DESIGN, CONSTRUCTION AND PROPOSED USE OF APPARATUS FOR MEASURING RESISTIVITY OF THIN FILMS IN THE TEMPERATURE RANGE 4.2-300°K

by

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Ronald D. Kern
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INTRODUCTION

There has been considerable interest in the study of the electrical resistivity of thin films. These studies have been motivated by the industrial demand for reliable thin film devices. Scientific curiosity about the behavior of two-dimensional solids has also been responsible for interest in thin films. With improved experimental techniques, it is now possible to obtain reproducible data on films of well-defined structures and deduce fundamental information with some degree of confidence.

Electrical resistivity is a quantity which is dependent on the scattering of conduction electrons in solids. Conduction electrons in a metal film are scattered by phonons, impurities, imperfections and by the surface of the film as well. The variation of electrical resistivity with temperature, impurity concentration, film thickness, etc., may be used to gain an insight into the various scattering mechanisms.

In this investigation we have designed and constructed equipment which can measure electrical resistivities of thin films in the temperature range from 2.4°K to 300°K.

The first part of the thesis gives a brief outline of the theory of electrical conduction in thin films. Experimental details are included. Results are given for some preliminary measurements on Al films. Resistivity versus temperature curves over the temperature range 77 - 300°K are shown for different thicknesses of Al films. The size effect contribution to the resistivity has been calculated. The concluding section discusses proposed uses of this equipment for future experiments.

THEORY

Electrical conductivity of metals and alloys depends on the mechanisms by which electrons may be scattered[1-4]. For a metal it is assumed that the electrons in the outermost incompleted shells of the atoms are free to move through the crystal lattice under the influence of the attractive forces of the ions, which are localized at the lattice sites. Electrons therefore move in a potential which has the periodicity of the lattice. Under these ideal conditions electrons experience no resistance to their motion. Scattering will occur when the periodicity of the lattice potential is upset.

From simple kinetic theory the resistivity is given by

$$\rho = \frac{m_e v_f}{ne^2\lambda} \qquad (1)$$

$$\rho = \frac{m_e}{ne^2\tau}$$

m_e = mass of the electron

v_f = Fermi velocity

λ = mean free path between collisions

n = number of electrons per unit volume

τ = relaxation time

This relation holds for isotropic metals with a single conduction band i.e. polycrystalline metals or single crystal metals with cubic symmetry.

Assuming the scattering mechanisms are independent of one another, the total resistivity can be written as the sum of the resistivities due to each of the different processes.

$$\frac{1}{\tau} = \sum \frac{1}{\tau_i} \tag{2}$$

$$\rho = \sum \rho_i \tag{3}$$

The electrical resistance observed in solids when an electric field is applied may arise from the following mechanisms.

1. Scattering by thermal motion of the ions.
2. Scattering by lattice defects i.e. missing atoms, interstitials, impurity atoms, dislocations, grain boundaries, etc.
3. Scattering from the boundaries of the specimen.

1. Scattering by thermal motion of the ions.

Electrons in a crystal are scattered when they interact with a quantized lattice vibration of the crystal, called a phonon. The resistivity due to phonon scattering, ρ_{ph}, is strongly dependent on temperature.

At temperatures greater than θ_D, the Debye temperature of the metal,

$$\rho_{ph}(T) \propto T \tag{4}$$

At low temperatures, $T < \theta_D$

$$\rho_{ph} \sim T^5 \tag{5}$$

At intermediate temperatures the Bloch-Grüneissen formula is valid

$$\rho_{ph}(T) = 4R \left(\frac{T}{\theta_D}\right)^5 J_5\left(\frac{\theta_D}{T}\right) \tag{6}$$

where $J_5(x) = \int_0^{\theta_D/T} \frac{z^5\, dz}{(e^z-1)(1-e^{-z})}$ and R is a constant.

According to eq. (6), $r = \rho_{\mu}(T)/\rho_{\mu}(\theta_D)$ should be a function of the reduced temperature $t = T/\theta$. A plot of r versus t should be the same for all metals in a temperature region where phonons are the dominant scattering mechanism.

2. Scattering from lattice defects.

As the temperature is lowered toward absolute zero, the resistivity of normal metals approaches a constant value called the residual resistivity. The residual resistivity arises from the presence of impurities, defects, and strains in the metal lattice.

For a small concentration of another element in a pure metal, the residual resistivity is proportional to the concentration. Mattheissen's rule, a special case of eq. (3), states that the increase in resistivity of a metal due to a small concentration of another metal in solid solution is in general independent of the temperature. The concentration of impurities must not be so much as to modify the electronic structure of the solid. Deviations from Mattheissen's rule are attributed to modifications of the properties of the metallic matrix.

Vacancies and interstitials may be treated as substitutional impurities. The scattering due to them is then proportional to the concentration.

For the addition of transition metal impurities, the residual electrical resistance does not remain constant. At low temperatures the resistivity versus temperature curve may show a minimum. The temperature at the minimum is a function of the resistance ratio at the minimum. In some cases the minimum is followed by a maximum at lower temperatures.

In most cases scattering from impurities is essentially Coulomb scattering. The impurity atom may have a different valence from the host atom. Impurities

represent local disturbances in an otherwise perfect lattice which scatter electrons and contribute to the residual resistivity. A valency difference ΔZ between the host and impurity atoms then would produce an extra perturbing potential $\Delta Z e^2/r$ at a distance r from the impurity atom. In practice the potential falls off much more rapidly because of the screening effect of the electron gas. The scattering probability is proportional to $(\Delta Z)^2$. Even if the impurity atom has the same valence, it will cause a charge deviation in the lattice due to screening effects.

Scattering from vacancies and interstitial atoms is also Coulomb scattering. A vacancy behaves to a certain extent like an impurity atom of valency zero. The scattering probability is proportional to $(\Delta Z)^2$ just as in the case of impurities. For vacancies this probability may be an underestimate because the crystal lattice will relax around a vacancy to a much larger extent than is possible around an impurity atom. The resistivity of an interstitial atom is of a similar order of magnitude to that of a vacancy. While ΔZ is now zero, this is offset by the fact that the lattice distortion is more severe.

The scattering power of dislocations is not well established. Resistivities due to dislocations are significantly larger than predicted by the most reliable calculations. This may be due to stacking faults and the splitting up of a dislocation into two partial ones. Effect of grain boundaries is the same as a linear array of dislocations.

3. Scattering from specimen boundaries.

Specimen size is another factor which affects the resistivity under certain conditions. This contribution becomes important when the mean free path of the free electrons is of the order of or greater than the dimensions

of the specimen. The mean free path increases with decreasing temperature. In Al the mean free path at room temperature is $\sim$ 170A°. At liquid helium temperatures, assuming $R_{300}/R_{4.2} \sim 10^4$, the mean free path is 0.017 cms. The size effect is essentially a low temperature phenomon.

The size effect contribution to the resistivity has been calculated for a thin film by Fuchs[5] and Sondheimer[6] using the linearized Boltzmann transport equation subject to the appropriate boundary conditions.

One of the assumptions in the above theory is that the surface roughness can be characterized by a parameter P which represents the fraction of conduction electrons specularly reflected at the surfaces. P can take on values between 0 and 1. Specular scattering is said to occur when the electron velocity component normal to the surface is completely reversed on collision with that surface. For specular scattering the parameter P = 1. Diffuse scattering occurs when electrons have completely random trajectories and lose their drift velocity. P = 0 for completely diffuse scattering.

Lucas[7] has modified Fuch's and Sondheimer's expression for the thickness contribution to the resistivity to allow for thin metal films in which the scattering of conduction electrons is different at each surface.

