

Au-PbPc-Si(p) Devices Under Mechanical Pressure

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Abstract: - In this work PbPc films were investigated as active material in a pressure sensor device. Au-PbPc-Si(p) structures was fabricated and the current-voltage characteristics at different pressures applied on the top electrode (Au) were drawn at room temperature. It was found a change in the current level flowing through the device with the pressure. Taking a constant voltage of 8 V from those J-V curves, the current-pressure behavior was plotted and it was found to have a lineal relationship. The slope S of that plot was higher on forward polarization (Au+, S=1.74 $\mu\text{A/kPa}$) than on reverse (Au-, S=0.046 $\mu\text{A/kPa}$).

Key-Words: - PbPc films, Pressure sensor, Au-MPc-Si structures, current-voltage curves, ohmic contact, SCLC transport.

1 Introduction

During the previous three decades, there has been an increasing attention in studying the properties of metal-substituted phthalocyanines (MPc's) thin films, due principally to their potential use in applications as gas sensors, solar cells and optoelectronic devices [1-5].

Electrical and optical properties of the MPc's have been observed to change when they are exposed to different external factors, environment, incident radiation, pressure are some of them [3-5].

The pressure is a parameter that can influence the conductivity in the MPc's [6-8]. It is reported that the conductivity changed up to six orders of magnitude if a pressure is applied on metallophthalocyanines [7], but these data were collected from powders and very high pressures. The effect was attributed to, metal-ring

interaction, metal-metal interaction and solid - state reaction in the macromolecule of the MPc's. T. Hiejima et al [8] studied the pressure induced charge transfer in one-dimensional phthalocyanine conductor, NiPc(AsF₆)_{0.5} and they found that a pressure-induced charge transfer from the central metal ion to the macrocycle which changes the band filling factor of the d- and π - bands. But those data correspond to powders and very high pressures (up to 6 GPa).

Pressure studies on MPc films were performed more recently by Pakhomov [9], by using M-PbPc-M, sandwich like structures. The author found that the electrical current level flowing trough the device changed as the contact pressure increased from 0.8 MPa to 2MPa, an increase in the electrode area and/or some processes arising in the bulk of PbPc, for instance, a decrease in

the intergrain distances in a packed polycrystalline film were suggested for the observed phenomenon.

In this work the electric characteristics of PbPc films, deposited on glass slides or crystalline silicon, type p, substrates under relatively low pressures (100 to 664 kPa) are reported. The characteristics current - pressure- (I - P) of the Au-PbPc-Si(p) device exhibited a linear behavior. Neither effect of a film or electrode deformation was detected.

2 Experimental Details

PbPc starting material was obtained from Merck and purified by successive sublimation before film deposition. The substrates were cleaned to eliminate the moisture on their surface. Two classes of substrates were used, glass slides (3 x 3 cm) and silicon, p type, (100) oriented, 40 Ω-cm of resistivity, one polish side CZ substrates. Au-PbPc-Au structures were fabricated following a cycle of technological process. A thin (1 μm) Au film was thermally evaporated on the glass substrates followed by a PbPc film deposition. Au dots were also evaporated through a metal mask on the PbPc films, the final area of this top electrode was 0.8 cm². The final PbPc film thickness was around 0.8 x 10⁻⁴ cm as determined from profilometer measurements. Au-PbPc-Si(p) devices were fabricated by the same technological steps but the PbPc film was deposited directly on the silicon surface followed by the Au dots evaporation. Prior, an Al film was deposited on the back surface of the silicon substrates and annealed in N₂/H₂ ambient at 425 °C to get an ohmic contact. Metal and PbPc evaporations were performed in vacuum at a pressure of 1 x 10⁻⁶ Torr using a tantalum boat for the organic materials and a tungsten basket for the metals.

Current density - Voltage (J-V) and Current - Pressure (I-P) characteristics from the devices were drawn by using an automatic C-V, MDS system. The J-V characteristics from the structures were plotted using the schematic

shown in figure 1, the applied pressures on the top electrode were 101, 130, 214, 382, 664 and 900 kPa. All measurements were performed at room temperature and nitrogen environment.

