DETERMINATION OF CRITICAL CONDITIONS FOR CONTACT RELIABILITY OF Ag-BASE CONTACT MATERIAL

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LATE PAPER
24th International Conference on Microelectronics, MIEL'96
32nd Symposium on Devices and Materials, SD'96
September 25. - September 27., 1996, Nova Gorica, Slovenia

Keywords: electrical contacts, material for electrical contacts, contact resistance, potential difference of closed contacts, voltage levelling, contamination of electrical contact, heating of contact, supertemperature of contact spot, measuring systems, vacuum degassing, cleaning of contact surfaces, RF plasma cleaning, CFC solvents, ChloroFluoroCarbon solvents

Abstract: Due to cost-effective manufacturing of electromechanical relays and similar switching devices for low power switching applications the feasibility of Ag-base contact materials in order to replace Au-base contact materials has been studied. Commercialy available materials were used for test samples: AgNi 0.15, Ag/Ni 10 and Ag/CdO 10. Samples were pretreated by various cleaning methods prior to testing. A low power limit for reliable application of sample material was estimated by measuring contact resistance versus contact force relationship and close-contact voltage fall versus electric current relationship under various ambient conditions and state of contact surface

Določitev spodnje meje stikalne moči za kontaktno zanesljivost pri gradivih za električne kontakte na osnovi srebra

Ključne besede: kontakti električni, materiali kontaktov električnih, upornost kontaktna, razlika potencialov kontakta sklenjenega, stabilizacija razlike potencialov, onesnaženje kontakta električnega, segrevanje kontakta, supertemperatura mesta kontaktnega, sistemi merilni, razplinjevanje vakuumsko, čiščenje površin kontaktov, FR čiščenje plazemsko radiofrekvenčno, CFC topila klorofluoroogljikova

Povzetek: Raziskana je možnost, da se v relejih za preklapljanje električnega toka malih moči namesto dražjega gradiva za kontakte na osnovi Au uporablja gradivo na osnovi Ag. Za raziskavo so bili uporabljeni komercialno dobavljivi vzorci sledečih gradiv: AgNi 0.15, Ag/Ni 10 in Ag/CdO 10. Površina vzorcev je bila predhodno obdelana z različnimi čistilnimi postopki. Spodnja meja za zanesljivo preklapljanje kontaktov iz vzorčnega gradiva je bila ocenjena z meritvijo odvisnosti med kontaktno silo in kontaktno upornostjo, ter odvisnosti med tokom skozi sklenjen kontakt in razliko potenciala na njem pri različnih pogojih okolja in stanja kontaktne površine.

1. Introduction

High contact reliability even at extremely low switching current and voltage can be achieved by Au-base contact materials, which are on the other hand not price-friendly. For low-to-medium switching power less expensive Ag-base material are more suitable. In order to enlarge the application range a multilayer contacts are used, having thin outer layer of Au-base material and bulk of Ag-base material.

In order to make proper decision not to choose expensive material if not necessary, a study of applicability of Ag-base contact material for low power switching is performed.

The reliability of contacs depends not only on material, but also on contact force, microscopic conditions of contact surface and ambient conditions in which contacts operate. In low power switching devices contact parts are ordinary incapsulated thus providing a certain degree of protection against influence from ambient. From our own experience it is known, that the initial contact surface state before assembly are essential for contact reliability.

2. Preparation of samples prior to measurements

The research was oriented on application of contact materials at manufacturing conditions, therefore commercially available materials were used as sample materials:

- AgNi 0.15 alloy
- Ag/Ni 10 composite
- Ag/CdO 10 composite

Pretreatment of contact surface prior to measurements was made by following methods:

- cleaning in chloro-fluoro-carbon (CFC-Freon) at ultrasound agitation
- vacuum degassing at elevated temperature
- etching in RF low pressure hydrogen plasma
- sulphurizing in H_2S
- exposing to laboratory dust ambient

3. Principles of measurements

In order to evaluate contact reliability following quantities were measured:

- contact resistance R_C (four-connection measurement)
- potential difference on closed contacts U_C (contact voltage fall)

A cross-rod principle of contact system was applied. Contact pair consists of two crossed miniprofile strips with cross-section, shown on Fig. 1. Sample strips are

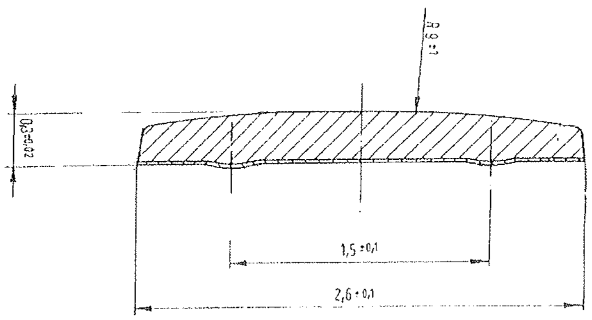

Fig. 1: Cross-section of sample contact strip. Mating contact surface has a semicilindric form with curvature radii of 9mm.

