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Models of Electric Transport in Bilayer Ni/Cu And in a Tri-layer Ni/Pd/Cu Thin Films

M. K. Loudjani[1,*] *and C. Sella*[2].

[1] Université Paris-Saclay, ICMMO-UMR 8182 (CNRS), SP2M-Bâtiment 410, 91405 Orsay Cedex, France.
[2] Institut des Nano-Sciences de Paris, Université de Paris-VI, campus Boucicaut, 140 rue de Lourmel 75015 Paris, France.

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Abstract: In this work we propose to measure the resistivities of bilayer Ni/Cu and tri-layer Ni/Pd/Cu thin films. We will compare the experimental resistivity of bilayer Ni/Cu or a tri-layerNi/Pd/Cu to the resistivity calculated from the resistivities of the simple layers of copper, nickel and palladium. We show that in the presence of aconstantelectric fieldparallel to the interface of Ni/Cu, electronic transport in bilayer, is equivalent to that of two distinct layers (of Ni and Cu) laid out in two parallel circuits, and that of a tri-layer Ni/Pd/Cu is equivalent to that the electronic transport of three distinct layers (of Ni, Pd and Cu) laid out in three parallel circuits.
Keywords: Resistivity, Bilayer Ni/Cu, Tri-layer Ni/Pd/Cu, Parallel resistance.

1 Introduction

Several authors [1, 2, 3] used resistivity measurements to characterize the adhesive character in composites of the type aluminium/steel or aluminium/copper obtained by cold roll welding technique. These authors show that in the system aluminium/steel or aluminium/copper more the rate of rolling is high more the difference between the calculated resistivity and the experimental resistivity is low and more the peel strength is high. All these studies are based on the fact that the resistivity of the interface in the composites studied is negligible. In the case of bilayer Ni/Cu thin film the order of magnitude of interface resistivity was calculated [4] and showed that this resistivity is indeed negligible compared to the resistivities of the layers of copper and nickel. We want in this work to check the validity of these assumptions for bilayer Ni/Cu film and to generalize these assumptions with the case of a tri-ayer Ni/Pd/Cuthin films.

2 Preparation of Pure Films of Bilayer Ni/Cuand Tri-LayerNi/Pd/Cu Thin Films

The thin films were prepared by R.F. sputtering from a disk-shaped target of 13 cm in diameter with a target substrate distance of about 4 cm. The base pressure of the vacuum chamber was 1.3310-4 Pa and sputtering took place in an argon atmosphere at a pressure of 1.33 Pa.Before deposition, the target was subjected to a presputtering. During this presputtering time (15 to 30 mn) the substrate was protected by a shutter. The films are deposited on plates of glass-Corning-1737 thickness equal to1 mmin the shape of a disc of diameter equal to30.5 mm., Fig-1. The deposition rate of copper, nickel and palladiumfilms are respectively 3.54 Å.s-1, 1.94 Å.s-1, and 7.11 Å.s-1. During the preparation of bilayer or tri-layerfilms, the second layer is deposited after that the first layers was exposed to air. Tree bilayer Ni/Cu and one tri-layer Ni/Pd/Cu thin films were elaborated for this study.

Fig1. Samples ofcopper andbilayer Ni/Cu thin films deposited on a glass substrate.

*Corresponding author E-mail: mohamed-khireddine.loudjani@u-psud.fr

3 Thickness Measurements of Thin Films

Thickness measurements are obtained using an interference microscope.

The thicknesses of pure thin films of bilayerNi/Cu and the tri-layerNi/Pd/Cu thin films are reported on Tables-1-2.

Table1. Thicknesses of bilayer Ni/Cu films

Materials	Thickness (nm) bilayer-1	Thickness (nm) bilayer-2	Thickness (nm) bilayer-3
Copper	49.5	69	168
Nickel	22.5	72	138

Table 2. Thicknesses of the tri-layer Ni/Pd/Cu film

Materials	Thickness (nm) Tri-layer Ni/Pd/Cu
Nickel	72.7
Palladium	95
Copper	64

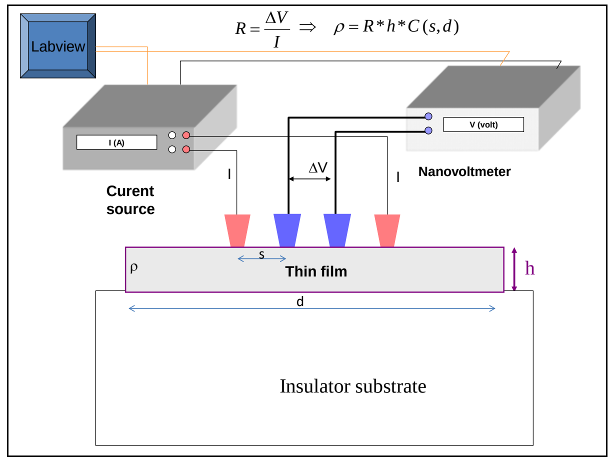


Fig 2. Principle of measurement of theresistivity (ρ) by the method of the four points probes.

