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ELECTRICAL PROPERTIES OF RF SPUTTERED NiCr THIN FILM RESISTORS WITH Cu CONTACTS

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Investigations on RF sputtered NiCr thin film resistors, fabricated using Cu as conductor metallization, were made. The contact resistance characteristics, resistor film characteristics and TCR of the resistors were measured. The effect of heat treatment on the resistor characteristics was studied. A suitable annealing cycle for the resistor stabilization was studied. A suitable annealing cycle for the resistor stabilization was obtained. The effect of passivation by a thin quartz film on the resistor properties was also examined. The results are presented and discussed in this paper.

1. INTRODUCTION

NiCr is one of the most commonly used resistive material for fabricating precision thin film resistors. This transition metal alloy exhibits a wide range of resistivity, low temperature coefficient of resistance (TCR) and high stability of electrical properties. Owing to its technological importance NiCr resistors have been the subject of several investigations. Numerous publications on different aspects of resistor fabrication and characterization have appeared in the literature during the past fifteen years.[1–19]

Conventionally a multilayer Ti-Pd-Au conductor system is used as the contact metallization for NiCr resistors.[11] In recent years due to increased cost of the precious metals a need for a low cost replacement metallization for the expensive Ti-Pd-Au has been realized. Different metals[10,15] and metal combinations[16,17] have been investigated for the purpose. We have examined the use of copper as the contact metallization. Copper has a higher conductivity and is less expensive compared to gold. Also, copper is easily solderable. The limitation on using Cu for contact metallization is that the Cu/NiCr contact cannot be annealed at the high temperature, usually required for resistor stabilization, due to oxidation of Cu and interdiffusion of Cr into Cu.[18]

The purpose of this paper is to report the results of our investigation on NiCr resistors fabricated with Cu contacts. The contact resistance was measured. The effect of heat treatment on the contact characteristics was studied. An optimum thermal annealing cycle for the resistors stabilization was obtained. The resistor characteristics and TCR of the resistors measured before and after the heat treatment are presented. The effect of passivation by a thin quartz film on the resistor properties is also reported in this paper.

2. EXPERIMENTAL

The resistors were fabricated on Alsimag glazed ceramic substrates. The substrates were cleaned by the standard procedure and were dried by blowing nitrogen gas before loading onto a water cooled anode in the sputtering chamber. An 8620J rf sputtering machine of MRC was employed to sputter the resistor (NiCr) and the conductor (Cu) films. The composition of the NiCr target purchased from MRC was stated to be Ni40/Cr60. The procedure adopted for the films deposition was as follows:

The sputtering chamber was first evacuated to a pressure of 8×10^{-7} torr. Then UHP argon gas was introduced in the chamber through a needle valve. The pressure inside the

TABLE I
Typical NiCr/Cu film deposition parameters:

Substrate	Glazed Ceramic
Sputtering gas	UHP Argon
Argon Pressure during sputtering.	5 m torr.
Distance between target and the substrate holder.	7 cm.
NiCr target composition	Ni 40/Cr 60
NiCr sputtering voltage	2 KV.
sputtering time	3 min.
Cu sputtering voltage	1.5 KV.
sputtering time	60 min.
Quartz sputtering voltage	1.5 KV.
sputtering time	30 min.

chamber was maintained at 5 m torr and the chamber was evacuated, in this state, for 15 minutes to ensure an inert atmosphere in the sputtering chamber. Both the NiCr and Cu targets were presputtered separately for 20 minutes each at a target voltage higher than the actual sputtering voltage. The NiCr and Cu films were sputtered sequentially in the same pump-down. Typical data of the sputtering process are given in Table I. The sheet resistivity of the NiCr film was 200 Ohms/square and thickness of the Cu film was 1.5 microns.

The resistor and conductor patterns were delineated by selectively etching the Cu and NiCr films using a photolithography technique. The copper contacts were protected by Sn Pb 60/40 solder immediately after fabrication. Measurements were taken on the as prepared resistors, after heat treatment of the resistors and after depositing a thin quartz film (0.3 microns) on the resistors.