For a film of thickness of d and $K \equiv \frac{d}{\lambda}$ where λ is the mean free path, according to Lucas' theory,

$$\frac{\rho_0}{\rho} = 1 - \frac{3}{4K} \int_0^1 \frac{(t - t^3)\left\{1 - e^{-(K/t)}\right\}}{1 - PQ\, e^{-(2K/t)}} \times \left[2 - P - Q + \left\{P + Q - 2PQ\right\} e^{-(K/t)}\right] dt \qquad (7)$$

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where,

$t = \cos \theta$

P = 0 completely diffuse scattering

P = 1 completely specular scattering

P, Q are surface roughness parameters for the lower and upper surfaces respectively (Fig. 1).

P, Q are assumed to be temperature and thickness independent.

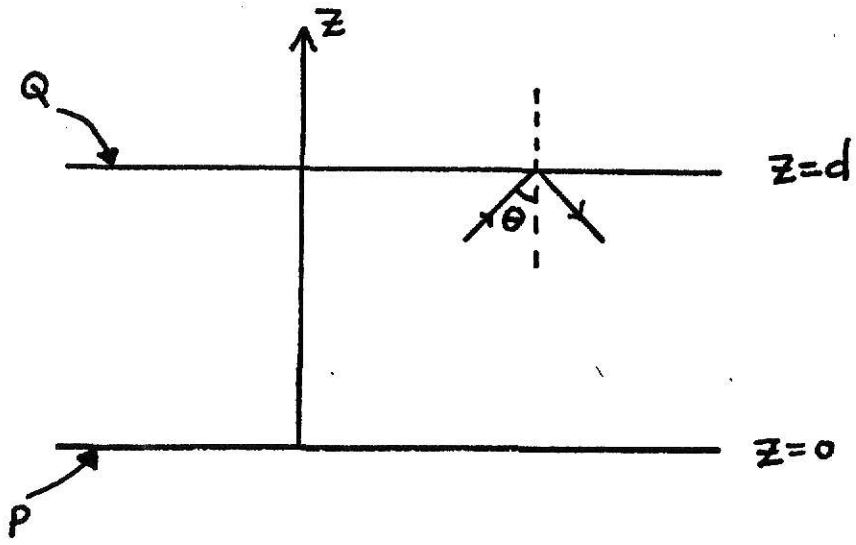

Fig. 1

Cross section of a thin film of thickness d. z = 0 indicates the lower surface, z = d the upper surface. θ is the scattering angle of an electron at the surface. P and Q are the surface roughness parameters of the z = 0 and z = d surfaces respectively.

EXPERIMENTAL

Experimental apparatus was constructed which permits measurement of the resistivity of thin film specimens over the temperature range 2.4 - 300°K.

A. Liquid He Cryostat

1. Construction

The design takes into consideration the type of refrigerant used, the heat inflows, the range over which the temperature is to be controlled, and the time for which the specimen needs to be kept at a constant temperature. Ref. (8) is a good general reference.

The schematic of the cryostat is shown in Figure (2). The outer dewar (D_1) is made of double-walled glass and is silver coated, to minimize radiation losses. The space between the walls is evacuated and sealed. This evacuated space acts as a thermal shield and prevents heat leak into the refrigerant, which is liquid N_2. The inner dewar (D_2), also double-walled glass, may be filled with liquid He or liquid N_2 depending on the temperature range desired. The space between the walls of (D_2) is attached to a pumping system. The pressure in this space can be lowered to 10^{-6} Torr. The pumping system utilizes a 2" oil diffusion pump to reach these pressures. The nitrogen gas inlet on the pumping line is used to admit nitrogen gas into the space between the walls of the inner dwar. This allows the liquid N_2 in the outer dewar to precool the inner dewar to about 80°K prior to transfer of liquid He into the inner dewar. The N_2 gas is then pumped out and liquid He may be transferred. The inner dewar D_2 may be connected to a high capacity rotary pump to reduce the temperature below 4.2°K by reducing the pressure above the He thus lowering its boiling point. The He gas inlet on this pumping line is used to control pressure over the He bath. A safety release is also included to prevent excess gas pressures from building up.

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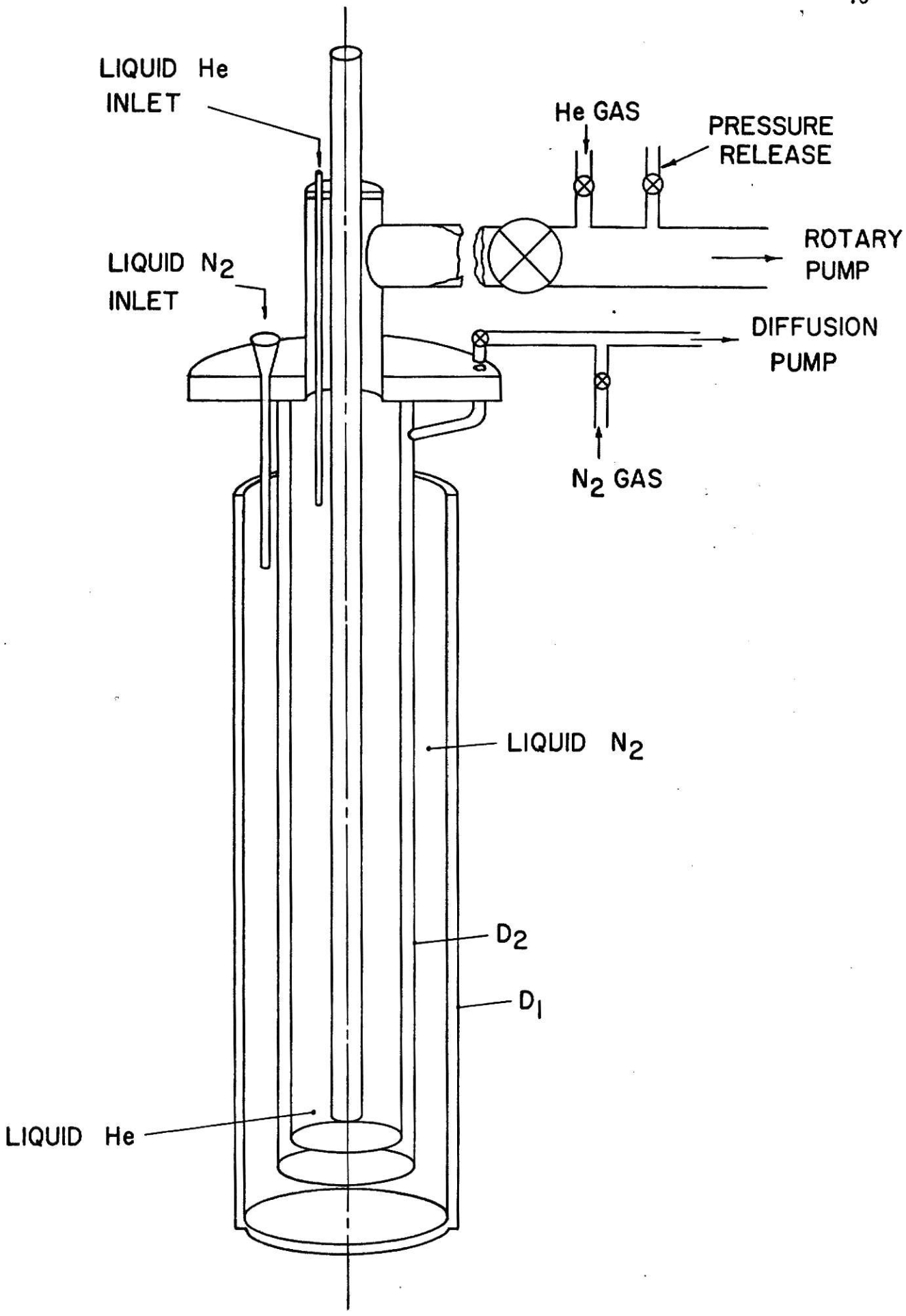
Fig. 2.

Schematic diagram of a cryostat used to measure the resistivity of thin film samples.