4 Measurements of The Electrical Resistivity of A Thin Film By Four Points Probes Technique (Fig.2).

4.1 Resistivities Measurement on Pure Thin Films And On Ni/Cu Bilayer Films

In this method one imposes a sweeping of D.C. current (I) via bothexternal probes (Fig-2) and one measures the potential drop between the two internal probes (ΔV), the electric resistance is deduced: R = ΔV/I. For meausuring the current we used a power source (KEITHLEY-6220) to supply a D.C. current to the two external probes and a nanovoltmeter (KEITHLEY-2182A) to measure the voltage drop between the two internal probes.

The four aligned probes being separated by the same distance s = 2.54 mm.The resistivity of film is given by the relation of Smits [5], ρ = R*h*C(s, d), h being the thin film thickness and d the diameter of the film, C (s, d) the geometrical correction factor.

The resistivities measured on pure thin filmsof nickel, copper and palladium on bilayerNi/Cu thin films and tri-layer Ni/Pd/Cu films are reported on Tables-3-4-5-6.

Table 3. Resistivities of pure andbilayer-1 Ni/Cu thin films.

Materials	Thicknesses films (nm)	Resistivities films (μΩ.cm)	Resistivity bilayer-1 film (μΩ.cm)
Copper	49.5	8.7	10.84
Nickel	22.5	60	

Table 4. Resistivities of pure andbilayer-2 Ni/Cu thin films.

Materials	Thicknesses films (nm)	Resistivities films (μΩ.cm)	Resistivity bilayer-2 film (μΩ.cm)
Copper	69	5	8.26
Nickel	72	23	

Table 5. Resistivities of pure andbilayer-3 Ni/Cu thin films

Materials	Thicknesses films (nm)	Resistivities films (μΩ.cm)	Resistivity bilayer-3 film (μΩ.cm)

Copper	168	6.3	8.92
Nickel	138	18.8	

Table 6. Resistivities of the tri-layerNi/Pd/Cu thin film.

Materials	Thicknesses layers (nm)	Resistivities layers (μΩ.cm)	Resistivity tri-layer film (μΩ.cm)
Copper	64	4.78	11.65
Nickel	72.7	23.4	
Palladium	95	30.5	

From the resistivitiesvalues ριand thicknesses hi, a modeling of electric transport in bilayer Ni/Cu thin film represented by an electric circuit with two parallel electric resistances could be established. Fig-3. The resistivity measured on the surface of bilayerNi/Cu (ρBilayer) is connected to the resistivities determined separately on each of the two pure thin films of nickelρNιand copperρCuby the expression (8).

This experimental law (expression-8) is compatible with the principle of conservation of the current on the one hand and the assumption of the existence between the internal points probes of a constant electric field parallel with the Ni/Cu interface on the other hand (equations: 2-9):

$$I = I_{Ni} + I_{Cu} \qquad (2)$$

$$J.S = J_{Ni}S_{Ni} + I_{Cu}S_{Cu} \qquad (3)$$

$$\sigma.E.S = \sigma_{Ni}.E_{Ni}S_{Ni} + \sigma_{Cu}.E_{Cu}S_{Cu} \qquad (4)$$

$$\text{If: } E = E_{Ni} = E_{Cu} \qquad (5)$$

$$\sigma = \frac{S_{Ni}}{S}\sigma_{Ni} + \frac{S_{Cu}}{S}\sigma_{Cu} \qquad (6)$$

$$\sigma_{Belayered} = \frac{h_{Ni}}{h_{Ni}+h_{Cu}}\sigma_{Ni} + \frac{h_{Cu}}{h_{Ni}+h_{Cu}}\sigma_{Cu} \qquad (7)$$

$$\frac{1}{\rho_{Belaered}} = \frac{h_{Ni}}{h_{Ni}+h_{Cu}}\frac{1}{\rho_{Ni}} + \frac{h_{Cu}}{h_{Ni}+h_{Cu}}\frac{1}{\rho_{Cu}} \qquad (8)$$

$$\frac{1}{R_{Belayered}} = \frac{1}{R_{Ni}} + \frac{1}{R_{Cu}} \qquad (9)$$

INi and ICu are respectively the average currents in the film of nickel and copper, JNi and JCu the currents densities in the thin films,σιthe electric conductivities of the films, Si the transverse sections of the films and Eitheconstant electric field parallel with the interface Ni/Cu, Rithe electric resistances of the films.