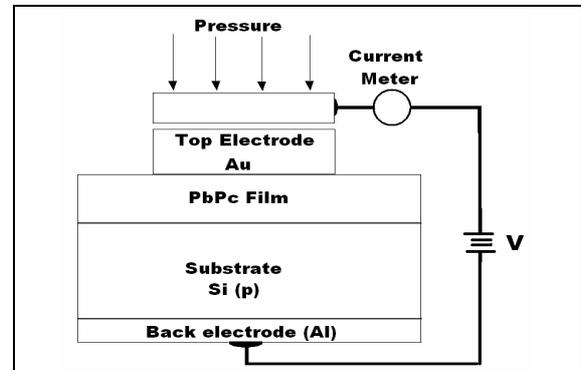


Fig. 1. Experimental set-up for the J-V measurements. The voltage source and the current meter are representing the C-V MDS system.

3 Experimental Results and Discussion

J-V plots from Au-PbPc-Si(p) structures are shown in figure 2. As it can be seen from that figure, the current flowing through the device increases up as the applied pressure is increased from 100 kPa (room pressure) to 664 kPa. The current value ranged from 3 x 10⁻⁹ to 4 x 10⁻³ corresponding to 100 and 664 kPa respectively and taking a reference voltage of 8 V. In this case the Au electrode was positively biased (forward polarization) but similar behavior can be found if the Au electrode is negatively biased (reverse), as can be seen from figure 3.

The experimental J-V data were approximated by typical functions describing possible situations at an Au-PbPc interface. The best matching fit over the voltage range were obtained for a linear dependence on forward polarization (positive on the Au electrode). It is known the resulting contact from Au-PbPc is ohmic and the relation J-V follows a power law of the form; $J = b V^n$, where for $n = 1$, correspond to an ohmic behavior. A value for $n \geq$

2 suggests a SCLC dominated by traps in the volume of the organic material.

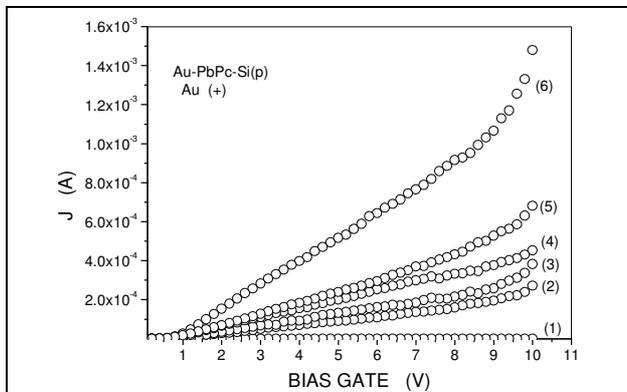


Fig. 2. J-V characteristics drawn from an Au-PbPc-Si(p) device under applied pressure, (1) 101, (2) 130, (3) 214, (4) 270, (5) 382 and (6) 664 kPa. Au(+), Si(-).

The total resistivity of the device changed from 1.7×10^7 to $5 \times 10^4 \Omega\text{-cm}$ for 101 kPa and 660 kPa of pressure respectively.

The J-V characteristics did not exhibit hysteresis with the applied pressure (no shown here), the level current measured before and after to apply the maximum pressure (up to 920 kPa) were the same, therefore changes in the film structure, for instance, a decrease in the intergrain distances in the packed polycrystalline film and/or an increase in the contact area of samples under pressure [9], which result in a rise in the level current may be discarded as responsible for the effect.

Experiments performed on PbPc films deposited on glass slides substrates and used as pilot samples, shown some morphological differences at the film surface with regard to those deposited on silicon crystalline substrates. The films deposited on glasses substrates exhibited a grainy morphology while the deposited on silicon exhibited a smooth surface.

