MECHANICAL AND ELECTRICAL PROPERTIES OF EVAPORATED THIN LAYERS

Tomas Vejmola. Doaa Yahya, Josef Sandera
Department of Microelectronics, Faculty of Electrical Engineering and Communication,
Brno University of Technology,
Technická 3058/10, 616 00 Brno, Czech Republic
E-mail : xvejmo00@stud.feec.vutbr.cz, xyahya00@stud.feec.vutbr.cz, sandera@feec.vutbr.cz

Annotation:
The study deals with the vacuum evaporation technique of thin layers, considering different process parameters and their influence on electrical properties. Parameters, such as temperature, different substrate types, substrate vibrations, etc., are considered. The effects of the process parameters on the coating structure are observed. The temperature affects the coating quality and stability [1] [2]. Regarding electrical properties, the surface resistivity is measured by four-point method, whereas the influence of process parameters on the surface resistivity is determined as well.

INTRODUCTION

The study deals with the vacuum evaporation technique of thin layers, considering different process parameters and their influence on electrical properties. For instance, heating samples before evaporation is an input parameter. The influence of substrate vibrations process parameters on the surface resistivity is determined as well.

DESCRIPTION

During the experiment were all samples heated in a room using resistance at a temperature of 20ºC, 50ºC, 100ºC or 150ºC and right after heating a sample evaporation a thin layer of 200nm was launched. The pure metals as Al, Ag, and Cu were spread over the samples of Aluminium oxide. For slowing a process of aging and oxidation, after creating a thin layer, the samples were put into a box. There is a possibility to compare results, because evaporation occurred at similar parameters.

In the second part of experiment, the sample was vibrated with a reproducer at frequency of 50Hz and 15Hz in a horizontal and vertical direction. Photos were made by an electron microscope and as follows a resistivity of samples was measured and its values were compared in a table below.

PREPARATION OF THIN LAYER

Thin layers on samples of ALUMINIUM were made by means of vacuum set. Inputs parameters were monitored due to a reproduction of experiment.

Subsequently, we have chosen layer´s thickness of 200nm, which was steamed in a range 4-5*10-3Pa at speed in a range of 15-19 Å/s. To set a temperature we have used an output resistor of 10W whose purpose is heating an aluminum substrate.

Thanks to all input parameters we are able to compare measured results.

RESISTIVITY MEASUREMENTS OF THIN FILMS

Four-point method

The four-point probes are placed collinearly with equal spacing between them on the sample. The current is passed through the two outer probes and the potential is measured between the two inner probes. The errors due to electrical contacts are absent because the current and voltage leads are separate. This is a widely used technique to measure the electrical resistivity by superficial contact. This technique is mainly used in the semiconductor industry, research and manufacturing field. [3]

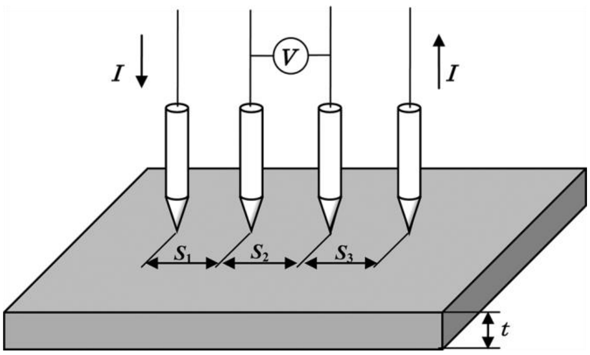

Figure 1: Four-point method of resistivity measurement

For measuring resistivity and calculation of sheet resistance a four-point method was applied. It is being used a standard formula:

$$\rho_s = (\pi/\ln 2)(V/I) \qquad (1),[3]$$

A value $\pi/\ln 2$ is valid in a ratio d/s>40, where **d** is an average of a sample's pattern on a surface and **s** is a distance between a measured probe's points.
We have used values out of a Tab. 1, therefore the values of ours samples are d=10mm and s=1mm.

