Zbigniew Złonkiewicz

Technical University of Lublin, Institute of Fundamental Electrical Engineering and Electrotechnology,
ul. Nadbystrzycka 38A, 20-618 Lublin, Poland; e-mail: zbigz@eltecol.pol.lublin.pl

LOW – CURRENT CONTACTS ANALYSIS WITH THE APPLICATION OF MATHEMATICAL-PHYSICAL MODELS

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The paper presents the results of modelling of contacts used in low current circuits. Mathematical and physical models are useful in the analysis of such contacts to describe the complex real shape of contact areas. FLUX 2D packages have been used for simulations assuming contact model in the form of an ellipse. The selected contacts are covered with a hard golden layer on a PdNi20 beneath layer. The distribution of current intensity, power and voltage in the contact areas has been determined.

1. INTRODUCTION

The paper presents the results of modelling of contacts used in low current circuits. Selected contacts covered with golden layer and multilayer contact comprising three layers were the subject of our analysis.

High level of the equipment integration, increased exploitation demands led to the necessity to conduct research on new contact materials and their properties as well as their analysis by the simulation methods provided by modern software packages. Knowledge of the processes emerging during contact operation has been expanded along with the number of the applied contacts. Contacts applied in low current circuits shall fulfil high utilisation demands, which are caused by the specific features of the electronic devices where special attention is focused on the stability of operation as well as the maintenance of the useful parameters.

For the analysis of contact operation mathematic-physical models are helpful that can present real shapes of the contact points which are difficult to describe. The materials used for the contacts, the selection of which requires detailed analysis are also highly important due to a great number of factors influencing their operation. For such studies, computer software packages enabling the receipt of result data are an asset, that makes feasible to use wide internal base. The paper presents the simulation of multipoint contact with the application of the mathematical-physical models in the form of cylinders and truncated pyramids. Our attention is focused on the distribution of current intensity, power and voltage in the contact, especially in the contact area.

Modelling of low-current contact area was made with the application of Flux 2D software. Modelling was conducted in the cylindrical coordinates. The paper presents the studies for two different contact materials:

a) structure made of golden layer of 5μm thick on the beryllium bronze

b) multi-layer structure 0,1μm of gold, 15μm of PdNi20, 3μm of nickel on the beryllium bronze.

The calculations and the models performed are used for the simulation of the operating electric contact regarding the length of the reduction zone of the current circuit, as well as the tolerable surface densities of current.

The results of the analysis are focused on the possibility to use the computer simulation for the application of different contact coating and the selection of the model of the relevant contact. The performed simulation of various aspects of contact operation connected with the manufacture and the parameters' estimation of the received coating allows to evaluate quickly the selection of the material as well as the quantities required for the contact operation.

2. THE INFLUENCE OF THE EXPLOITATION PARAMETERS ON CONTACT OPERATION

Contact features are influenced by several functional parameters like: mechanical, economic and exploitation. The crucial parameter, which determines contact application, is the value of the transition resistance. The passage of current results in the heat generation especially in the contact area. The increased heat generation in the contact areas is explained by the concentration of the current streams inside them. The experimentally proven statements confirm that only a part of the contact surface conducts current. Therefore, two types of the contact surface are distinguished: apparent – visible contact surface, and real contact surface, which is relevant to the operating surface of the contact. Real contact surface is considerably smaller as it is influenced by several factors. The following factors are considered to be crucial: contact tip pressure, components of the contacts, type of contacts i.e. the shape of the front part of the contacts as well as the contact surfaces.

Except the mentioned factors, the real contact surface is also influenced by: operating conditions, type of load and time velocity of current passing through the contact.

Fig. 1 Current streams in the contact

The passage of current is present in the contact area, thus the contraction of the current circuit increases the transition resistance. The local increase of current voltage is present at the contraction points as it is shown in Fig. 1. The contraction of the current circuit is difficult to be presented in relation to the mathematical view. This is caused by the random irregularities formed on the contact surfaces. Therefore, different mathematical models shall be used in order to obtain the computing results approximate to the result experimentally achieved at the selected assumptions.