LIQUID He
INLET
He GAS
PRESSURE
RELEASE
ROTARY
PUMP
LIQUID N_2
INLET
DIFFUSION
PUMP
N_2 GAS
LIQUID N_2
D_2
D_1
LIQUID He

2. Temperature Control

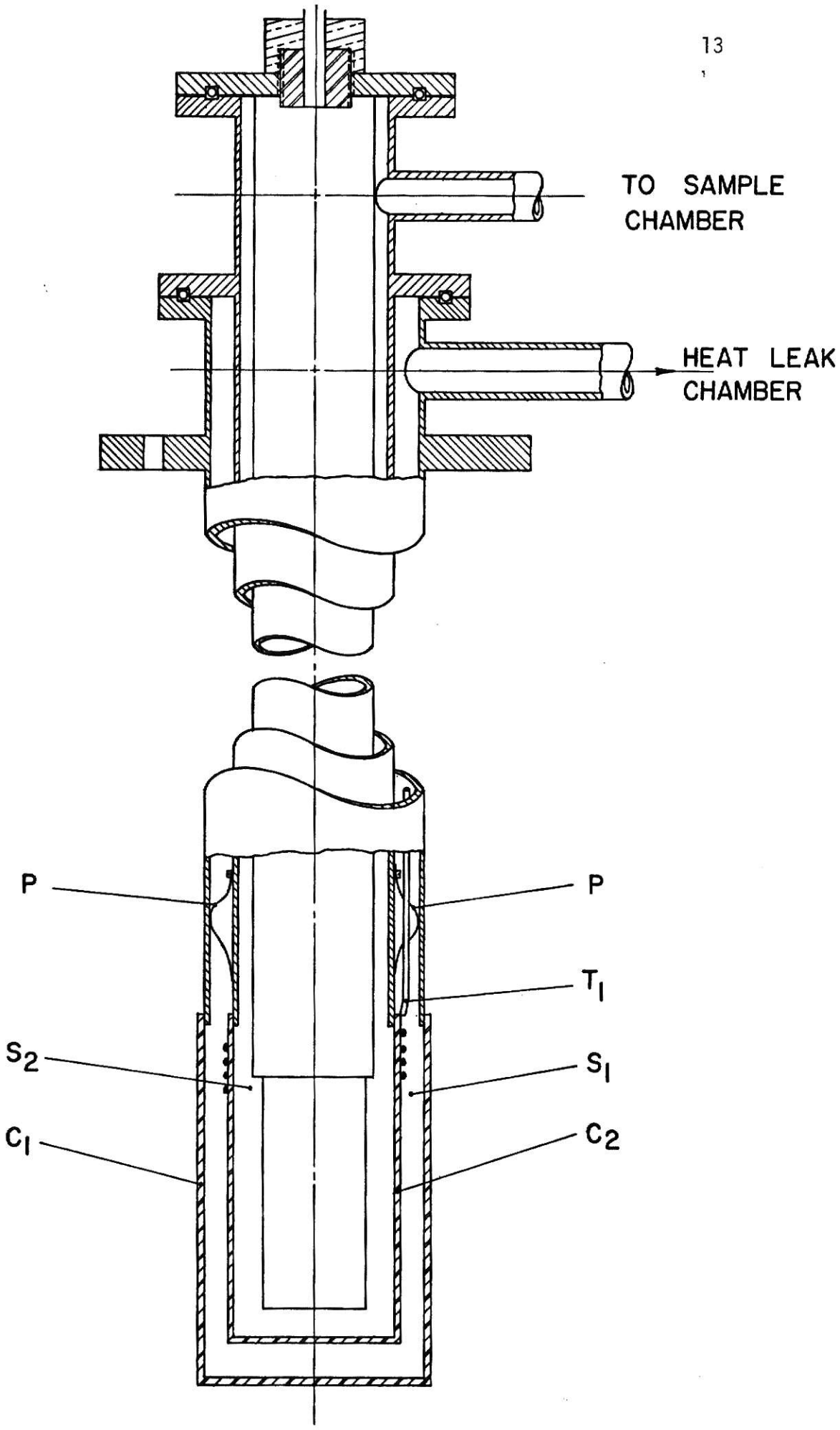
The heat leak chamber in the cryostat Fig. (3) and the temperature controller serve to maintain the temperature inside the sample chamber constant to within ±1°K. To achieve the lowest temperatures the apparatus permits use of liquid He as a refrigerant. Liquid He has a boiling point of 4.2°K and temperatures down to 2.4°K can be achieved by controlling the pressure above the liquid He, thereby controlling the temperature at which the liquified gas boils. By controlled electrical heating of the heat leak chamber, temperatures above 4.2°K can be obtained. At temperatures greater than 63°K a convenient refrigerant is liquid nitrogen.

Fig. (3) is a schematic of the sample and heat leak chambers S_2 and S_1 respectively. The sample is isolated from the liquid refrigerant by two concentric tubes C_1 and C_2 forming the heat leak chamber S_1. The lower part of both tubes is made of copper for good heat conduction. The upper part is made of thin walled stainless steel to minimize direct conduction of heat to the He bath. The space between the two tubes can be evacuated to isolate the sample from the bath. The heater wire (constantan 30 gauge) is wound round the copper tube C_2. A copper vs. constantan thermocouple is also glued to the tube C_2. This thermocouple senses temperature changes in the system. Phosphor bronze spring clips P provide a thermal path between heater and refrigerant. The heat leak chamber S_1 is connected to a small tank which can be pressurized by He gas.

The sample chamber S_2 is normally operated full of He exchange gas at a pressure of a few Torr. The exchange gas provides thermal contact between the sample and the heat leak chamber. All electrical connections are made by thin (30 gauge) copper wires which are thermally anchored before being connected to the specimen. The electrical feedthrough is a Conax seal.

Fig. 3.

Schematic of the sample chamber and heat leak chamber. S_1 is the heat leak chamber; S_2 is the sample chamber. T_1 denotes a thermocouple; P denotes phosphor bronze clips; C_1 and C_2 are the outer and inner copper tubings.


TO SAMPLE CHAMBER
HEAT LEAK CHAMBER
P
P
T_1
S_2
S_1
C_1
C_2

Temperature Controller

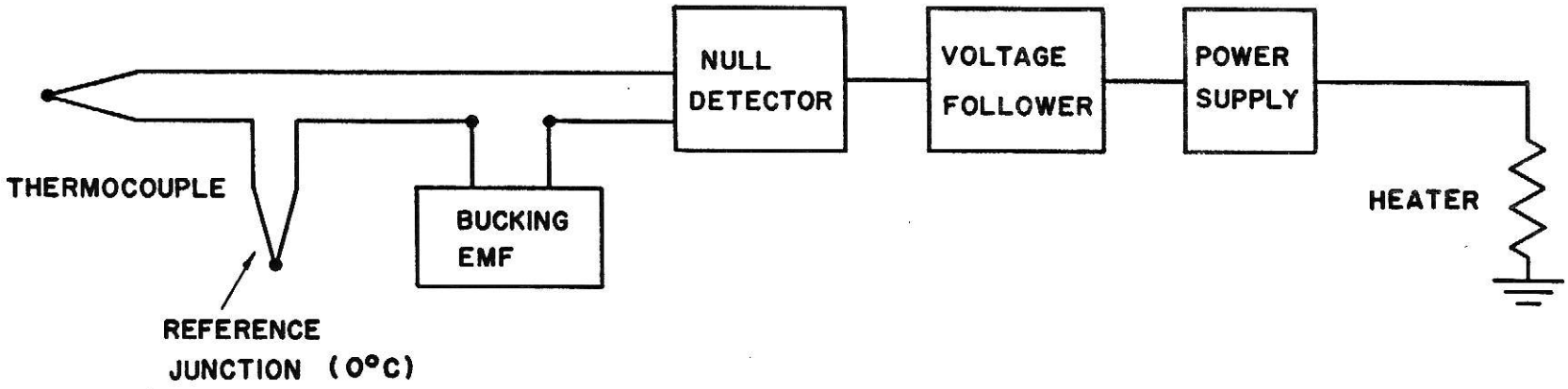
The block diagram of the temperature controller is shown in Fig.(4). The temperature is set to a particular value by adjusting the input voltage to the heater wire wound round the copper tube C_2 (Fig. 3). The emf of the thermocouple T_1 is fed to a bucking circuit, which is adjusted to give a null output at the desired temperature. The output of the bucking circuit is fed into a Keithley Model 155 null detector. If the temperature fluctuates, there is an off-balance signal seen by the null detector. The off-balance signal is amplified by the null detector whose output voltage in volts is the input voltage divided by the range switch setting. Maximum output voltage is $\pm$1V. The output voltage from the null detector is used as a programming voltage and is fed through a voltage follower to the programming terminals of a Lambda Model LP 410 FM regulated power supply. A change of $\pm$V in the output of the null detector produces a change of $\pm$V in the output of the power supply. The output of the power supply is connected to the heater wire in the heat leak chamber, hence the programming voltage changes the total input voltage to the heater. The polarity of the signal from the null detector (i.e. sign of the programming voltage) determines if the heater power is increased or decreased. The change in voltage is proportional to the excess or deficit temperature as seen by the thermocouple T_1. Fig. (3).

