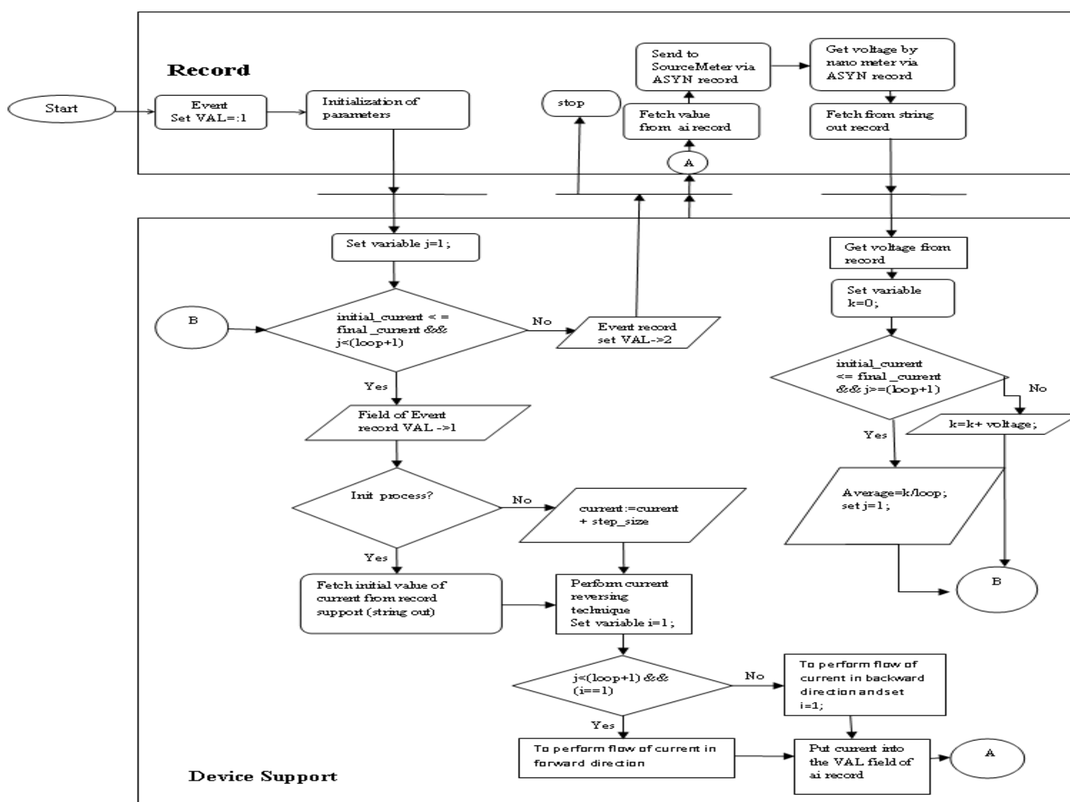

Figure 2: Flow Chart of Resistivity Measurement

For Resistivity Measurement:

$$R= V/I \text{ --------- } (1)$$

In the first step for finding the resistances fix the value of current and measure the variation of voltage corresponding to that current. The universal formula of resistivity is used for measurement that is shown below:

$$Resistivity= (Resistance\ of\ sample * Area)/Length$$

Here *Length* is the distance between two inner probes and *Area* is cross sectional area of sample wire.

IV.GRAPHICAL USER INTERFACE

The Graphical User Interface (GUI) is designed in Extensible Display Manager (edm) which is operator interface (OPI) toolkit of EPICS. For running the GUI, EPICS IOC (input output controller) should be in running stage.

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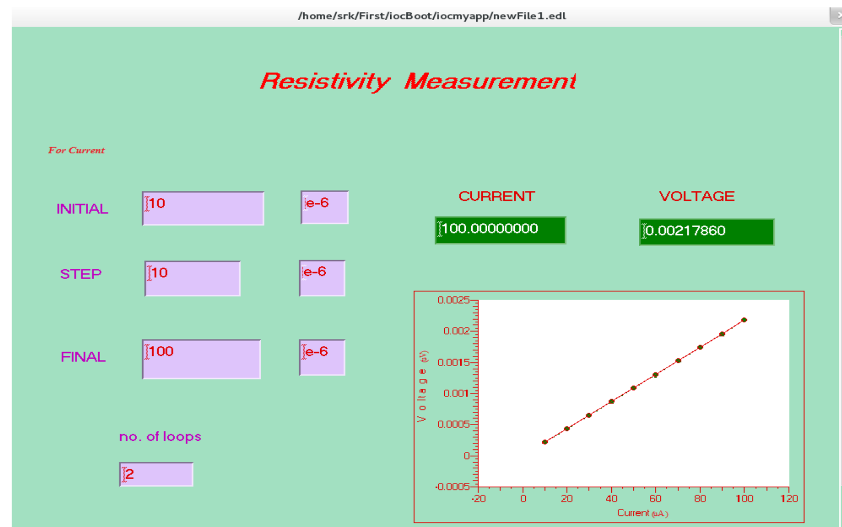

Figure 3: Resistivity Measurement Tool

The GUI of resistivity measurement shows the initial and final value of current along with step size. For current reversing technique, user enter the “no. of loops” to set a constant value of current in forward and reverse direction. The software also shows the V-I characteristic in GUI.

V.RESULT

The software produces the accurate result of potential drop with corresponding current of sample which is passed across the two outer probes. The following test cases are generated during the testing of software.