Tab. 1: Values for the four-point method [2]

(d/s)	Circle	Square
10.0	4.1716	4.2209

The results of sheet resistance on layers without vibration

Pure metal of Al, Ag and Cu at a temperature of 20ºC, 50ºC and 150ºC were used while measurement. These results are seen in Figure 2.

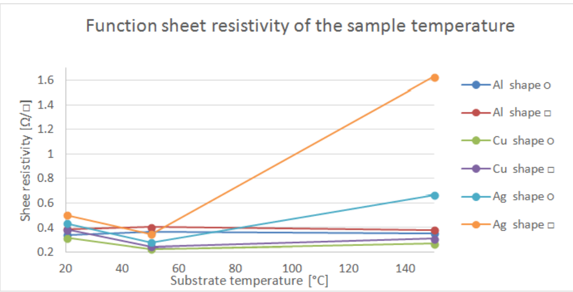

Figure 2: Function sheet resistivity of the sample temperature

In a Figure 2 we can see a progress of resistance depending on a temperature of supported substrate. Out of the values we can see a change of Ag at a temperature of 150ºC. For the rest of metal, Cu and Al, the temperature is stable and sheet resistance is invariable.

Measurement of resistance on the samples which had been vibrated while evaporation

We have used a holder substrate with a reproducer for creating thin layers on a substrate, whose mechanism was a source of vibrating. A rectangle signal of 20Hz and 15kHz in both horizontal and vertical direction was determined maintaining input parameters of 20ºC at a pressure of -5*10-3Pa, at a speed of spreading a layer of 15-19 Å/s. The thickness of our resulting layer was 200nm.

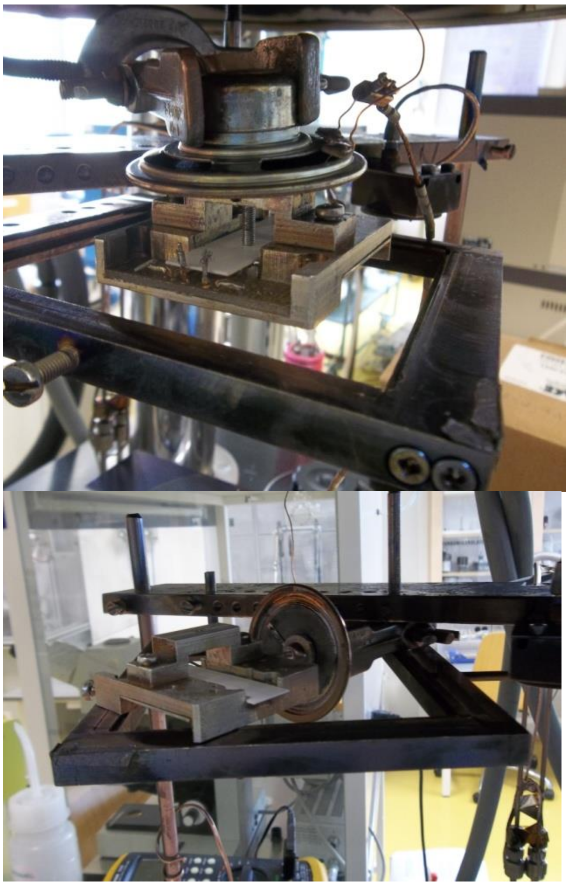

Figure 3: Vertical oscillation (top) horizontal vibrations (bottom)

After forming the layers maintaining mentioned condition, the values of resistance were changed by four-point method again. All results are presented in a Table 2.

Tab. 2: Sheet resistance values

metal	vibration: 0Hz	vibration: 20Hz		vibration: 15kHz		units
		horizontal	vertical	horizontal	vertical	units
Al	0,3387	0,37718	0,4137	0,363	0,4233	Ω/□
Cu	0,3159	0,2306	0,4534	0,3695	0,3126	Ω/□

Out of the table above we can observe that horizontal oscillation does not have any influence on values sheet resistance spread on the layers nor on a quality of a layer itself. At a vertical oscillation there is a light alteration unlike the values without oscillation. This alteration is caused by a surface roughness of Aluminium oxide or by imprecise thickness of 200nm.