B. Sample Holder

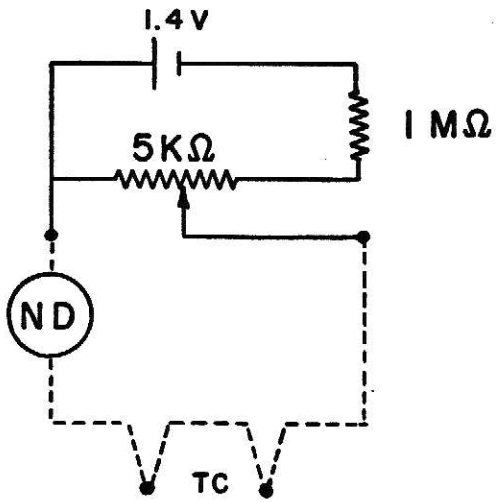
Fig. (5) shows the design of the sample holder. The sample holder is a solid piece of copper. The mass is large enough to provide an adequate heat sink for the electrical connections to the sample and to minimize thermal gradients along the sample. The specimen, a thin film evaporated onto a microscope cover slip, is held against the sample holder by clips. A

Fig. 4.

Block diagram of the temperature controller electronics.



BUCKING CIRCUIT



VOLTAGE FOLLOWER

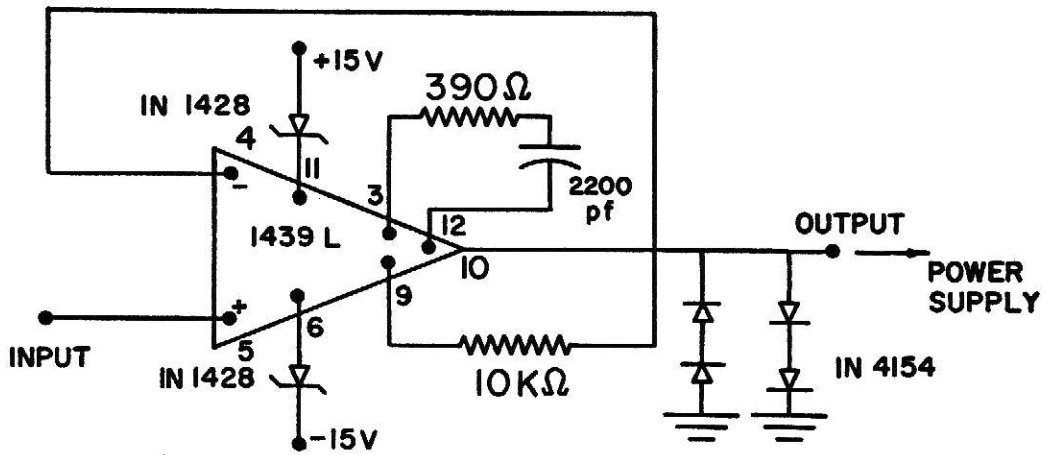
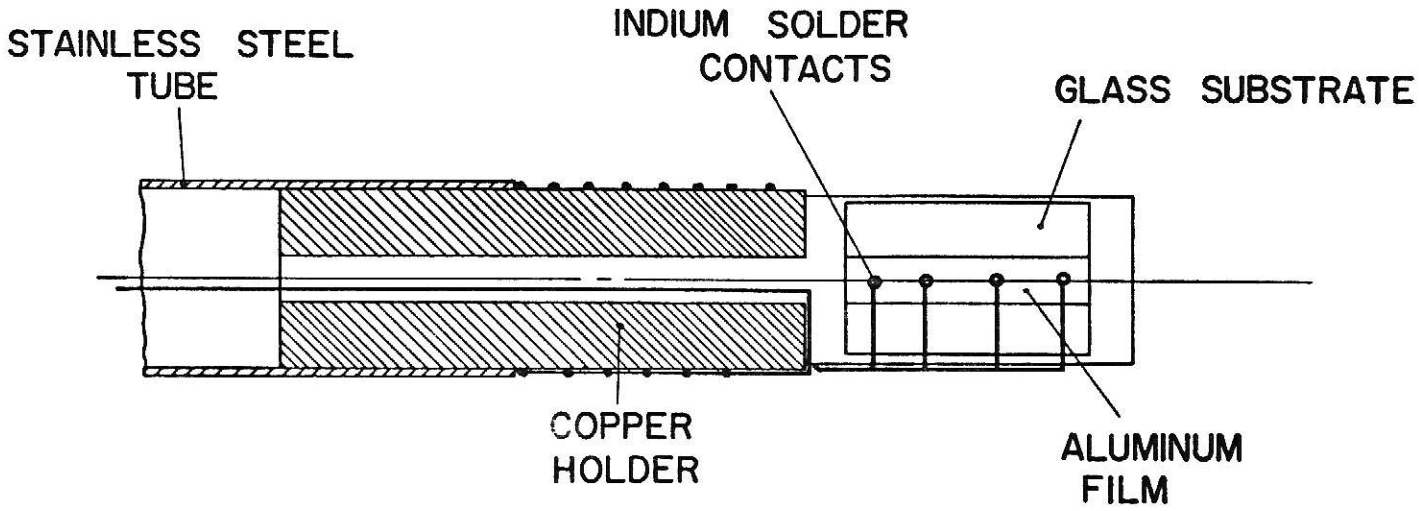
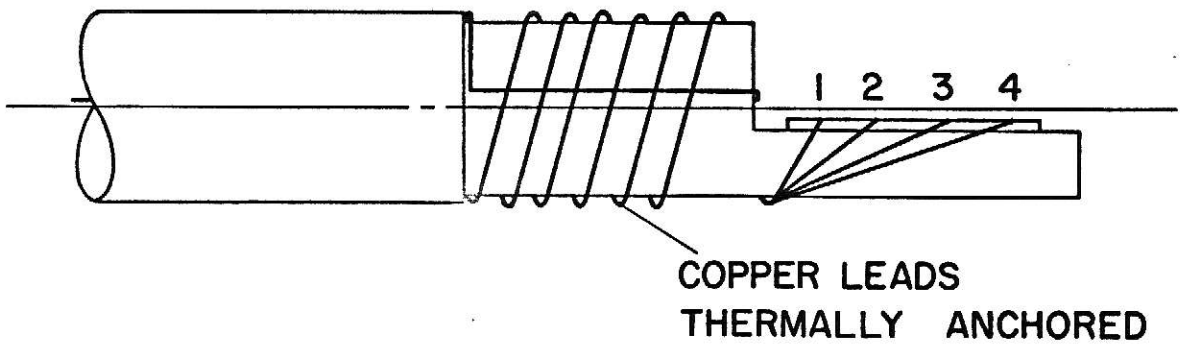


Fig. 5.