3. RESULTS AND DISCUSSION

3.1 *Contact Resistance Characteristics.*

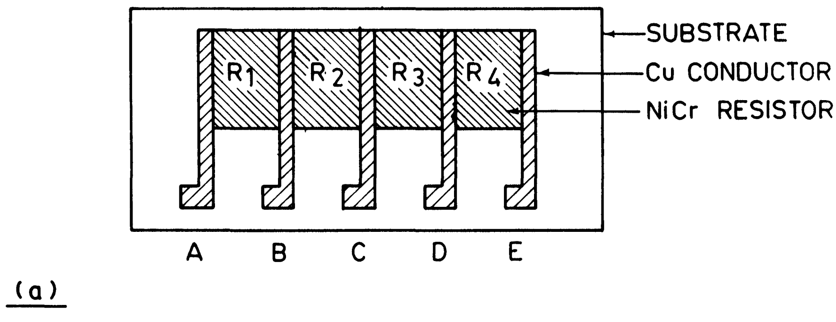
The contact resistance of the Cu-NiCr contact was measured by a simple bridge balance technique.[19] The electrical equivalent circuit of the measuring system is shown in Figure 1(a). It consists of two symmetrical parts. R_1 and R_2 are the resistances of the NiCr resistors, which are nearly equal in value, and R_A, R_B and R_C are the resistances of the contacts A, B and C respectively, as shown in Figure 1(b). R_p, R_q and R_x, R_y are the resistances of the potentiometers used to control the voltage drop in the circuit. E_1 and E_2 are the potentials of the power supplies. R_v is a fixed resistance and a d.c. micro-voltmeter is employed to detect the null position.

In the method used, a source of potential E_1 is connected to provide a current i_1 between points A and B. The compensation current i_1', between B and C is provided by the source of potential E_2. After compensation i.e. for a given E_1 adjusting E_2 such that $i_1 = 0$, the voltage drop V_p will clearly be given by

$$V_p = i_1', R_B$$

By measuring i_1' and V_p, the contact resistance R_B of the contact B can be calculated. Similarly the resistance of the other contacts can be measured.

Employing this technique the current – voltage characteristics of the contacts was measured at room temperature (25°C) after heating the resistors for an hour at different temperatures ranging from 25°C to 225°C. A representative plot of the characteristics is



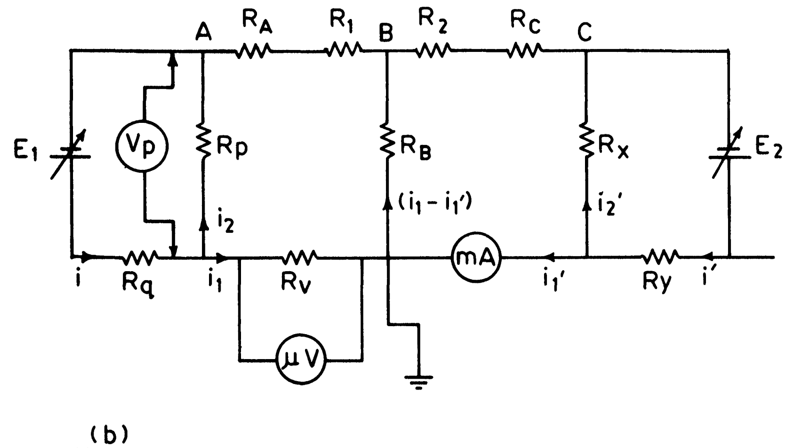


FIGURE 1 Measurement of contact resistance: (a) the fabricated structure of the NiCr resistors with copper contacts; (b) the electrical circuit.

given in Figure 2. The nature of the characteristics reveal that the Cu-NiCr contact is ohmic in the entire range of measurement. The contact resistances of the as prepared resistors is within 2-3 m Ohm cm.[2] This value increases only marginally, as shown in the figure, when the temperature of the resistor is raised from 25°C to 200°C. At 225°C although the contact I-V characteristics as shown in the figure remain ohmic, the contact resistance increases drastically. It is at this temperature that we believe the interdiffusion of Cr into Cu is substantial. There is also a possibility of some copper film being dissolved in the Sn/Pb solder.[20] The increase in the contact resistance is about 7 times the value obtained after annealing at 200°C.