Passing current due to the transition resistance caused heat generation in the contact area. According to the Joul's law, the amount of the generated heat is:

$$Q = \int_0^t I^2 R_s dt \tag{2.1}$$

where: I – current intensity, R_s - contact resistance

Constant voltage of the passing current causes heat generation at the contact area, local increase of the temperature. Gradually, depending on the heat return from the contact area – thermal balance is reached along with the specified temperature distribution. Taking the law of Wiedemann – Franz into consideration concerning the relation between resistivity ρ, thermal conductivity λ and temperature T, general dependence for each conducting area can be described:

$$\rho * \lambda = L * T \tag{2.2}$$

where: ρ - resistivity of conducting metal, λ - thermal conductivity, L – temperature constant, T – temperature

If the contact elements are loaded with the current of variable intensity, local maximum temperatures are changed and are fixed after the time of nanoseconds along with the change of the supplied voltage. Along with the increase of current intensity passing through the contacts the maximum temperature of contact micro-surfaces grows. This influences the extension of micro-surfaces of contacts. Therefore, the distance between the contacts is extended which causes that the space in some micro-surfaces is formed and the value of the transition resistance increases. The density of current passing through the contact surface is still growing and along with the increased voltage the temperature of the contact reaches the point of material softness. The process of welding starts at the contacts, the contact surfaces are close to each other again, new places of micro-surfaces appear, real contact surface is extended and rapid decrease of the transition resistance is observed. The above mentioned phenomena cause non-stability of the operating elements of the contact and may cause the disturbances resulting from the rapid changes of the transition resistance value.

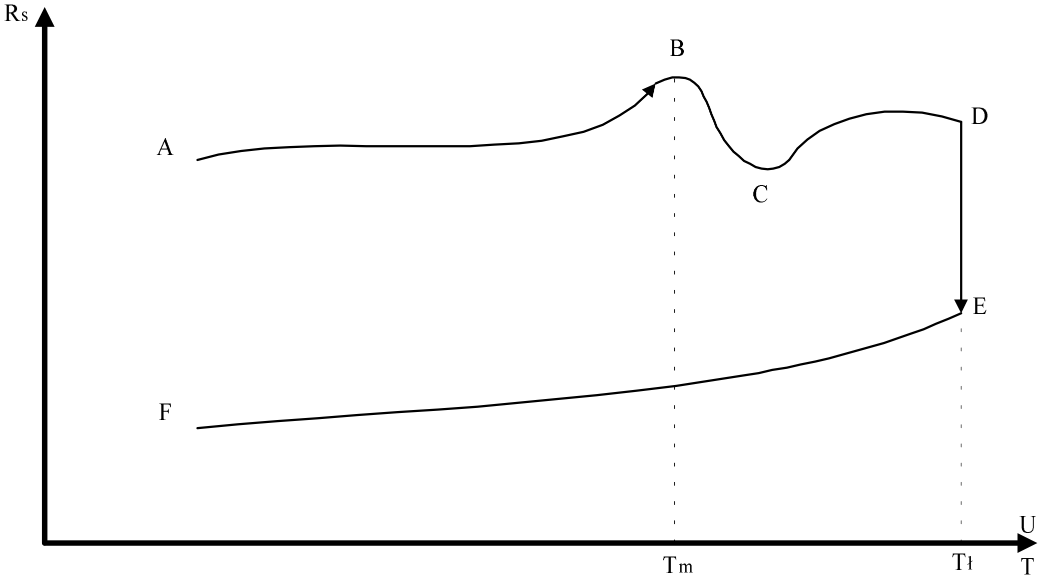

Fig. 2. The dependence of the contact resistance on voltage and temperature of the contact area

Fig. 2. shows the relation between R_s and voltage (U) and temperature (T). The path AB is relevant to the increase of the resistance due to the temperature growth. BC – corresponds with the phenomenon of material softness of micro lips increase of the real contact surface and resistance decrease, CD – resistance growth similar to AB, but at wider contact surface, DE – welding of contact material and further growth of the real contact surface. The path EF presents the situation where along with the voltage decrease, the temperature falls down and contact resistance decreases according to the similar relation as for AB. It follows from the above that the contacts installed in low-current circuits shall operate within the range of AB without reaching the point B.

