18TH INTERNATIONAL CONFERENCE ON
ELECTROMAGNETIC FIELDS AND MATERIALS

VA Characteristics of Gold-Polystyrene-Gold Structures

P. Buchar, J Macháč, J. Zehentner

Czech Technical University, Technicka 2, 16627 Prague 6, Czech Republic
Phone: +420 224352279, Fax: + 420 224355865, E.mail: bucharp@fel.cvut.cz

Abstract

This work presents the preliminary results from our investigation of the electrical properties of metal-insulator-metal structures consisting of two sputtered gold layers, several tens of nanometers in thickness, separated by a polystyrene layer, several hundreds of nanometers in thickness. These structures were reproducibly prepared, and their VA characteristics were measured at room temperature in a vacuum chamber. The effect of electroforming, i.e., a sharp increase in current at a certain threshold voltage, was regularly found in the measured VA characteristics. This phenomenon was accompanied by significant current fluctuations. The threshold voltage decreases with pressure.

Introduction

Electrical phenomena in thin metal-insulator-metal (MIM) structures have frequently been investigated in recent decades. One of the first summaries on these phenomena was made in 1970 by G. Dearnaley et al. [1]. In this paper, amorphous oxides were used as insulators in MIM structures, while ZnS was used in [2], and Si_3N_4 was used in [3]. The authors of [4] preferred polystyrene as the insulator.

In all works listed here, the existence of a phenomenon referred to as electroforming was reported. When a voltage exceeding a certain threshold value is applied between metal electrodes, the current rapidly rises by several orders. A further voltage increase then results in a fall in current. Accordingly, a region with negative differential resistance occurs in the VA characteristic of the structure.

This phenomenon is usually explained as a result of growing conducting filaments between the two electrodes through the insulator. When the voltage is increased, more and more filaments arise, and the current increases. However, with increasing current, the ohmic losses in the filaments also grow, and some of them are destroyed due to overheating. The destruction of filaments may exceed the creation of filaments and, thus, current may fall with increasing voltage.

This phenomenon occurs only when the structure is placed under low pressure. According to the available equipment, pressures in the order of 10^2 Pa to 10^{-2} Pa were reached within the framework of this work. The VA characteristics of samples placed under such pressure were measured.

The characteristics measured under individual pressure levels showed that the lower the pressure, the lower is the threshold voltage. In addition, the results show that the increase in current at the threshold voltage is accompanied by significant current fluctuations that also remain for voltages higher than the threshold voltage.

A region of negative differential resistance within the measured VA characteristics was found only exceptionally, and was not stable.

Preparation of Layers

The structures were prepared on a glass substrate. At first, the bottom gold layer was sputtered through a mask forming the set of contacts, shown in Fig. 1. This layer is approx. 50 nm in thickness. Then the insulator layer was made up from a polystyrene solution by the spin coating technique. The thickness of this layer depends on the concentration of the solution and on the rotation speed. It was designed to be approx. 250 nm in our case. Finally, the top gold layer was sputtered through the same mask, but rotated by 90 degrees. Its thickness is the same as that of the bottom gold layer.

At first, a mask giving the active area of the MIM contact itself of 1 mm^2 was used. The yield of preparation of contacts using this mask was very low, due to unwanted penetration of the metal through the polymer in the process of sputtering. This problem was solved by using a new mask, providing an active contact area of 0.16 mm^2. With a lowered active area, the probability of shortcutting the insulating layer was also lowered, and the yield grew almost to 100 %.

Measurement of VA characteristics

The space surrounding the prepared structures was evacuated by a diffusion pump. According to the particular available apparatus, pressures from approx. 10^2 Pa to 10^{-2} Pa were reached. The structure was connected to the Keithley 487 Picoammeter/Voltage source. This is an adjustable voltage source that measures its output current at the same time. A voltage was applied to the structure, it was gradually increased, and the current was measured. The structure layout and measurement set-up are sketched in Fig. 1.