In the light of the above results we decided on 150°C as a safe annealing temperature for the Cu contacts protected by Sn/Pb solder. That the 150°C temperature would be safe for annealing is evident by the phase diagram[21] of Cr-Cu and Ni-Cu. Any possibility of interdiffusion at this temperature would be negligible. Further the heat treatment at 150°C in air rather than at a higher temperature also reduces the possibility of producing an open circuited resistor during the relatively long heat treatment time.[4]

The change in the contact resistance during annealing in air ambient at 150°C was measured as a function of time. The data is shown in Figure 3. For comparison the

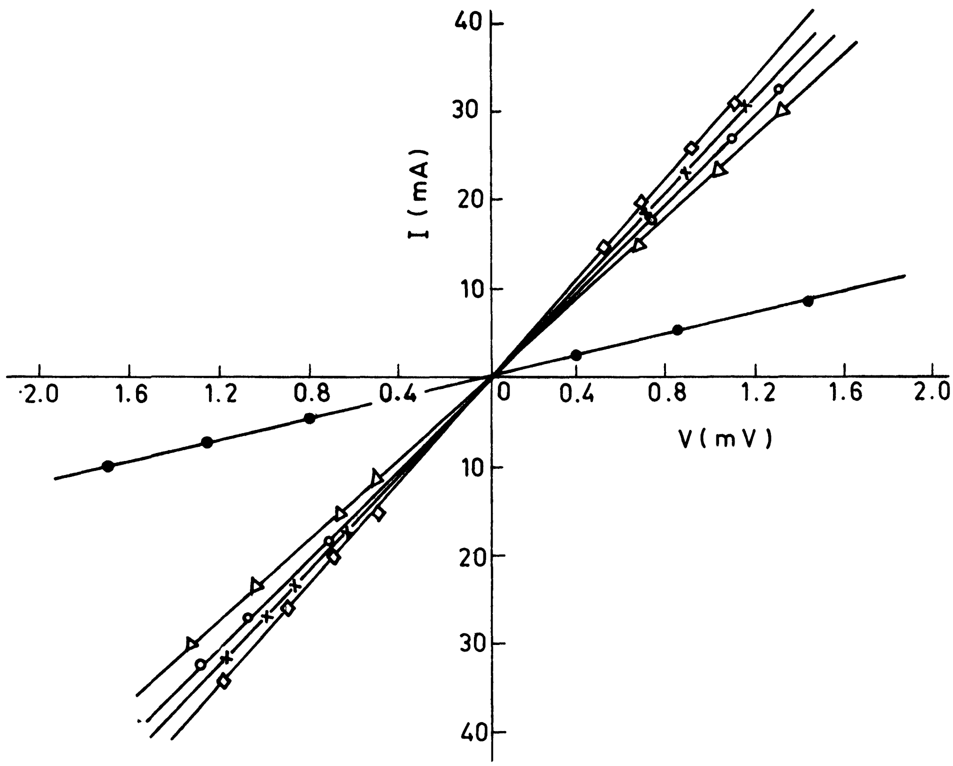


FIGURE 2 The contact I-V characteristics measured at room temperature: (□) before annealing; and after annealing for 1 hour (X) at 75°C, (○) at 150°C, (△) at 200°C and (●) at 225°C.

contact resistance measured at room temperature before and after annealing is also included in the figure. It may be noted that the contact resistance before annealing was about 2.5 m Ohm cm.^{2} This value increased to about 3 m Ohm cm^2 after annealing for 48 hours at 150°C.

3.2 *Resistor Film Characteristics.*

Freshly deposited NiCr films shows a tendency for self annealing.[8] This results in changes in resistance and TCR of the film. It is therefore necessary to stabilize the film properties. Usually NiCr films are annealed in air at 300°C for 2 hours for stabilization of the resistor film characteristics. The NiCr-Cu resistor system, as discussed in the previous section, cannot be annealed at such high temperatures. The film stabilization temperature was therefore restricted to 150°C.

As the films were being stabilized in an oven at 150°C, the change in the film resistance was measured as a function of heat treatment time. Figure 4 shows the increase in the film resistance plotted as a function of the square root of the heat treatment time. The variation is linear. The data indicates that the increase in the film resistance is due to surface oxidation of the NiCr film and is limited by the diffusion mechanism.[4] It may be remembered here that oxidation of the NiCr is preferential. Exposure of the film surface produces Cr_2O_3 while Ni remains virtually in the metallic state.[13] By oxidizing