Schematic of the sample holder.





1 , 4 CURRENT LEADS

2 , 3 VOLTAGE LEADS

thermocouple glued to the sample holder is used to measure the temperature of the sample. The sample holder is fixed to the end of a thin walled stainless steel sample tube by means of Duco cement.

C. Temperature Measurement

The temperature is measured with a copper-constantan thermocouple. The reference junction is kept at the temperature of melting ice. The other junction is attached to the copper portion of the sample holder. The thermocoupld emf is measured with a potentiometer. The potentiometer used is a Leeds and Northrup K-4 type potentiometer.

D. Resistivity Measurements

Electrical resistivities of thin metallic films lie in the range of a few $\mu\Omega$-cm. At liquid helium temperatures and for very pure material the resistivity of bulk metal is small, typically 0.0006 $\mu\Omega$-cm for aluminum. Since the resistance of a sample of length ℓ and cross-sectional area A is $\rho\ell/A$, ℓ is normally made as big and A as small as possible to give measurable values of resistance.

Potentiometric methods offer the most accurate and convenient means of determining the resistances of 4 terminal resistors, whatever the temperature and resistance of the leads. The presence and effect of high-resistance leads is rendered quite unimportant, because in the final balance position no currents flow in the potential leads. The effect of any thermal emf's that are present may be eliminated by current reversal through the sample.

The resistance of the thin film specimens was determined by measuring the potential drop between the two inner contacts to the film which were

approximately 1 cm apart. The current was measured by noting the drop across a 100 Ω standard resistor.

E. Specimen Preparation

Thin films of Al were deposited onto cleaned microscope cover slips by evaporation in a vacuum of 10^{-6} torr. The evaporations were made from a tungsten boat in an ion pumped vacuum system. The substrates were cleaned by ultrasonically agitating them in a detergent bath followed by rinsing them in running water. They were then etched in chromic acid and rinsed in deionized water. The substrates were dried in a vapour of isopropyl alcohol.

The shape of the film was rectangular, typically 3 cm long and 1/2 cm wide. Current was passed along the length of the specimen. Contacts were made to the specimen with indium solder.

RESULTS

Resistance versus temperature curves have been obtained for four different thicknesses of Al films. The thickness was measured by the Tolansky interferometric technique[9]. The technique involves an evaporation of a reflecting coating on the top of the specimen. A partially reflecting mirror is tilted against the specimen surface, and a fringe system of equidistant fringes is produced. An elevation or depression in the specimen surface causes a displacement of the fringes at the location of the step. The amount of displacement is a direct measure for the height or depth of the step.

$$d = \frac{K\lambda}{2}$$

d = step height (A°)

K = relative fringe displacement expressed in parts of one fringe

λ = wave length of light used for the measurement (A°)

This measurement could be made only for the thickest sample. For this sample the fringe shift was .14 of the fringe spacing. For the other samples the fringe shift was too small to measure.

The thickness of the sample can be calculated from the temperature variation of the resistance by the following procedure[10, 11].

$$R = \frac{\rho \ell}{tw} \qquad (8)$$

where R is the resistance of the sample

ρ is the resistivity of the sample

ℓ is the length of sample in cms

w is the width of sample in cms

t is the thickness of sample in cms

$$\frac{dR}{dT} = \frac{\ell}{tw} \frac{d\rho}{dT} \tag{9}$$

From equation (7)

$$\frac{\rho_o}{\rho} = F(P,Q,K) \tag{10}$$

If the size effects are independent of temperature

$$\frac{d\rho}{dT} = \frac{d\rho_o}{dT} \tag{11}$$

ρ_o = bulk resistivity

$$\Delta R = \frac{\ell}{tw} \Delta\rho_\infty \tag{12}$$

$\Delta\rho_\infty$ is the change in resistivity of an infinitely thick sample between temperatures 100°K and 300°K and is obtained from bulk resistivity data.

ΔR is the change in resistance of the sample between the same two temperatures

$$t = \frac{\Delta\rho_\infty}{\Delta R} \frac{\ell}{w} \tag{13}$$

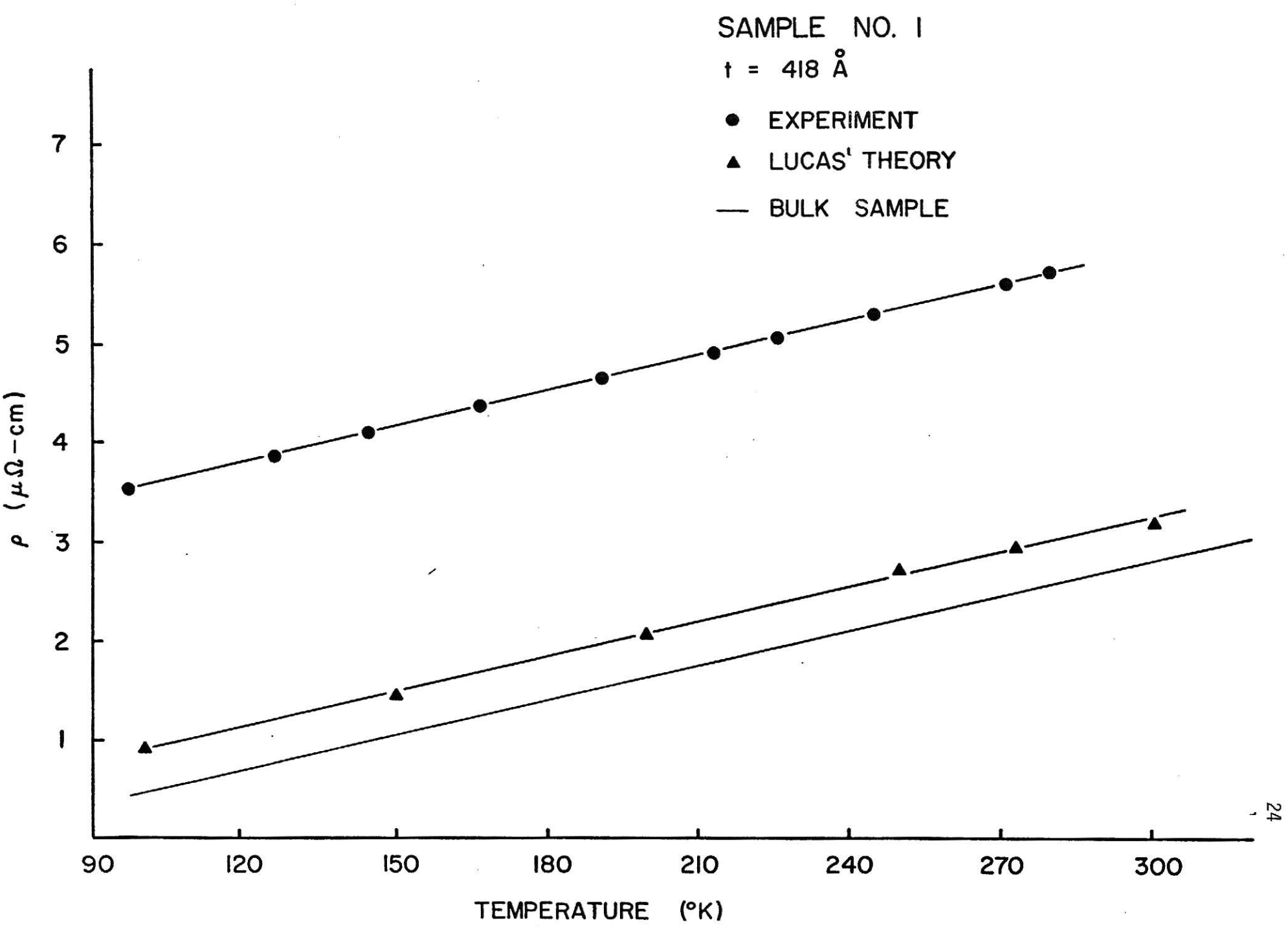
The calculated thickness was compared to a measurement by the multiple-beam interference technique for the thickest film. The discrepancy between the measured and calculated thickness of the film, which was less than 500A° thick, is $\sim$ 30%.