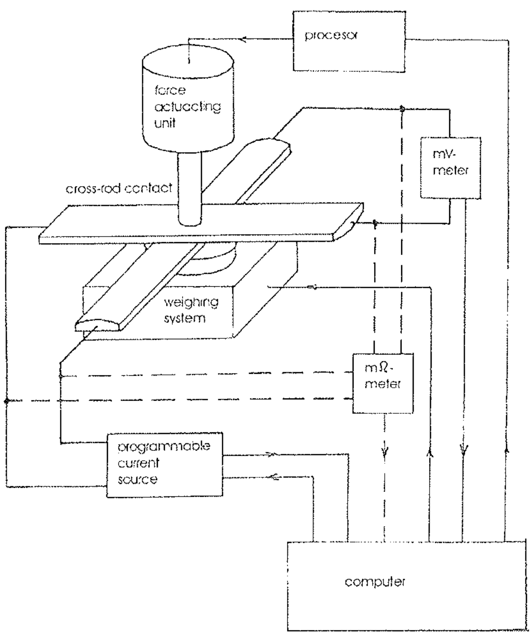

Fig. 2: Arrangement of control and measuring system for measurement R_C - F_C and U_C - I relationship

pressed by contact force F_C, which is set by actuator of force control and weighing system. Measuring and control system were interconnected via computer due to synchronization of force setup and measurement of contact characteristics, as shown on Fig. 2. Special computer software has been made for control and measurement operations.

In order to enable measurement on various contact sites of individual contact sample, contact strip was mounted on holder with computer controlled XYZ-axis drive. Obtained measured results can therefore be averaged along contact strip.

4. Measurement of R_C versus F_C

Contact force F_C was set in the range from 3 cN to 50 cN, starting with minimal value and gradualy increasing in steps. At each step contant force was maintained constant during measurement of contact resistance R_C. Special care was taken to minimize the effect of ambient vibrations. An average of 10 measurements obtained on 10 contact spots 1mm apart of each other at each specified F_C value and standard deviation was calculated. Results were arranged on R_C (F_C) plot of average values.

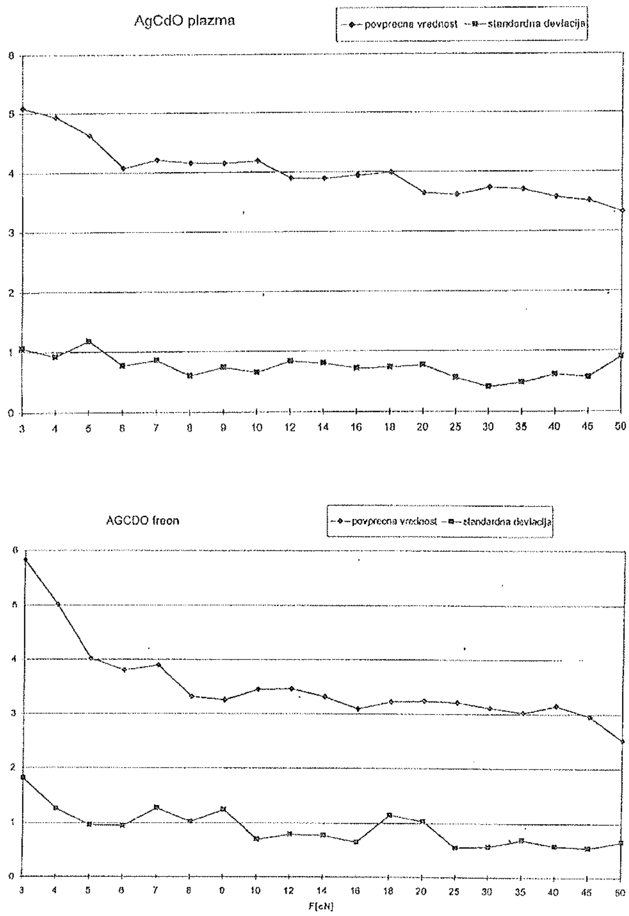

Fig. 3: Graphs of R_C (F_C) and standard deviation for Ag/CdO 10 sample material after treatment in RF hydrogen plasma (upper plot) and after cleaning in CFC (lower plot); R_C scale in [mΩ]