The temperature dependence of the VA characteristics was not assessed and, therefore, the temperature was constant and equal to the room temperature.

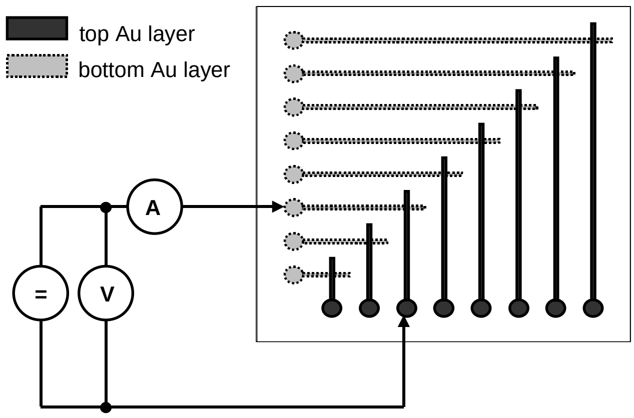

Fig. 1 Sketch of the structure layout and measurement set-up

Measured characteristics

Measurements of the VA characteristic of many MIM samples were performed. Several of them, having common features of the measured characteristics, are shown and commented on here. All these tested samples were as identical as possible, with gold layers approx. 50 nm in thickness and a polystyrene layer approx. 250 nm in thickness.

In the first case, a typical sample was placed under a pressure of 10^2 Pa. Then the applied voltage was increased and subsequently the current gradually rose from the order of 10^{-12} to 10^{-10} A, as shown by the squares in Fig. 2. At 80 V a sharp increase in current occurred. The current rose up to 10^{-7} A and started to fluctuate from about 10^{-9} to 10^{-7} A. When the voltage was further increased, the current continued to fluctuate. In Fig. 2, these current fluctuations are marked at the corresponding voltages by vertical lines determining the interval within which the current fluctuated.

In the second case, a typical sample was placed under a pressure of 10^{0} Pa. With increasing voltage the current gradually rose from 10^{-12} to 10^{-10} A. A sharp increase in current to 10^{-7} A occurred at 26 V, and the current fluctuated from 10^{-8} to 10^{-7} A, as shown in Fig. 3. These fluctuations continued when the voltage was further increased.