The basic materials used for the contacts are metals or alloys characterised by low resistance on corrosion. For this reason they are covered with the layers consisting metals resistant to the influence of environmental factors and characterised by low value of resistivity. The required elastic features of the contacts are mainly obtained under the process of plastic forming. Thus, the elements of high inner stresses are produced of the enriched surface containing the complex of metallic layers. Due to the instantaneous progress the contacts become old-fashioned even if they are stored or currently used which makes contact operation worse or even impossible.

3. MATHEMATICAL – PHYSICAL MODELS USED TO COMPUTE CONTACT TRANSITION RESISTANCE

Contact transition resistance can be described at significant simplifications. Real contacts have various shapes and dimensions but they are modelled by mathematical – physical figures of simple geometry. The assumption is then that the dimension is the mean of all dimensions of all contact areas that belong to a given contact. The simplifications and assumptions that characterise particular models enable approximated computations of transition resistance. However, the use of computations based on significant simplifications is limited in practice of surface layers. Furthermore modelling and the introduction of corrections resulting from the experience gives further perspectives for more precise computations of contact transition resistance. The most frequently used models are:

- modelling by means of conductive dots,
- spherical model,
- elliptical model,
- pyramid model.

4. COMPUTER SIMULATION

The paper presents the mathematical – physical model of a sphere and its Au – Ni coating that is applied in the case of low current contacts. FLUX 2D software used at the Institute of Fundamental Electrical Engineering and Electrotechnology makes possible to perform simulations of contact area at some assumptions of contact materials, applied voltage and contact force expressed thorugh the contact area. This software was used for the analysis of this model and gave in the result the distributions of current density, power and voltage in the working contact at equal voltage values. The Au coating on a Ni sub-layer was analysed. This formulation of the problem makes possible to determine electrical phenomena occurring in contacts which was not possible with physical models. Simulation results show that the distributions of current density and power are very ununiform. This is caused by assumed models, used materials and the distribution of equipotential lines. The analysis enables the selection of conventional materials and monitoring of phenomena occurring on contact surfaces and sub-layers. The finite element mesh of a spherical model is presented in Fig. 3.

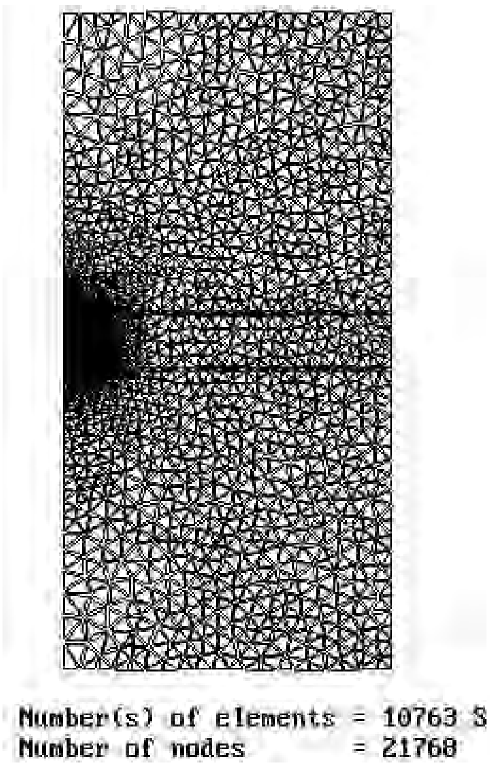

Fig. 3. Mesh of finite elements of the whole contact for the model of the pyramid

The mathematical – physical model used for the simulations – model of two pyramids. When the method of finite elements is applied, the space shall be divided into finite elements. The automatic mesh generation enables to obtain triangular elements. They are formed due to the Delaunay's method that allows to form interactively the triangles by inserting to the mesh the nodes existing at the points and lines as well as the nodes on the surface. The figures show modelled contact with the mesh of finite elements for the whole contact.