R_C follows significant decreasing function at increasing of F_C, as shown on graph of Fig. 3, according to general theory of contact resistance /1/. Standard deviation is over the entire range approx. 1 mΩ. At 3 cN contact resistance is between 5 and 6 mΩ, approaching to 3 mΩ at 50 cN, irrespective of sample material. Characteristics are more sensitive on state of contact surface, then on the composition of sample material. Plasma etched samples exibit for about 1 mΩ higher contact resistance at 50 cN than samples prepared by other cleaning methods.

Very high and unpredictable values of R_C were also obtained on various contact samples at low F_C untill some critical value has been reached. Beyond this limit R_C again decreases to low and stable value. The effect is attributed to insufficient cleaning and thin films remaining from previous handling of sample material (grease, finger prints, dust particles embedded on contact surface, etc.). By increasing contact force con-taminating film was destroyed and low contact resistance is obtained.

5. Measurements of U_C versus I

For this type of measurements contact force was set on predetermined value and kept constant during measurement procedure. Measurements were performed at 3 cN and 15 cN. The potential difference U_C was measured on closed contacts at current I through contact spot. U_C was measured during the increase of I starting from 0 value to 3 A.

By comparing results of individual contact sites of the same sample, significant differencies between characteristics can be indicated. Some of them are linear functions U_C (I) reaching few mV at 3 A. In such cases contact spot behaves as pure ohmic resistor due to constriction resistance. A weak influence of various pretreatment of contact surface is presummably also indicated on graphs of Fig. 4, although any existence of contaminant films on contact spot is indicated. Other characteristics reveal deviations from linearity and at 3 A measured voltage reaches a value of few 10 mV. A tendency of contact voltage to approach toward certain limiting value can also be observed, as shown on Fig. 5. In this case not only constriction resistance, but also resistance of foreign film over contact spot contributes to measured contact voltage /1, 2/. Foreign films often reveals semiconducting characteristics /3/, therefore in consequence a nonlinear behavior of voltage-current characteristic. In the extreme case nonlinearity results on so called "voltage levelling", where U_C value at increasing current approaches constant value /4/. Levelling phenomenon on Ag-base contact sample is displayed on graph of Fig. 6. According on theory of contact spot potential difference U_C relates to supertemperature on contact spot /3/, therefore at levelling thermal decomposition of foreign films by fritting and broadenning of current conducting area take place. The highest U_C value is obtained at melting of contact spot /5/ or even evaporation of contact bridge. For pure Ag and composite Ag-base materials (Ag/Ni, Ag/MeO, etc.) following data /6/ at melting of contact spot ($U_{C\ melt}$) and disruption of contact bridge ($U_{C\ disr}$) due to evapo-

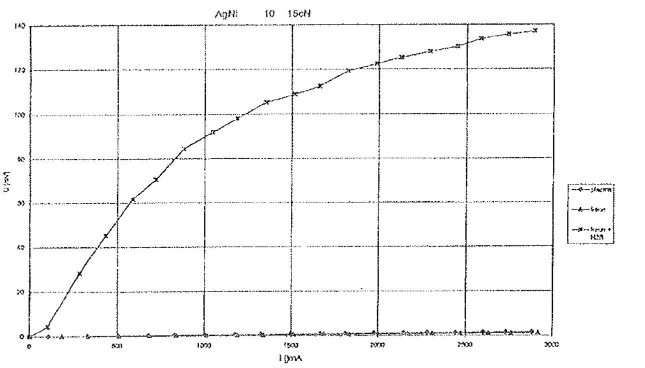

Fig. 5: Strong nonlinearity of U_C (I) graph, obtained on Ag/Ni 10 at 15 cN after H_2S treatment (--), presummably due to heating of contact spot*