All values differ, but it is not necessarily due to oscillation. Photos which had been made by electron microscope support this assertion, but it has not been clearly stated, thus this assertion is still being in a research.

STABILITY OF THIN LAYER

Electric and mechanic characteristics of thin metal layers realized by a vacuum evaporating rely on many factors. If we take into account a conductivity of thin metal layers according to its thickness, we would be able to declare that up to 1500 A (150 nm) holds true so called Sondheimer theory [4]. The particles of metal are dispersed randomly into this thickness on a surface of substrate and electric conductivity evinces a nonlinear reliance on a thickness. This nonlinearity is decreasing if it appears above a thickness and holds true a relation for metal material. Nevertheless, electric conductivity is always lower than a conductivity of an ordinary metal material.
Thin layers are unstable and its conductivity rely on various factors, such as cleanness or temperature of surface. The temperature of substrate also has an impact on characteristic of thin layers.

DESCRIPTION OF A MEASUREMENT OF STABILITY

For a measurement of stability evaporated metal layers were gotten a results of samples on ALUMINIUM of a 0,8mm thickness. Evaporated figure is seen on Figure 4. Samples with a thickness of 150 – 300nm were put into practice with a layers of copper, silver and aluminium. During a process of evaporation a subtrate´s temperature was 50, 100 and 150˚C. Subsequently, the samples were put to the aging test for 120 hours under a 100 ˚C.

All samples were tested by a cyclical temperature. A device based on Peltier thermocouple effect was used for cyclicality. This mechanism enables to place samples on either heated or cooled metal desk in an indoor room, considering also a little influence on atmosphere. Thermal cycles were set on 0 – 100˚C without any time lag. This cycle is shown in Figute 5.

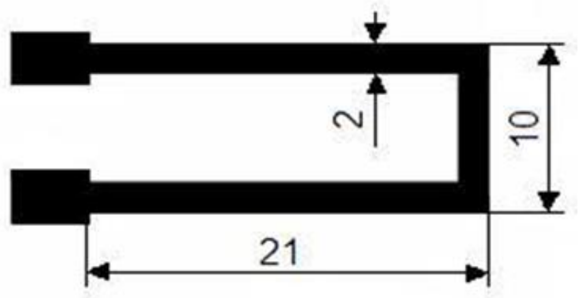

Figure 4: Evaporated layer

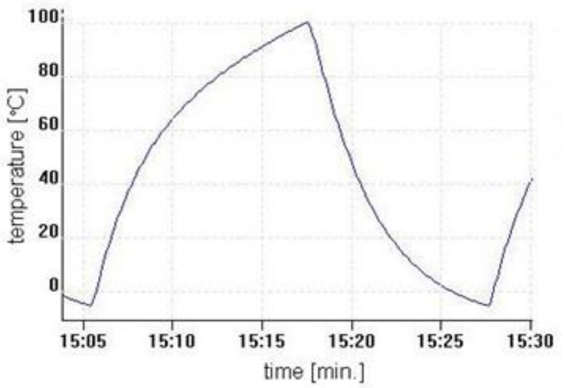

Figure 5: Thermal profile

MEASURED RESULTS

The results of measured particular values of resistance thin layers while thermal cyclicality are shown in a Tab. 3

Tab. 3: Electrical resistance of layers during a thermal cyclicality

Metal	Thick-ness [nm]	Tempe-rature [˚C]	Value of temperature cycles Resistance layer [Ω]					
			0	2000	3000	4000	5000	6000
Cu	150	20	37.160	57754	71448	-	-	-
	200	20	10868	14763	14980	15785	16.039	16367
	300	50	3.219	3.658	4.128	4.125	4.210	4.215
	300	100	6.032	6.934	9.766	9.871	10.113	10.102
	200	150	5.954	13.460	15.172	15.594	16.305	16.898
Ag	200	50	5.230	5.566	5.964	6.705	6.952	7.185
	200	100	6.213	6.231	6.586	7.219	7.627	7.682
	200	150	9.717	8.432	10.010	11.296	11.686	11.958
Al	150	50	86.867	93.70	317.4	-	-	-