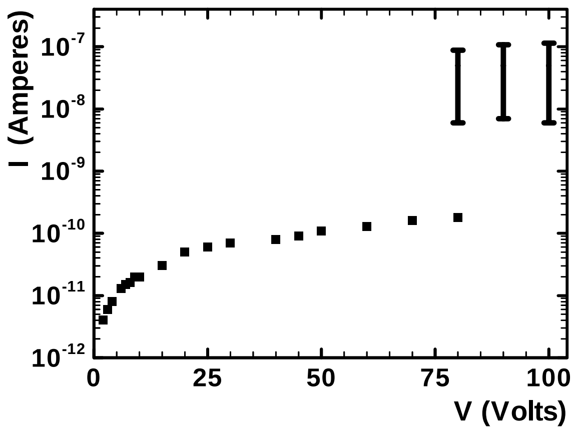

Fig. 2 VA characteristic of a sample measured under a pressure of 10^{2} Pa

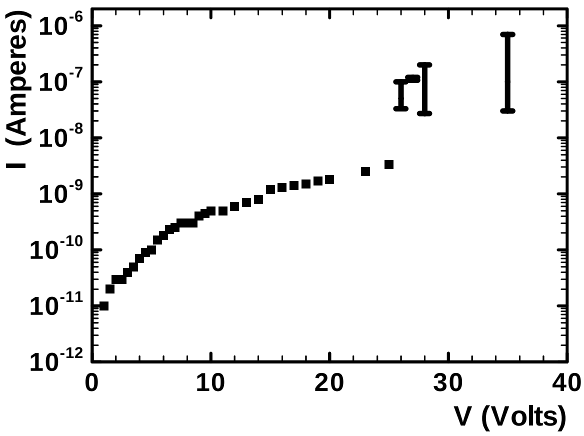

Fig. 3 VA characteristic of a sample measured under a pressure of 10^{0} Pa

In the third case, a typical sample was placed under a pressure of 10^{-2} Pa. As shown in Fig. 4, for voltages lower than 5 V the current could not be measured due to equipment limitations. With increasing voltage the current gradually grew to 10^{-11} A, and a sharp increase in current to 10^{-4} A occurred at 8 V, accompanied by significant current fluctuations from 10^{-6} to 10^{-4} A. For increasing voltage the current continued to fluctuate from 10^{-11} to 10^{-7} A.

In this case a region with negative differential resistance was found. This was observed within several cycles of increased and decreased voltage in the interval from 9 to 12 V. In Fig. 4 the existence of the negative differential resistance is shown by circles that correspond to the mean value of the measured current.

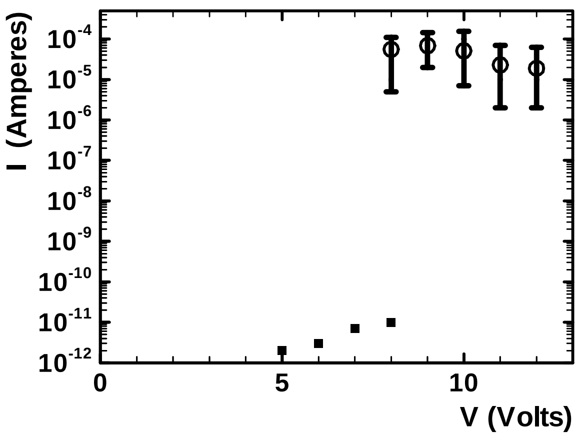

Fig.4 VA characteristic of a sample measured under a pressure of 10^{0} Pa. Circles show the temporarily revealed part of the characteristic with negative differential resistance.

Conclusion

MIM structures consisting of two gold sputtered layers approx. 50 nm in thickness and separated by a polystyrene layer approx. 250 nm in thickness were reproducibly prepared. Their VA characteristics were measured and the effect of electroforming was observed. This effect results in a sharp increase in current by several orders at a threshold voltage. This voltage strongly depends on the pressure in the vacuum chamber used for measurement of the VA characteristics. Changing this pressure from 10^2 Pa to 10^{-2} Pa lowered the threshold voltage from 80 to 8 V. All measured VA characteristics showed significant current fluctuations by several orders when the MIM structures were formed. This fact supports the hypothesis of growing conducting filaments throughout the structure. The current fluctuations could be a result of a random rise and disappearance of filaments.

The negative differential resistance reported in the literature [1-4] was observed only in some MIM structures. Within several cycles of increasing and decreasing of voltage, this phenomenon disappeared.

Acknowledgement

This work was supported by the Grant Agency of the Czech Republic under project 102/06/1106 “Metamaterials, nanostructures and their applications”.

References

[1] A. Dearnaley, A. M. Stoneham, “Electrical phenomena in amorphous oxide films,” Reports on Progress in Physics, vol. 33, no. 3, pp. 1129-1191, September 1970.

[2] R. R. Sutherland, “A theory for negative resistance and memory effects in thin insulating films and its application to Au-ZnS-Au devices,” J. Phys. D: Appl. Phys., vol. 4, no. 3, pp. 468-479, March 1971.

[3] R. D. Gould, S. A. Awan, “DC conductivity in RF magnetron sputtered gold–silicon nitride–gold sandwich structures,” Thin Solid Films, vol. 398-399, pp. 454-459, November 2001.

[4] K. Efimenko et al., “Electrical properties of Au-polystyrene-Au submicron structures,” Applied physics A. Materials science and processing, vol. 68, no, 5, pp. 503-505, 1998.