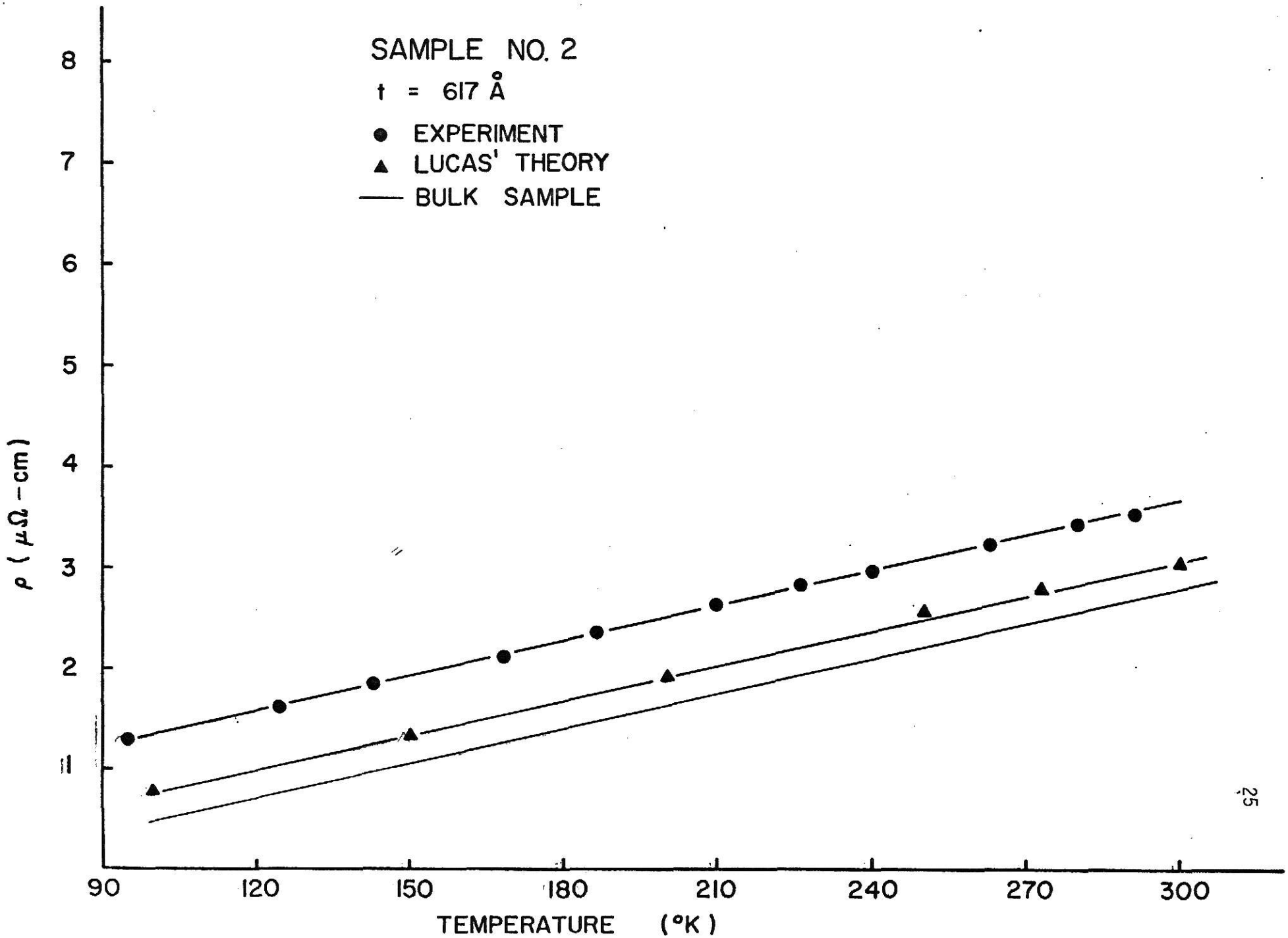
The resistivity at each temperature is calculated from the measured resistance using eqs. (8) and (13). Figs. (6-9) show the plots of resistivity

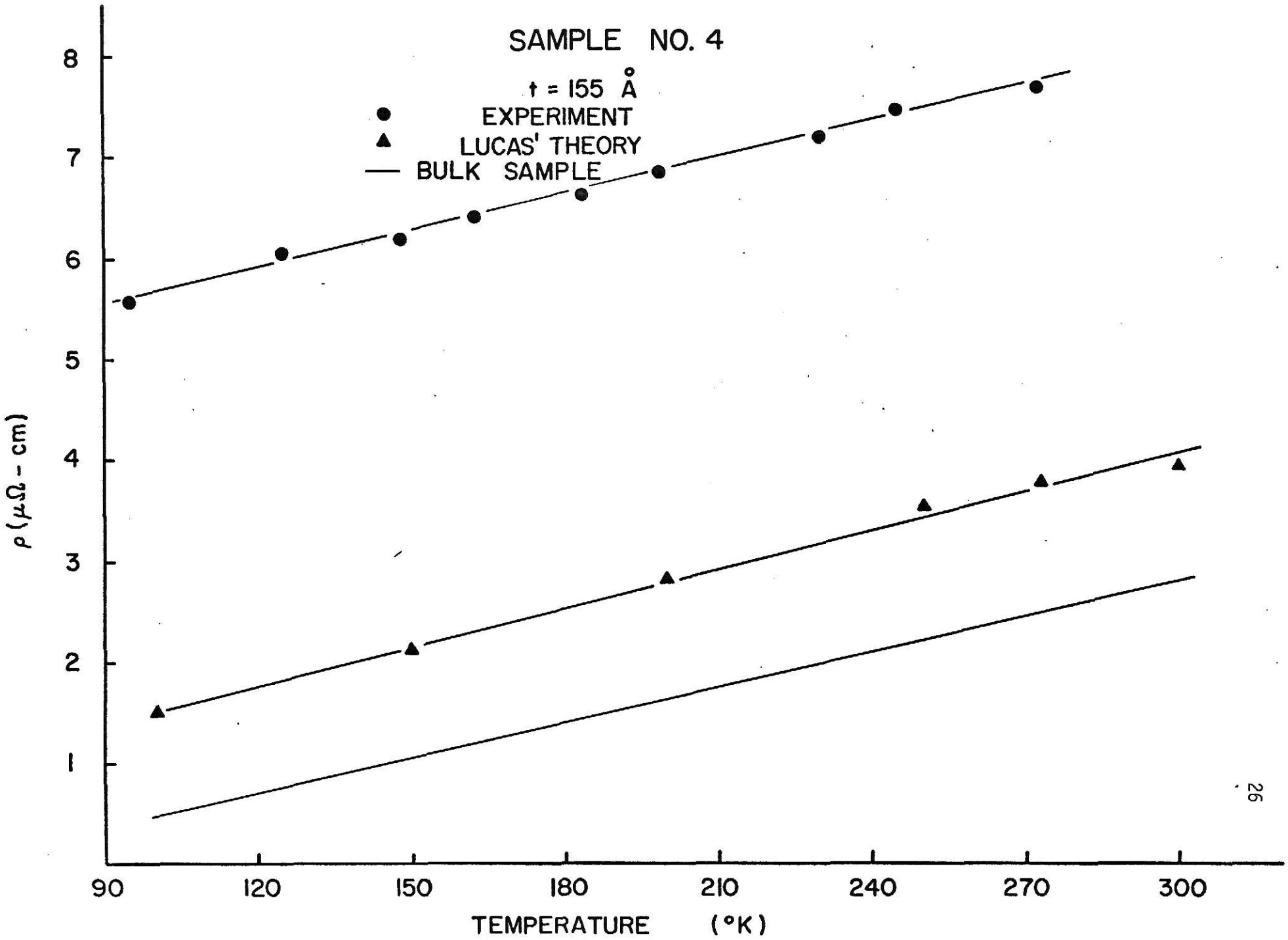
$$\rho(T) = \frac{\Delta\rho_\infty}{\Delta R} R(T) \tag{14}$$

Figs. 6-9.