It is well known that the orientation grain depends, on the other, on the substrate, heat treatment and conditions of substrates during film deposition [10]. This improves the electronic properties of the MPc's by increasing the hole mobility.

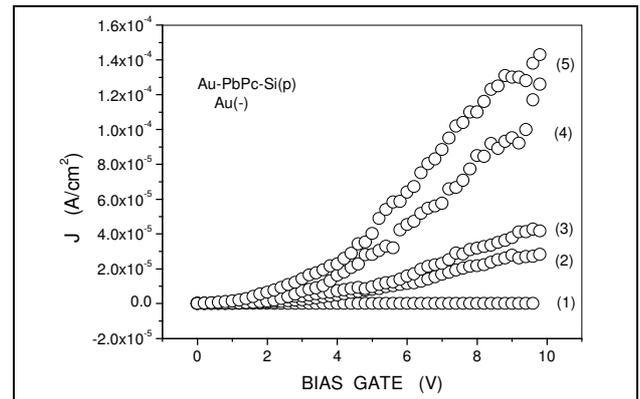


Fig. 3. J-V characteristics drawn from an Au-PbPc-Si(p) device under applied pressure, (1) 101, (2) 157, (3) 214, (4) 382 and (5) 664 kPa. Reverse polarization, Au (-), Si(+)

Although the better quality of the film enhance their electrical properties it appears no to be completely the cause for the observed response of the device to the applied pressure. The different slope observed in the low voltage region in figure 2 for the J-V curves drawn at higher pressure could be related to some effects at interface PbPc-Si(p).

Some charge induction into the silicon substrate from the MPc film could be carried on. It is known that high frequency (hf) capacitance-voltage (C-V) curve similar to those obtained from metal-insulator-semiconductor (MIS) structures can be drawn from some metal-MPc-Si structures [8, 11]. That could be why the forward (Au +) and reverse (Au -) J-V characteristics (figure 2 y 3) from the device are a little different in the low voltage region. The lower level currents obtained in reverse polarization could be related to this fact or to an effect of electrode limited.

The current-pressure (I-P) characteristics drawn from the curves from figure 2, is presented in figure 4. The slope S , in this case was $1.74 \mu\text{A/kPa}$ and for reverse polarization the value was $0.046 \mu\text{A/kPa}$. The reference value of 8 V was taken arbitrary but similar result can be obtained if other values in the linear region of the J-V characteristics are considered.

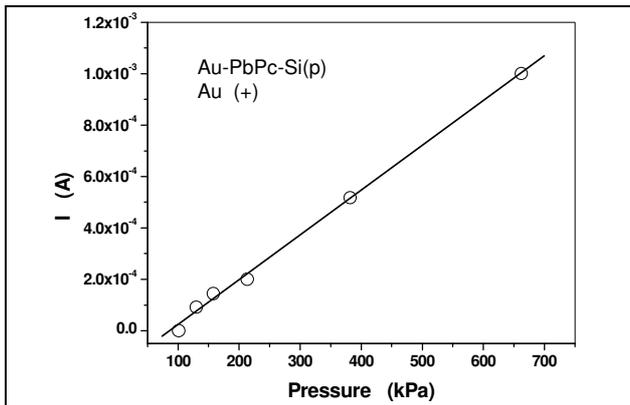


Fig. 4. Current-pressure characteristics drawn from J-V curves at 8 V. The device Au-PbPc-Si(p) was biased in forward polarization (Au +)

The values of S obtained in this work are low compared with others pressure sensors, but it is possible to measure in some level the pressure with this type of devices. More investigation is needed to low the sensing pressure range in this type of devices.

4 Conclusions

The Au-PbPc-Si(p) structures shown a linear response in the current level to relatively low mechanical pressures applied on the top electrode. It is thought the responsible for that fact is a better quality of the PbPc films compared with those deposited on glass (or conductive) substrates under same technological conditions.

In addition an induction of charge could be originated at interface PbPc-Si(p) and/or in the volume of the silicon so that the hole injection with the applied pressure is controlled in this region.

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