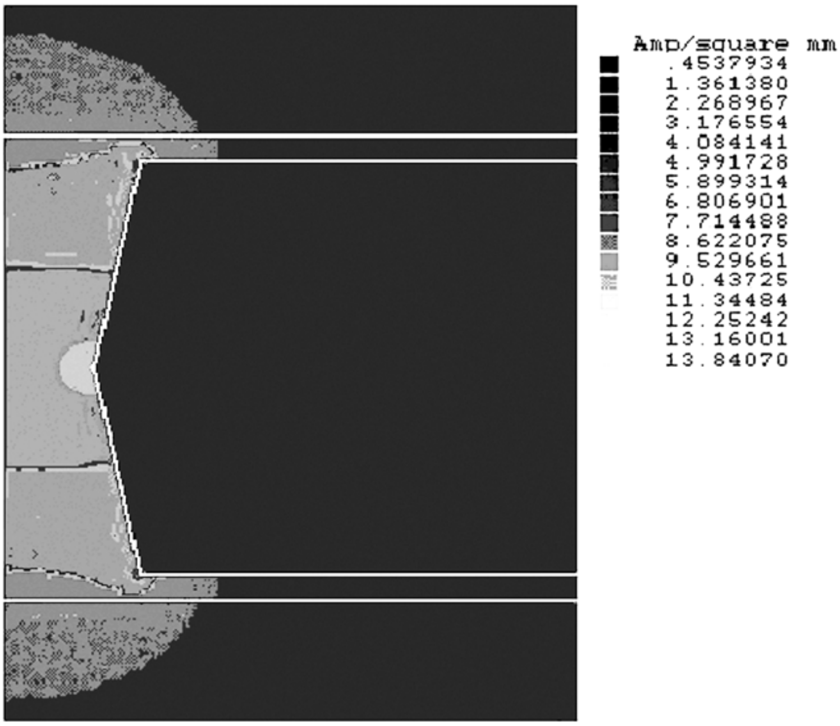

Fig. 4. Distribution of the current vectors for the model of the pyramids with the Au-Ni coating