Resistivity as a function of temperature for Al films. Circles represent the experimentally observed resistivity. The solid line represents bulk resistivity. Triangles represent the sum of the bulk resistivity and the contribution to the resistivity from diffuse scattering at the surfaces of the specimen.


SAMPLE NO. 1
t = 418 Å
EXPERIMENT
LUCAS' THEORY
BULK SAMPLE
ρ (μΩ-cm)
1
2
3
4
5
6
7
90
120
150
180
210
240
270
300
TEMPERATURE (°K)


SAMPLE NO. 2
t = 617 Å
EXPERIMENT
LUCAS' THEORY
BULK SAMPLE
ρ (μΩ – cm)
8
7
6
5
4
3
2
1
90
120
150
180
210
240
270
300
TEMPERATURE (°K)


SAMPLE NO. 4
t = 155 Å
EXPERIMENT
LUCAS' THEORY
BULK SAMPLE
ρ (μΩ - cm)
8
7
6
5
4
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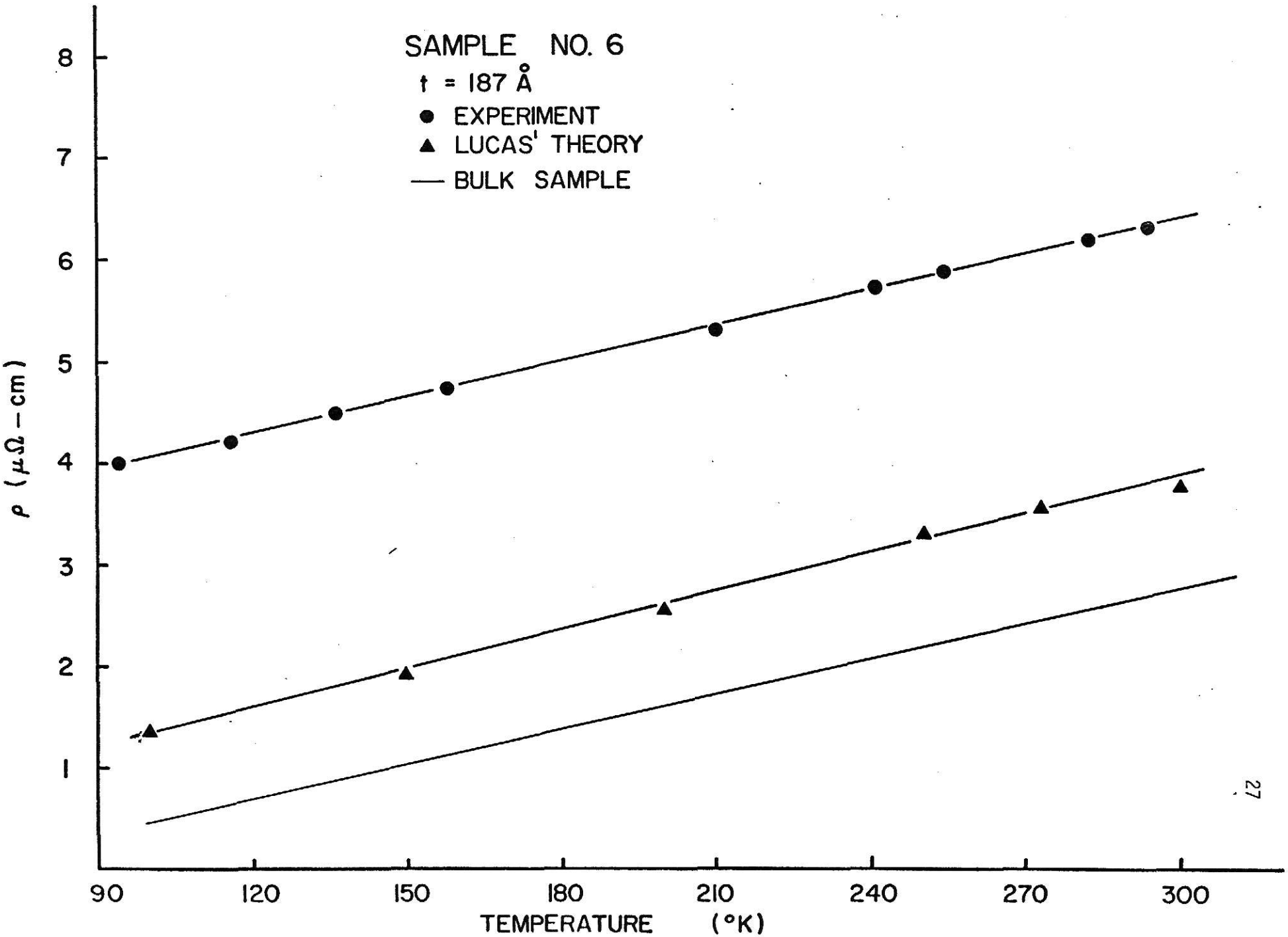
2
1
90
120
150
180
210
240
270
300
TEMPERATURE (°K)


SAMPLE NO. 6
t = 187 Å
EXPERIMENT
LUCAS' THEORY
BULK SAMPLE
ρ (μΩ − cm)
8
7
6
5
4
3
2
1
90
120
150
180
210
240
270
300
TEMPERATURE (°K)

vs. temperature for different thicknesses. The contribution to the resistivity due to the size effect has been estimated using eq. (7). Surface parameters P and Q have been assumed to be zero implying completely diffuse scattering.

Eq. (7) reduces to

$$\frac{\rho_0}{\rho} = 1 - \frac{3}{4K}\int_0^1 (t - t^3)\left\{1 - e^{-(K/t)}\right\} 2\, dt$$

where $K \equiv d/\lambda$ is the only temperature dependent quantity. The variation of λ with temperature is obtained from the theoretical Grüneissen curve of r vs t, where $r = R(t)/R(\theta)$ and t is the reduced temperature T/θ. ρ_0/ρ is calculated for different temperatures. ρ_0 is known as a function of temperature. Hence ρ can be obtained. This is plotted in the Figs. (6-9) as Lucas' theory. The value of bulk resistivity[12] is also plotted on Figs. (6-9) for comparison.

The difference between the measured resistivity corrected for size effect and the bulk is shown in Fig. (10). The films have been evaporated at room temperature. At the vacuum used in our experiment, residual gases can contaminate thin metal layers. In the absence of residual-gas analysis, the possibility that thinner films getter more impurities than thicker ones cannot be ruled out.

Fig. 10.

Experimental curves for different thicknesses. The size effect contribution has been subtracted in each case.