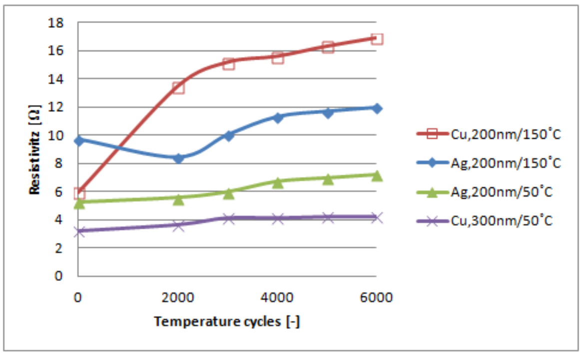

Figure 6 Cu and Ag layer´s resistance during a thermal cyclicality

During a steam conditioning there was a problem with evaporation a thicker steady metal layer, therefore only a layer of 150 nm was used. Its cyclical resistance increased rapidly and over 4000 thermal cycles was immeasurable. Cooper layers on substrate of 20˚C have very low stability, as shown in table. A total of 10 000 thermal cycles were

implement and on the photos it is possible to draw a comparison between before and after a cyclicality.
Out of the results shown in a table we are able to claim that not only stability of thin layers depends on its thickness, but also on a temperature of basis where layer is being evaporated. The best substrate´s temperature is 50˚C and thickness is over 200nm. Even though generally silver has a lower resistance than a copper, a stability is more or less the same.

The layer´s thickness less than 150nm is unstable (as seen in Tab. 3) and a degradacion increases with an amount of cycles until a point where a lack of metal layer splits up and resistance is not measureble. This effect arises thanks to a different metal thermal expansivity, material´s foundation and mainly to uninterrupted metal layer.

Stability od thickness mayor 200nm is sufficient and linear. As a result of growing amount of cycles, resistance slightly increases due to oxide layer. The main factor of influence is a sample´s temperature while evaporation layers. Seen in a tab., in a samples without pre- heating degradation comes about rapidly and samples age more frequently.

CONCLUSIONS

Although a thin layer technology formed by vacuum evaporation has been known for a while, its structure, thus mechanic and electronic characteristic evaporated thin layers are not examined excessively. This article helps to understand a measurement of resistance on thin layers by four-point method and influence of inputs parameters on a quality of evaporated layers. A pressure, speed of spreading a layer, substrate´s temperature, thickness and movement are examples of inputs parameters.

Moreover, to use metal layer for electronic devices is important to take into account a thickness over 150nm, otherwise a layer is nonlinear and inapplicable. For copper and silver 200nm layer is an optimal thickness with a pre-heated substrate. Tab.3 defines resistance in a various stadium of aging and affirms this assertion.

REFERENCES

[1] YAHYA, D.; ŠANDERA, J. Temperature stability of metal thin layers. In Proceedings of the Electronic Devices and Systems IMAPS CS International Conference 2013. Brno: Novpress, 2013. s. 27-30. ISBN: 978-80-214-4754- 7

[2] SHIMAMOTO, Akira, Keitaro YAMASHITA, Hirofumi INOUE, Sung-mo YANG, Masahiro IWATA a Natsuko IKE. A Nondestructive Evaluation Method: Measuring the Fixed Strength of Spot-Welded Joint Points by Surface Electrical Resistivity. In: Journal of Pressure Vessel Technology. published online, 2013-04-01, s. 021501-. ISSN 0094-9930. DOI:10.1115/1.4007957.URL: http://pressurevesseltech.asmedigitalcollection.asme.org/article.aspx?doi=10.1115/1.4007957.

[3] Chopra K L, Thin Film Phenomena MC Graw Hill Co., New York, USA, (1969).

[4] Reale C, Thickness Dependence of the Electrical Conductivity in Vacuum Deposited Copper Films, Proceeding of IEEE, Volume 57, Issue: 11, 1969. Pages 2073-2075.