We compared the experimental resistivities of bilayer (ρexp-Bi), calculated from the relationρ= R*h*C(s, d),to the calculated resistivities of bilayer (ρcalc-Bi)according to the relation (8), the results are reported on the Table-7. The results show that one can apply the relation (8), this enables us to deduce from it on the one hand that the electric lines of potential in films are flat in two films of bilayer considered and on the other hand that the resistivities of the interfaces in the bilayerare negligible.

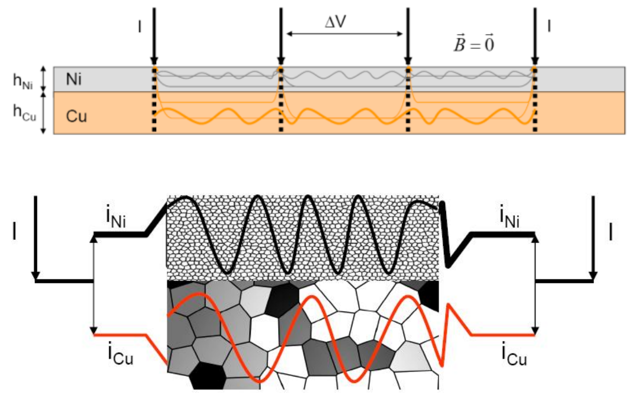
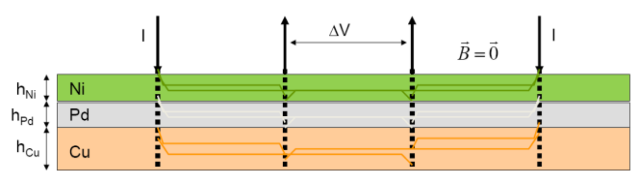


Fig 3. Modeling of electric transport in bilayer Ni/Cu/ thin film by two parallel circuits.

Table7. Comparison between the experimental resistivities of bilayer Ni/Cu (ρexp-Bi) and the calculated resistivities(ρcalc-Bi)according to the relation (8).

	(ρexp-Bi) (μΩ.cm)	(ρcal-Bi) (μΩ.cm)	Error (%)
Bilayer-1	10.84	11.87	9.5
Bilayer-2	8.26	8.32	0.72
Bilayer-3	8.92	8.99	0.78

4.2 Measurements of Resistivity on The Tri-LayerNi/Pd/Cu Thin Film Fig-4.



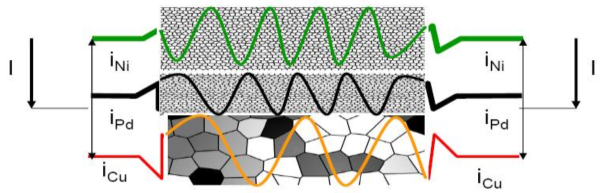


Fig 4. Modeling of electric transport in a tri-layer Ni/Pd/Cu films by three parallel electric circuits.

As in the case of the bilayerfilms, from the relation reported below:

$$I = I_{Pd} + I_{Ni} + I_{Cu} \tag{10}$$

$$\frac{1}{\rho_{Trilayered}} = \frac{h_{Pd}}{h_{Ni}+h_{Cu}+h_{Pd}}\frac{1}{\rho_{Pd}} + \frac{h_{Ni}}{h_{Ni}+h_{Cu}+h_{Pd}}\frac{1}{\rho_{Ni}} + \frac{h_{Cu}}{h_{Ni}+h_{Cu}+h_{Pd}}\frac{1}{\rho_{Cu}} \tag{11}$$

WhereIPd, INi and ICuare respectively the average currents in the palladium, nickel and copper thin films,ρPd,ρNι,ρCuthe intrinsic electrical resistivities of the palladium, nickel and copper thin filmshPd, hNi and hCuthe thickness of the palladium, nickel and copper thin films. We compared the resistivity of the experimental tri-layer (ρexp- Tri), calculated starting from the relationρ= R*h*C (s, d),to the resistivity of the calculated tri-layer (ρcal- Tri) according to the relation (11), the results are reported on the Table-8

Table 8. Comparison between the experimentalresistivities of the tri-layerNi/Pd/Cu(ρexp- Tri) and the calculated resistivities (ρcal- Tri) according to the relation (11).

Materials	(ρexp-Tri) (μΩ.cm)	(ρcal-Tri) (μΩ.cm)	Error (%)
Tri-layerNi/Pd/Cu film	11.65	11.82	1.46

5 Conclusion

Finally we showed in this study that bilayer Ni/Cu films in a constant electric field can be to modeled by an electric circuit equivalent of two parallel drivers. Electric transport in the bilayer Ni/Cu and tri-layer Ni/Pd/Cu films studied is equivalent respectively to that of two electric resistances (RNi, RCu) or of three electric resistances (RPd, RNi, RCu) laid out in parallel.

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