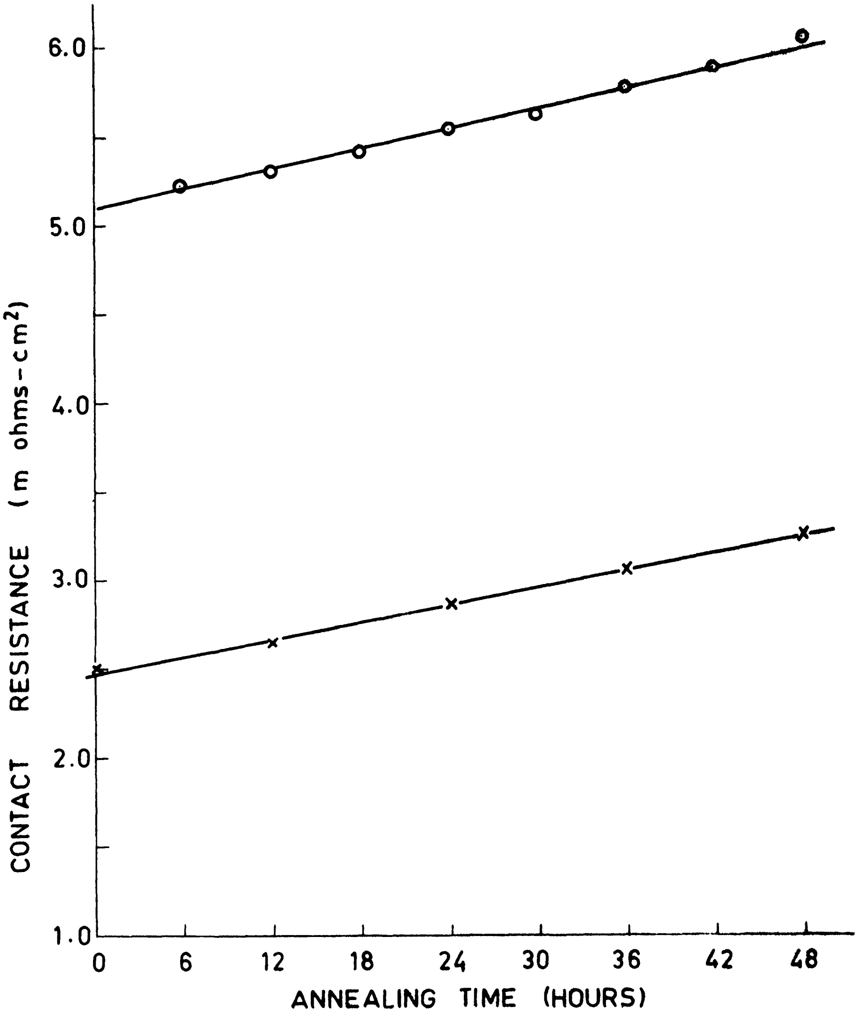


FIGURE 3 The contact resistance measured as a function of annealing time (○) at 150°C and (X) at room temperature.

the top surface of the film the material beneath is protected against further exposure to the ambient gases, thus stabilizing the films. Typical I-V characteristics of the as prepared resistor, after annealing the resistor and after 1000 hours measured at room temperature, are shown in Figure 5. After stabilization the increase in the film resistance measured on a 5 1/2 digit HP 3455A voltmeter was typically 0.35 percent after 1000 hours at room temperature. This shows that the long term stability of these resistors is not good. We believe that the stabilization by the thermal annealing cycle is not adequate. This was confirmed by depositing a quartz thin film on the heat treated resistors. We observed that the stability improves significantly. A plot of the resistance change measured as a function of time at 70°C on these resistors is shown in Figure 6. The stability of these resistors improves from 0.35 percentage to 0.04 percentage.