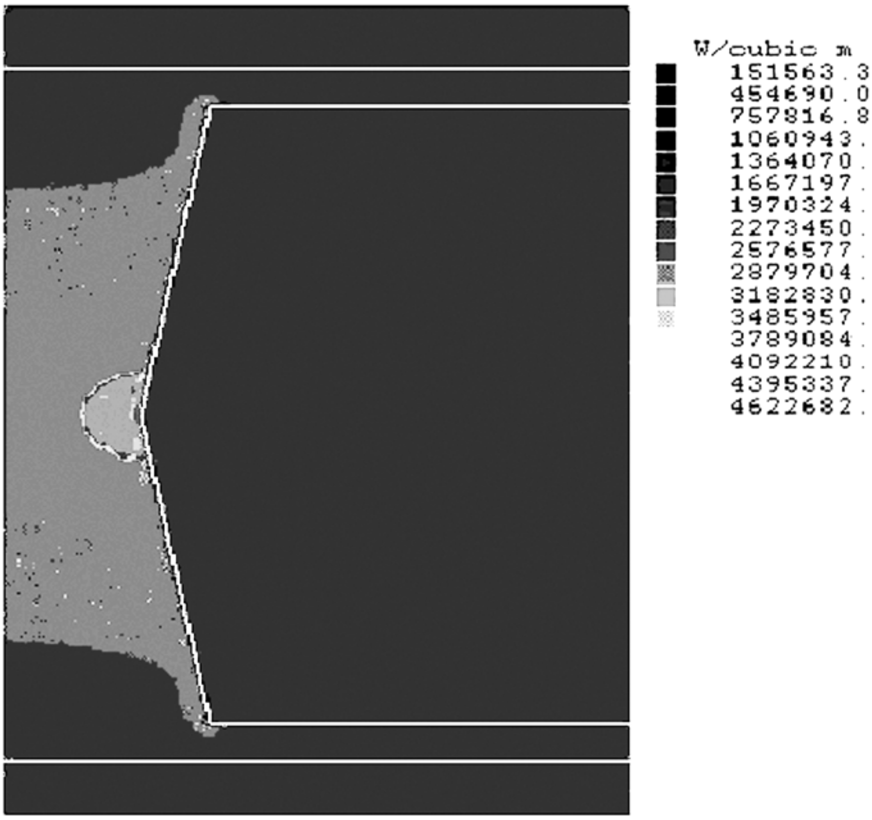

Fig. 5. Distribution of the power vectors for the model of the pyramids with the Au-Ni coating

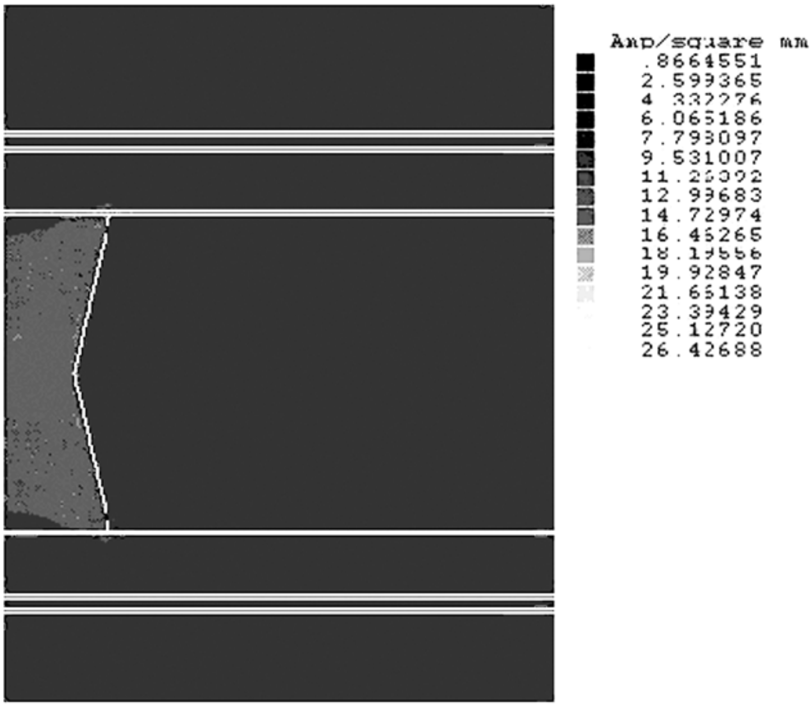

Fig. 6. Distribution of the current vectors for the model of the pyramids with multi-layer coating