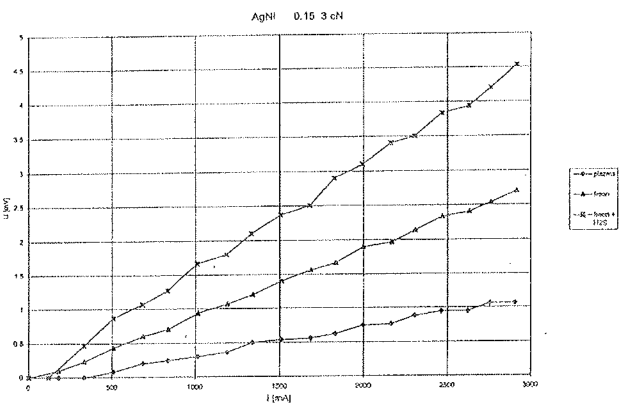

*Fig. 4: Graphs of $U_C(I)$ at F_C 3 cN for AgNi 0.15 sample material after various pretreatment procedure: ◆ - in RF hydrogen plasma, Δ - in CFC, * - exposed to H_2S. Linearity indicates constant constriction resistance of stable contact spot*

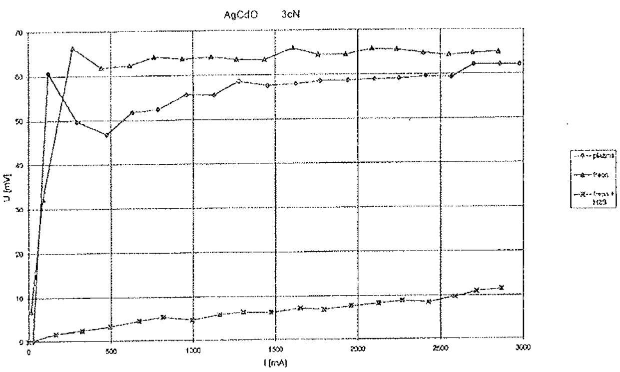

Fig. 6: Voltage levelling at approx. 60 mV observed on different Ag/CdO 10 samples at 3 cN after various (insufficient) cleaning process (◆ - plasma, Δ - CFC). Sample contact exposed to H_2S indicates slight nonlinearity of U_C - I characteristics. Results are reather controversal due to local variations of surface contamination

ration are valid:

$$U_{C\,melt} = 0.39\text{ V (at }961°\text{C)} \qquad U_{C\,disr.} = 0.70\text{ V}$$

Approximative relation between supertemperature T_m [K] and level voltage U_C derived from exact theoretical expression can be applied for estimation of temperature on contact spot. For Au and Ag the following expression give us values with accuracy of ±10% in temperature range from 100 to 500°C /3/:

$$T_m \cong 3100\sqrt{U^2 + 0.009}$$

Following values for voltage level values were obtained and estimated temperatures of contact spots were calculated:

U_C [mV]	T [°C]
200 ± 20	≅ 385
150 ± 10	≅ 250
80 ± 10	≅ 85
30 ± 5	-

Among these results only value of 200 mV can be referred to melting of Ag_2S layer. Values above 100 mV can be attributed to softening of silver, other values seems to be too low for indentification of melting of foreign substances on contact spot.

No correlation of U_C level values to the particular contact material is found. At lower contact forces sometimes higher level voltages were detected (Fig. 7). Consequently not only one layer is presummably present on contact spot.

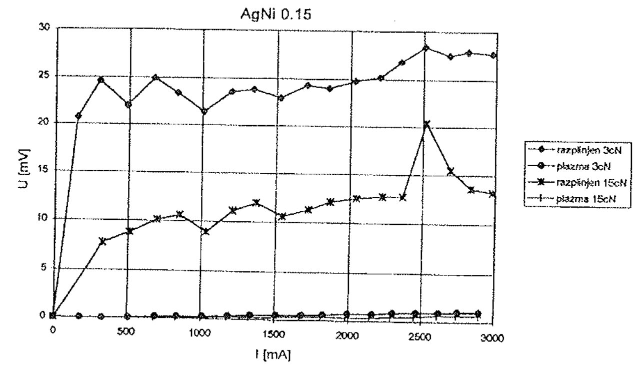

Fig. 7a: Voltage levelling at low values on various contact materials after vacuum degassing. Higher level is obtained at low contact forces (- ♦- 3 cN) and lower level at greater (-- 15 cN). Contamination on contact spot presummably consists of semihard insulating film*