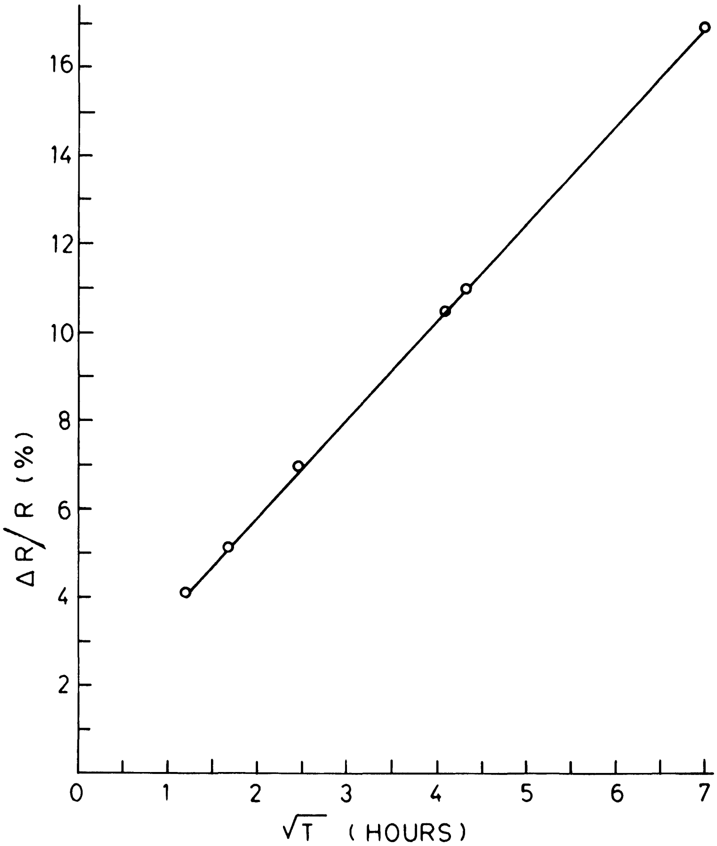


FIGURE 4 The change in the NiCr film resistance at 150°C as a function of square root of the annealing time.

3.3 *Temperature Coefficient of Resistance:*

TCR of the resistors was measured in the temperature range of 25°C to 125°C. Typically the TCR of the resistors after annealing was 25 ppm/°C. TCR of the resistors measured as a function of annealing time is given in Figure 7.

CONCLUSIONS

The results of our investigation show that it is possible to produce good NiCr resistors using Cu as a conductor with stable electrical properties.

The contact between the conductor Cu film and the resistive NiCr film is ohmic. The contact resistance is 2-3 m Ohm cm.[2] The contact I-V characteristics studied as a function of temperature show that above 200°C the contact resistance increases drastically.

The resistor stabilization cycle, decided on the basis of the experimental data, for the NiCr resistors with Cu contacts is to anneal at 150°C in ambient air for 48 hours. This cycle was found to be safe but the stability of the resistors was not good. The stability

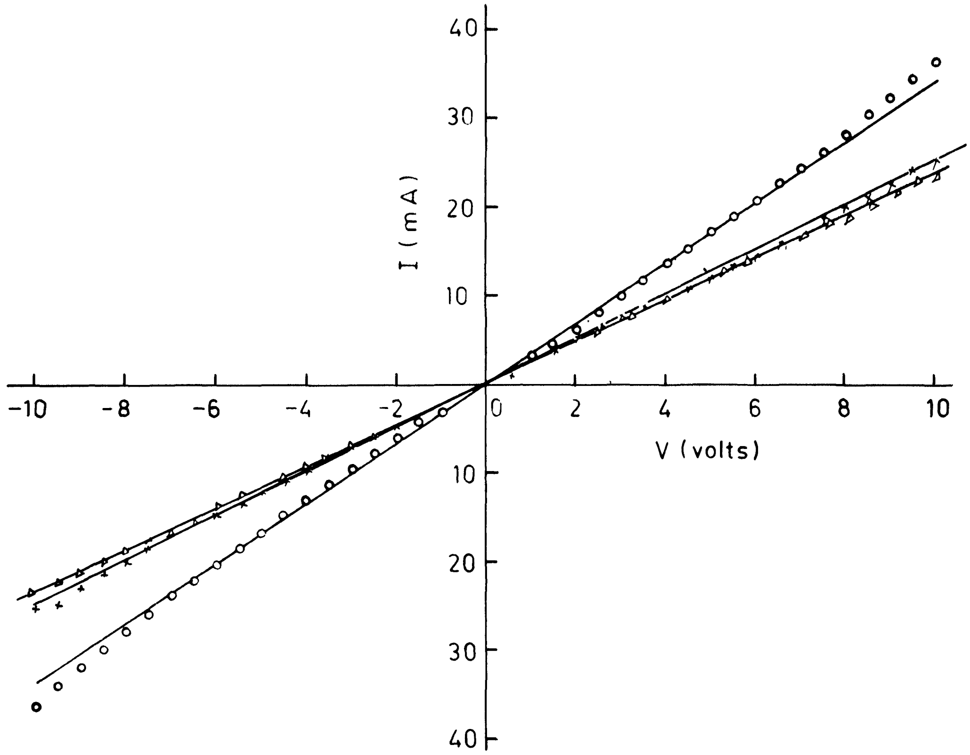


FIGURE 5 Current – voltage characteristics of the resistors: (o) as prepared, (X) after annealing and (Δ) after 1000 hours at room temperature.