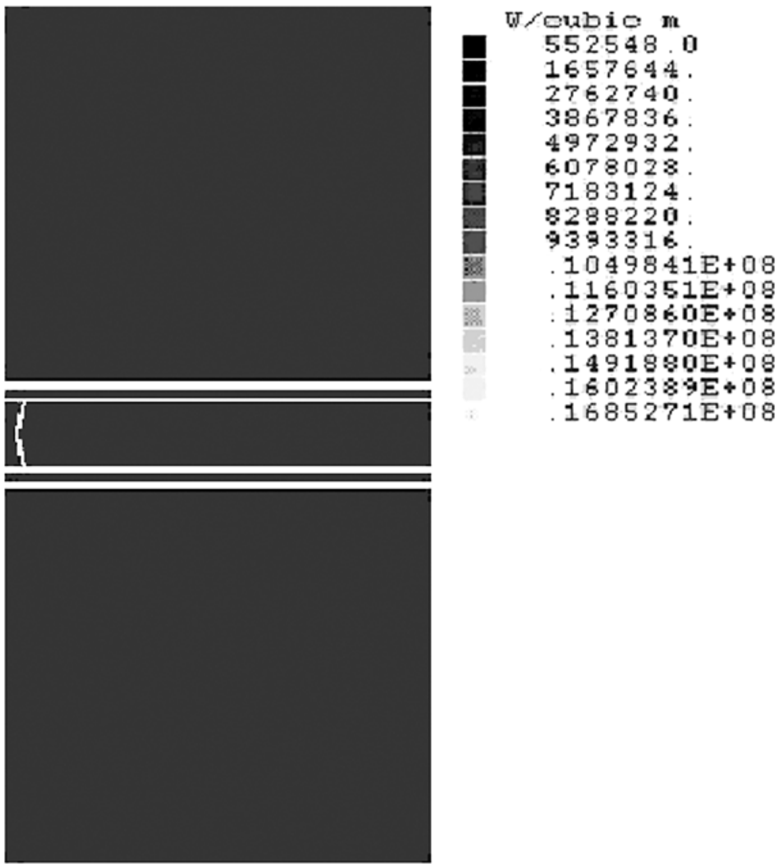

Fig. 7. Distribution of the power vectors for the model of the pyramids with multi-layer coating

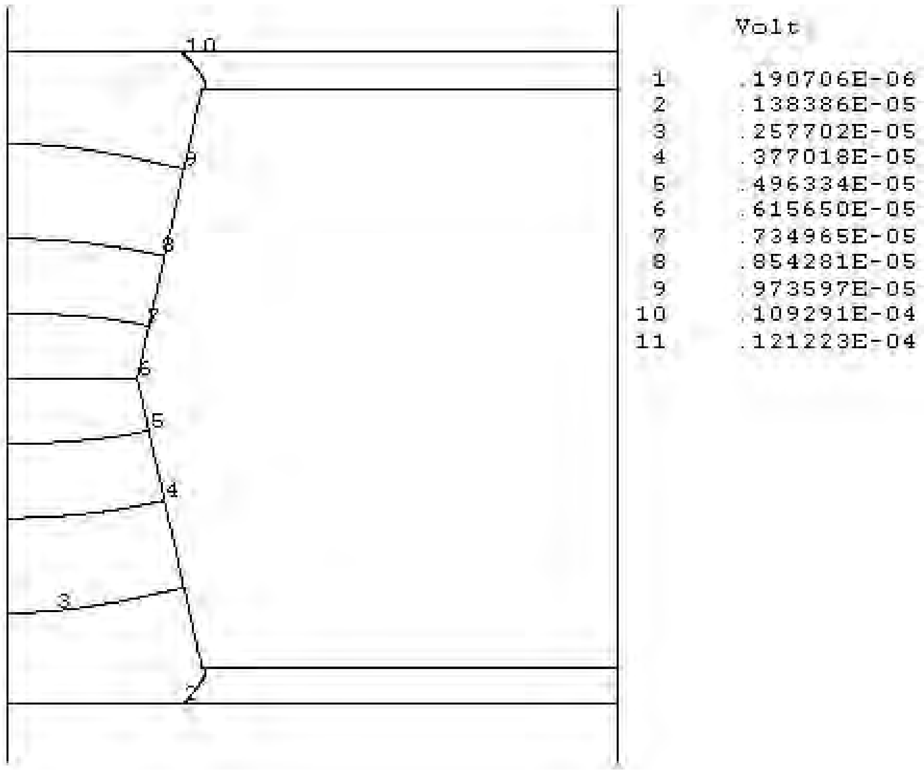

Fig. 8. Potential distribution for the model of the pyramids with the Au-Ni coating