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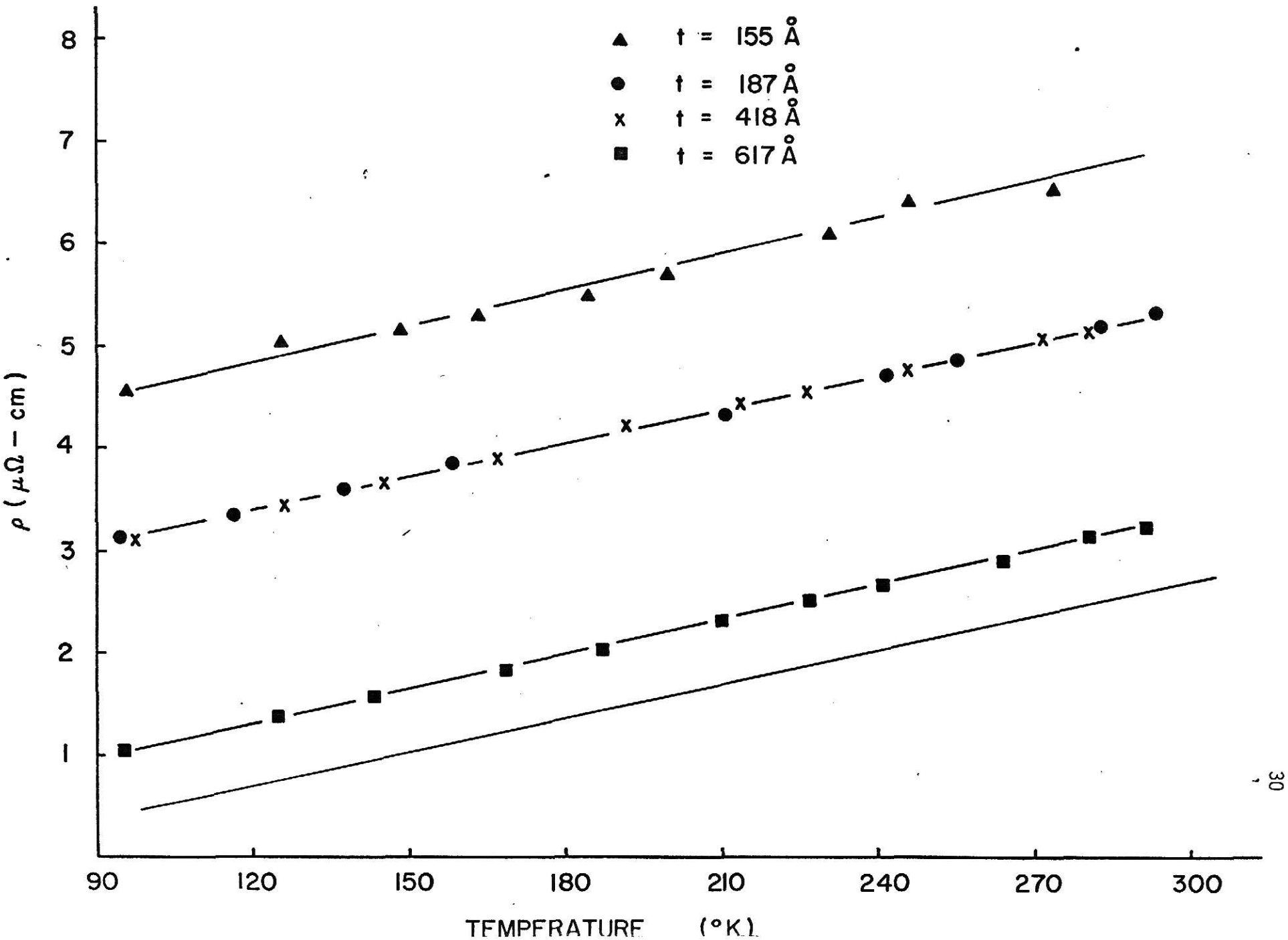
t = 155 Å
t = 187 Å
t = 418 Å
t = 617 Å
ρ (μΩ – cm)
8
7
6
5
4
3
2
1
90
120
150
180
210
240
270
300
TEMPERATURE (°K)

PROPOSED USE

Measurements on Dilute Alloy Thin Films

It is proposed to investigate the possibility of producing dilute alloys by ion implantation into a thin film and study the resistivity at low temperatures.

a) To characterize dilute alloy films produced by ion-implantation it is necessary to study the effect of radiation damage in the films. The damage may be studied by the changes it produces in electrical resistivity.[13] Measurements at low temperatures are necessary to minimize phonon resistivity background. At these temperatures the size effect contribution is significant. A study of the size effect for shallow implants can give an estimate of surface damage. Annealing conditions for removing damage (or minimizing it) should be looked into, otherwise the properties of the alloy films are likely to be dominated by the many defects each ion produces in coming to rest. Deviations from Mattheissen's rule can give an indication whether the thin film forms a dilute alloy or if damage plays too important a role.

b) A practical use of damage studies and one of current interest is the effect of radiation induced defects on electromigration rates.

Electromigration is mass transport under the influence of an applied dc electric field. In the electromigration effect the mass transport is treated as a result of the momentum exchange between the charge carriers and mobile ions. Electromigration can be studied using electrical resistivity measurements[14, 15].

The importance of electromigration in thin films is due to the fact that electromigration is a possible mode of failure in integrated circuits. The silicon wafer acts as a large heat sink and current densities $\sim 10^6 A/cm^2$ are obtained in a thin film on a Si substrate without appreciable rise in temperature. With these large current densities electromigration becomes a significant effect. Voids are formed and eventually the metallic interconnection forms an open circuit. In semiconductor device fabrication, evaporated metal interconnections between active regions on the wafer are essential features and the failure of a device will occur if there is a breakdown in one of the interconnections. Application of ion implantation to device fabrication is increasing. If the metallization of a device is exposed to the ion beam during implantation, a less reliable device may result. Ion beam damage to integrated circuit metallization has been reported. The electromigration rate and resistivity ratio of a thin film of Al both increase with the implant dose[14].

Optical microscopy[16] and scanning electron microscopy[15] have been used to view the kinetics of void and hillock formation due to electromigration in metal films. The dominant mechanism for current-induced mass transport in thin films appears to be grain boundary diffusion[17].

c) The preparation of alloys is complicated. High temperatures are necessary to produce them. The problem of segregation present in the bulk alloy preparation might be overcome by ion implantation of thin films. Although thermal annealing is necessary after implantation in order to reduce the effects of damage, annealing temperatures required are substantially less than for diffusion.

Experiments have shown that for certain metals the resistance at low temperatures does not become constant[18]. In some cases the resistivity vs. temperature curve passes through a minimum and as the temperature is further reduced starts to increase again. This effect is generally caused by the addition of the transition elements Fe, Mn, Cr, Co, and Ni. Associated with the minimum are other anomalous effects, i.e., anomalies in absolute thermopower, in electron and nuclear spin resonance and in the magnetic susceptibility.

Transition metal impurities could be implanted and the anomalous resistivity behavior in dilute metallic solutions studied. Experiments on Cu and Au with non-magnetic and magnetic solute atoms could also be carried out to compare deviations from Mattheissen's rule.

The difference $\Delta\rho$ between the resistivity of the alloy with addition of transition metal impurities and the pure metal plotted as a function of temperature shows a maximum (at 65°K for Au-Cr 0.09 at %). $\Delta\rho$ at low temperatures is not proportional to the concentration of the transition metal, in disagreement with results of Knook[19] which indicates the introduction of unidentified impurities. Implantation into a film could overcome this problem.

A system which could be readily investigated is Au-V. It has a fairly high temperature resistivity minimum ($T_{min} \sim$ 200°K). Since the contribution of lattice defects and non-magnetic impurities is significant only at low temperatures ($\sim$ 4.2°K), the magnetic behavior of this system would be relatively insensitive to their presence. Gold is a good candidate for the host material since it has been reported by Lucas[20] that films of gold in thicknesses down to 60°A can be obtained with conductivities approaching that of the bulk metal.

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DESIGN, CONSTRUCTION AND PROPOSED USE OF APPARATUS FOR MEASURING RESISTIVITY OF THIN FILMS IN THE TEMPERATURE RANGE 4.2-300°K

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ABSTRACT

A cryostat has been designed and constructed for the purpose of measuring the electrical resistivity of thin films at low temperatures. A temperature controller for the cryostat has been built and tested in the temperature range 77°K - 300°K. The cryostat system has the capability of maintaining temperatures down to 2.4°K if liquid He is used as the refrigerant. The resistivity of Al thin films has been measured by the four terminal potentiometric technique in the temperature range 77°K - 300°K. The temperature dependence of the resistivity has been interpreted in terms of bulk and surface scattering mechanisms in the Al films. Proposed uses of the equipment for future experiments have been included.