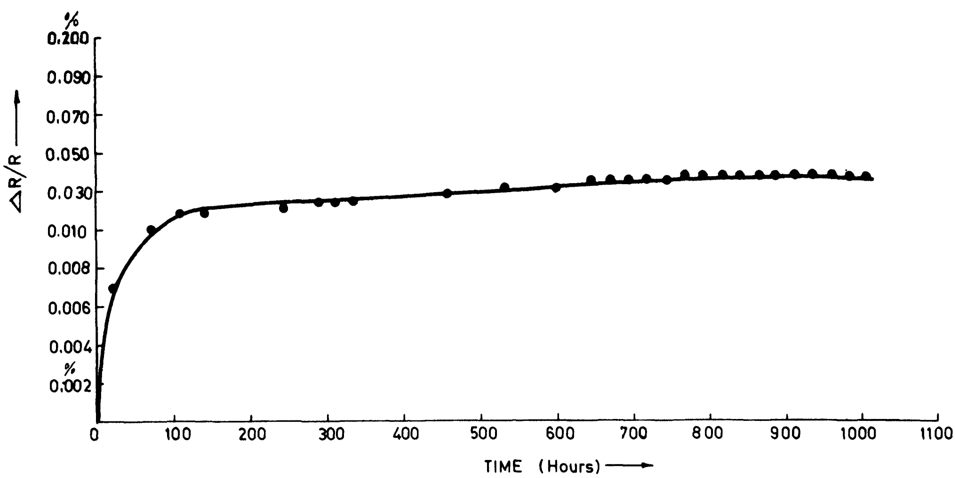


FIGURE 6 Percentage change in the resistance of quartz passivated NiCr/Cu resistors measured as a function of time at 70°C.

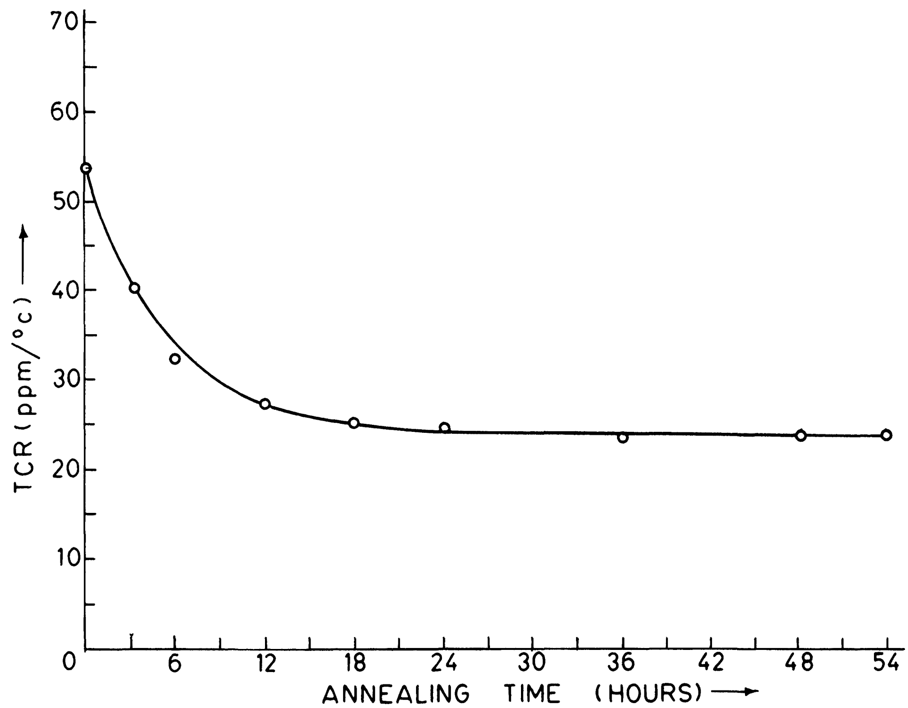


FIGURE 7 TCR of the NiCr/Cu resistors measured as a function of annealing time.

TABLE II
Electrical Properties of NiCr/Cu Resistors:

Property		Heat treated resistors	Heat treated and quartz passivated resistors
1.	Contact I-V characteristics	Ohmic	Ohmic
2.	Contact resistance (m Ohm Cm²)	2-3	3.5
3.	Change in the as prepared film resistance (%)	20	20
4.	Resistor stability after 1000 hours at room temperature (%)	0.15	0.01
5.	Resistor stability after 1000 hours at 70°C (%)	0.35	0.04
6.	TCR (ppm/°C)	25	25

improves significantly after passivation by a thin quartz film. The result of our investigation are summarized in Table II.

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