A Data controlling and monitoring:

On executing the software the EPICS IOC runs on the Linux PC and initializes all the devices that are attached to the port of PC. The SourceMeter and Nanovoltmeter, which are connected to the PC, initialize in remote mode. The Keithley SourceMeter is controlled by the software. The value of current is set from the software into SourceMeter which may be either in mA, µA or nA. The SourceMeter is connected with resistance in series and the Nanovoltmeter is connected in parallel. The voltage is acquired from Nanovoltmeter and monitored by the software. The required time is 5 seconds for controlling and monitoring the devices. If the event is generated in less than 5 seconds the Nanovoltmeter generates an error message as in the reversing technique the value of current is passed from positive to negative. So, the Nanovoltmeter takes more time to display the value of voltage. The precondition of software is that both devices (SourceMeter and Nanovoltmeter) should be on.

B. Verify the V-I characteristics of material:

The software verifies the V-I characteristics of material. For performing the resistivity experiment, a text file is created in the software which records the values of current and variations in voltage. We are measuring resistivity of Indium Arsenide (InAs). In the below figure, the value of current is taken from 10 µA to 100 µA and each value is recorded twice (for the 1st time, the positive value of current is passed and for the 2nd, the negative value) by the software.

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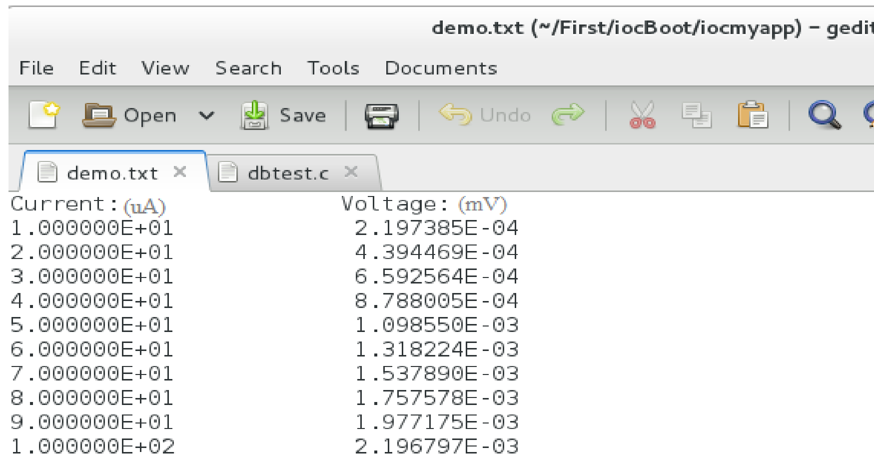
Correspondingly, the average voltage is stored in the file. All the following data value is used for computing resistivity of InAs at laboratory.



Current: (uA)	Voltage: (mV)
1.000000E+01	2.197385E-04
2.000000E+01	4.394469E-04
3.000000E+01	6.592564E-04
4.000000E+01	8.788005E-04
5.000000E+01	1.098550E-03
6.000000E+01	1.318224E-03
7.000000E+01	1.537890E-03
8.000000E+01	1.757578E-03
9.000000E+01	1.977175E-03
1.000000E+02	2.196797E-03

Figure 4: Current and Resulting value of Voltage

In case of four-point probe method, the resistivity is measured by following formula:

$$p_n = (V_n/I_n) * 2\prod s$$

Here p is resistivity, V is potential drop across the probe , I is the flow of current of sample, n is total number of iterations of current and s is distance between probes which is 0.23 cm (s is same between all probes). We are taking value of current range from 10 uA to 100 uA, corresponding value of voltage and put into above resistivity formula. Here n is from 1 to 10. The average of resistivity is calculated by using following formula.

$$p = (p_1 + p_2 + p_3 + p_4 + p_5 + p_6 + p_7 + p_8 + p_9 + p_{10})/10$$

After performing all calculations, the resultant of resistivity measurement of Indium Arsenide sample is found to be 14.1 ohm-cm. For identifying the accuracy of measurement, the software draws the V-I graph. Ideally the resultant V-I graph should be represented linearly. For plotting a graph in EPICS, the PV's of record (process variable which represents the value of current and potential difference across the probe) are processed into X-Y graph of EDM.

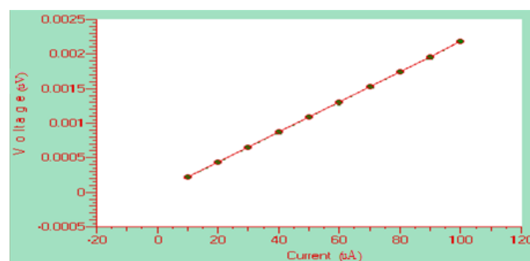


Figure 5: V-I Characteristics of Sample

The resultant graph shows that as the current through an outer probe increases, the potential difference across the inner probe increases linearly, that is the Ohm's law. Thus the V-I characteristics is a straight line that passes through the

origin of the graph. Thus V/I is a constant i.e. Resistance (R). Hence the software provides accuracy of measurement to the user via graph.

VI.CONCLUSION

This paper shows that the EPICS based software for resistivity measurement is a soft real time software system. This software is used for analyzing the structure of all types of materials and insulators. The system provides high accuracy, reduces the failure rate and avoids the developing cost of a system. EPICS provides facility to easily upgrade the software in the near future. Thus the software provides flexibility to the users.

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