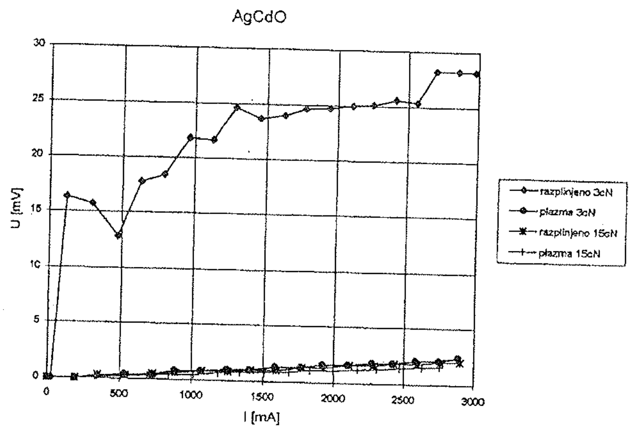

Fig. 7b: Voltage levelling at low values on various contact materials after vacuum degassing. Higher level is obtained at low contact forces (- ♦- 3 cN) and lower level at greater (-- 15 cN). Contamination on contact spot presummably consists of semihard insulating film*

6. Conclusions

Critical conditions, which restrict the application of Ag-base contact materials in low-power switching, are determined primary by the nature and degree of contamination on contact surface. Chemical composition of bulk contact has no significant influence on contact reliability at low-power switching.

Contact resistance of properly cleaned contacts is low and stable even at extremely low contact forces down to few cN.

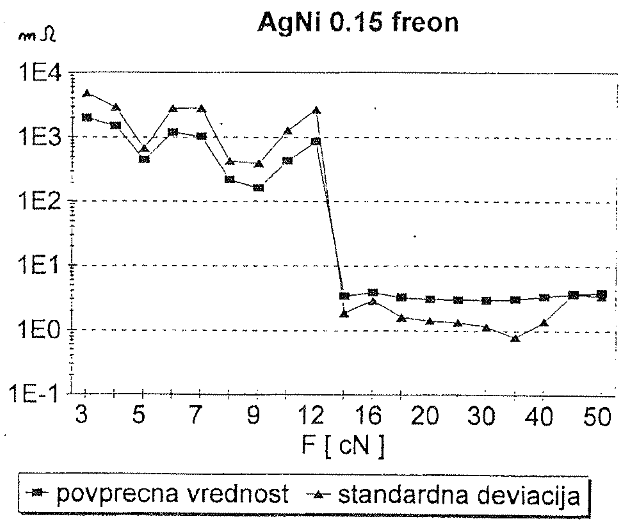

Fig. 8a: Critical contact force providing reliable switching can be estimated from graphs as shown on these plots. Insufficiently cleaned contacts reveal high and unstable contact resistance up to approx. 15 cN.

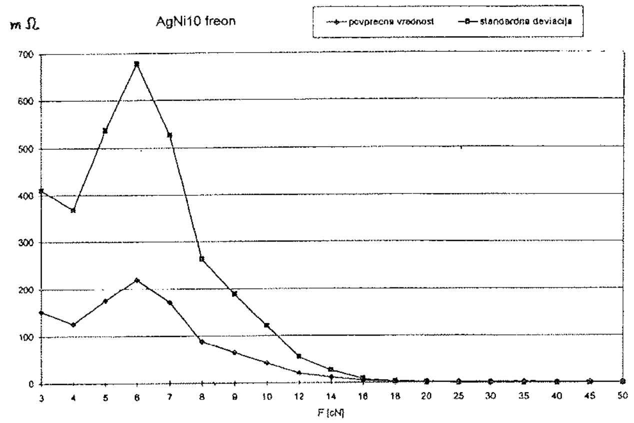

Fig. 8b: Critical contact force providing reliable switching can be estimated from graphs as shown on these plots. Insufficiently cleaned contacts reveal high and unstable contact resistance up to approx. 15 cN.

By comparing various cleaning methods cleanning in RF hydrogen plasma gives us best result, when parameters of the process ensure us apropriate cleaning effect. Standard application of chloro-fluoro-carbons is less successive even at very carefully performed cleaning. CFC agents are also ecologicaly unacceptable. Vacuum degassing is also not succesfull method of cleaning, because contamination films do not consists only of easily evaporating substances. This process presummably solidifies contamination films, therefore higher contact forces is required to achieve low and stable contact resistance, which can be estimated from graphs of Fig. 8.

Results of our present research indicate no detrimental influence on significant increase of contact resistance, when properly cleaned contacts have been exposed to moderate dusty or slightly sulphurizing ambient atmosphere for few days or even a week.

Acknowledgements

Present research is a part of the project accepted into National research programm sponsored by Ministry of Research and Technology of Republic of Slovenia. Authors wish to express thanks to company DODUCO, Pforzheim, which has delivered us samples of contact materials for research purposes.

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Prispelo (Arrived): 01.10.1996 Sprejeto (Accepted): 10.11.1996