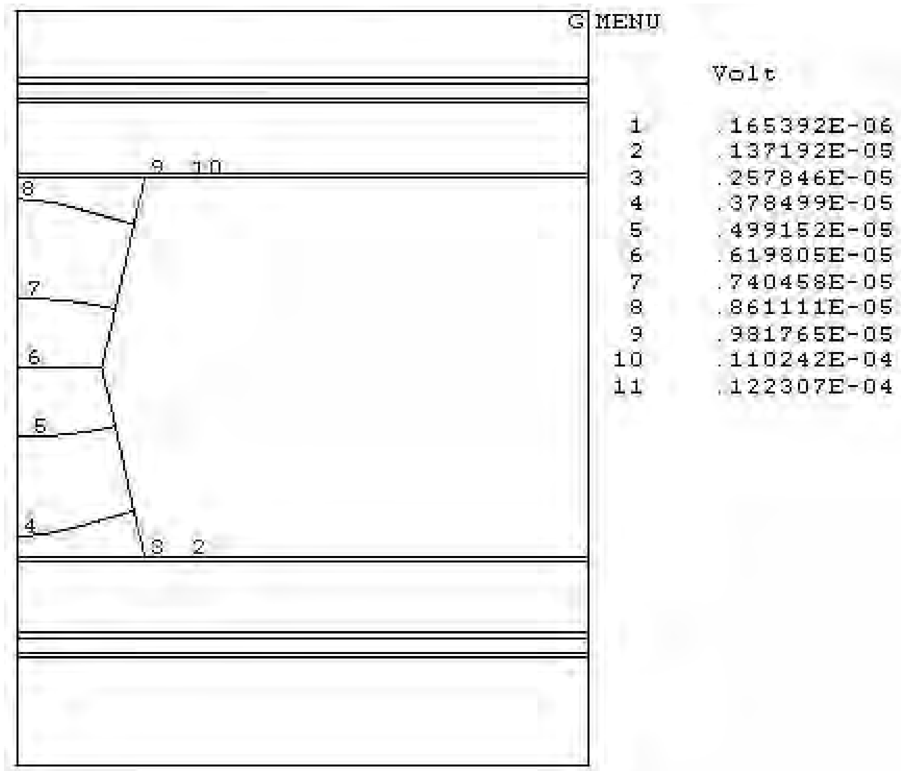

Fig. 9. Potential distribution for the model of the pyramids with multi-layer coating

The analysed contact models consisted of the Au layer on the Ni sub-layer, which enabled to specify electrical processes occurred during the contact operation whereas it was impossible to specify in case of the real models. The simulations showed high ununiform distribution of current density at the contact. This was influenced by the models applied as well as materials.

The conducted simulations enable to chose proper materials and follow the processes occurring in the coatings and sub-layers of the contact. It is related to the decreased value of the transition resistance influenced by the contact surface. It is influenced by the higher transition resistance dependent on the contact forces and the surface area of the contact. The simulation enables also to specify the points of the highest current concentration that may have a negative impact on the contact operation (overheating and damage). Maximum current density on the Au coating with the Ni sub-layer reached the value of 14 A/mm^2 for the single model of the sphere. The concentration of current streams is present at the contact areas at the shortest sections between the material of the sub-layer and at the contact point of the coating and the sub-layers material forming the multi-layer contact.

5. CONCLUSIONS

On the basis of the experiments performed with the application of FLUX 2D package a precise subsidiary model for the contact area can be designed. The simulations of truncated pyramids were aimed to select the model relevant to the real operating conditions of the contacts. The results indicated that for the model of truncated pyramids current concentration is the lowest and the geometry of this model is the most appropriate for the real conditions of the contact. The simulations ease also the determination of areas of the highest current and power concentrations, which is harmful for contact operation (e.g. heating and damage). According to the Fig.4 where distribution of area current density is presented the values reach even the range of 13.8 A/mm^2, however these are only contact edges and the value is low enough to avoid heating of the contact conductive surfaces. For the contact considered as the whole it can be stated that mean density of surface current do not exceed the value of 3A/mm^2. The tests resulted in designing the model of electrical contact regarding the surface irregularity and number of contact points. The concentration of current streams can be observed at contact areas along shorter distances between the sub-layer materials and where the coating touches the sub-layer material. Such contacts are called multi-layer ones and have additional contact surfaces. The power density distribution on the multi-layer sphere contact indicates that the highest density occurs on the contact between the coating and the sub-layer. This, surely, results from the difference between the resistivities of Au and Ni. It is faster to select the suitable material and model due to our needs. This selection presents also the influence of equipotential lines on current and power density distributions, which is caused by current streams around the models located at external surfaces of contacts.

6. REFERENCES

1. *Greenwood J.A.: Construction resistance and the real area of contact. British Journal of Appl.Physics, 1966, v.17, p. 1621-1631.*
2. *Holm R.: Electric Contact Handbook Springer - Verlag - Berlin Heidelberg 1967.*
3. *Konczic W.W., Mieszkow W.W., Myszkin N.K.: Tribotechnika elektriczieskich kontaktów. Mińsk (Nauka i Technika) 1986.*
4. *Showball R.F., Williamson J.B.P.: The ingress of reactans between contacting surfaces.*

5. *FLUX 2D, Version 7.1. CAD Package for electromagnetic and thermal analysis. User's Guide. CEDRAT 1994.*
6. *Złonkiewicz Z.: Wytwarzanie i właściwości powłok przewodzących palladowo-niklowych w technice słaboprądowej. Wydawnictwo Naukowe Lublin 1998r.*
7. *Złonkiewicz Z: Palladium-Nickel Conductive Coating in Low Current Engineering. 8th International Conference on Switching Arc Phenomena on Electrical Technologies for Environmental Protection, Łódź, 3-6.09.97, pp. 222-225*
8. *Złonkiewicz Z.: "Modelowanie przestrzeni stykowej metodami numerycznymi". IV Konferencja Naukowo -Techniczna: ZASTOSOWANIA KOMPUTERÓW w ELEKTROTECHNICE - ZkwE'99, Poznań/ Kiekrz 12-14 kwietnia 1999, str. 185-188*
9. *Złonkiewicz Z.: "Modele matematyczne - fizyczne wykorzystane do obliczeń rezystancji przejścia zestyków słaboprądowych" V Konferencja Naukowo - Techniczna: Zastosowania Komputerów w Elektrotechnice, Poznań/Kiekrz, 10 - 12 kwietnia 2000, str. 675-678*
10. *Złonkiewicz Z.: "Triple-Layer Contact Simulations" Electromagnetic Devices and Processes in Environment Protection ELMECO, Nałęczów, 04 - 06 czerwca 2000, pp. 231-237*
11. *Złonkiewicz Z.: "The Performance Analysis of Low-Current Contacts Modelled by Numerical Methods" Proceedings of 20th International Conference on Electrical Contacts, Stockholm Sweden, 19 - 23 June 2000, pp. 251-254*
12. *Złonkiewicz Z.: "Computer Simulation of Low Current Contacts". 9th International Conference*
13. *Switching Arc Phenomena, Łódź, September, 17-20, 2001, pp. 241-246*

Mariusz Trybus [1], Włodzimierz Kalita [2], Władysław Proszak [1]

[1] Rzeszów University of Technology, Department of Physics,
2 W. Pola Str., 35-959 Rzeszów, Poland
[2] Rzeszów University of Technology, Department of Electronic Systems,
2 W. Pola Str., 35-959 Rzeszów, Poland

RELATION BETWEEN DOMAIN STRUCTURE DISTORTION AND COERCIVE FIELD IN L-LYSINE DOPED TGS SINGLE CRYSTALS.

1. INTRODUCTION

Triglycine Sulphate (TGS) is one of the most intensively examined ferroelectric material, finding wide application, as active element of the IR sensors, in the range of room temperature. Temperature of the Curie point for TGS is 49ºC and the material shows second order phase transition. Structure of the crystal lattice is monoclinic, both below, and above the Curie point. Cleavage plane is perpendicular to the ferroelectric b axis (0,1,0). One of the most important disadvantage of TGS is depolarisation process, influencing the electric parameters and performance of the detectors based on this material. Well known method for improvement of electric properties and elimination of depolarisation process is doping pure TGS with optical active particles [2,3,4].

TGS single crystals doped with l-lysine (TGSL10) were grown below Curie point with use of static method, by evaporation of the solvent. Morphology changes were observed in new grown single crystals in comparison to pure TGS. Parameters of the crystal lattice were determined with use