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Electronic Properties of Au/Cef$_3$/Au Structures at Different Temperatures

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Abstract

In this experimental work, some electronic properties of vacuum evaporated Au/CeF_3/Au structures such as circuiting I_c and emission I_e currents versus the applied voltage, electron attenuation lengths in both gold and CeF_3 layers and the role of the latter layers have been investigated. Experimental results show that these devices undergo an electroforming process leading to resistivity decrease of several orders of magnitude along with a negative resistance region in their current–voltage characteristics. By decreasing the temperature, both I_c and I_e are decreased and at low temperatures the negative resistance region disappears completely. Electron attenuation lengths are measured between 6 and 14 V for gold and CeF_3 layers and their significance are discussed on the base of electron-impurity and electron-defect scatterings. The conduction mechanism is also discussed on the base of a filamentary model. Results for current – voltage characteristics, forming effects, temperature dependence of conductance, and the emission of electrons into a vacuum are described .Comparatively high emission current densities are archived for low applied voltages with the cathodes at or near room temperature. High values of hot electron attenuation lengths in the insulator are obtained and the significance of these high values is described.

Key words: Thin film, cold cathodes, electron emission, electroforming

Introduction

Thin layers of insulators sandwiched between metal electrodes, exhibit a number of interesting properties. When a bias voltage is applied across an unformed sample an electroforming process takes place and the device resistance is decreased. After forming, devices in which the dielectric is an oxide, halide or a fluoride generally show a voltage – controlled negative resistance, electroluminescence, electron emission into a vacuum and a possible memory effect.

Experimental techniques

Specimen preparation

Thin insulator layers used in this experimental work were prepared by thermal evaporation of magnesium fluoride form a tantalium source in a balzers 510 coating unit.

This unit consisted of evaporation facilities and a vacuum system capable of producing a vacuum of 10^{-6} torr and lower pressures of the order of 10^{-7} torr could be achieved with the addition of a liquid nitrogen trap. A radiant small heater was mounted in the vicinity of the substrates holder were employed and was capable of holding two $1'' \times 3''$ Substrates .Masks below the substrates could be rotated by an external rotary seal , and a maximum of four different layers could be deposited. For deposition of Au layers a tungsten clucible with Al_2O_3 , layer was used. To control the deposition rate and the thickness of the samples, two were separate quartz crystal monitors were used. All samples used in this study were prepared by successive evaporation of the various layers with out breaking the vacuum. For one evaporation procedure, eight specimens were prepared on each substrate.

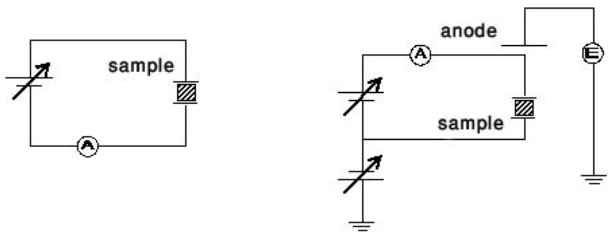

Figure 1: Schematic of circuits.

Measurements

All electrical measurements were carried out in a vacuum system capable of maintaining the samples at a pressure if about 5×10^{-6} torr. The current – voltage characteristics were measured by traditional methods. To measure the temperature dependence of the current – voltage Characteristics and also of the electron emission from $Au - CeF_3 - Au$ Specimens, a small heater was used long with a metal cryostat which could be filled continuously with liquid nitrogen. The heater made of nichrome wire was placed between the cryostate which could be filed continuously with liquid nitrogen. The heater made of nichrome wire was placed between the cryostate. It was so designed that it would not have an undesirable magnetic influence on the electron emission characteristics. A constant power supply unit was used to feed the heater and by the judicious use of cryostat and heater the required temperatures could be obtained. Device temperatures were recorded from a copper constantan thermocouple to the surface of the substrate. Electron emitted into vacuum were collected at a copper anode $(2.5cm \times 7.5cm \times 0.1cm)$

placed at a distance $1.0cm$ from the specimens anode was kept at a potential of 100 vlots with respect to earth. The circuits used are sketched in Fig.1 .An electrometer was used for measurement of the emission currents.

Attenuation length measurements
Measurements of the relative numbers of electron emitted through the thin top layer as a function of layer thickness yield directly values of the hot electron attenuation length. To determine λ_{CeF_3} experimentally, samples with constant top electrode thickness but with insulator layers of different thicknesses were prepared.

Conclusions

Electrical characteristics

The conductivity of the samples increases by several orders of magnitude when they are formed at room temperature in vacuum. As the voltage across the sample is increased, critical voltage is reached at which a sharp increase in current through the insulator layer occurs. On lowering the current through the sample, a pronounced negative resistance region occurs. On raising the voltage to successively higher values, the current voltage characteristic continues to show a negative resistance region for both increasing and decreasing voltages. Currents through the CeF_3 layer are noisy and highly erratic during the first time that a voltage range is covered. However, on successive tracings of a characteristic the currents are much less erratic. The electroforming process consists of cycling the voltage applied across the sandwich between 0 and 14 volts with top electrode positively biased. The voltage required for the forming increase with the insulator thickness and it was found possible to form sandwiches electrically in which the insulator thickness was $1.5\mu m$ The forming voltage increased with decreasing temperature. The voltage at which the maximum peak current occurs varied between 2 and 3 volts for diodes having different material (Au and Cu) and seemed to increase only very slightly with the thickness of the insulator layer. The onset of electron emission into a vacuum occurred for the same applied voltage as that at which the voltage – controlled negative resistance (VCNR) occurred. A typical curves illustrating the circulating and emission currents in a $Au-CeF_3-Au$ sandwich is shown in Figure 2.

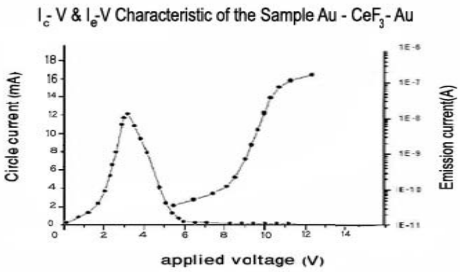

Figure 2: Variations of circulating current versus the applied voltage for a Au/CeF_3/Au sample and Variations of emission current versus the applied voltage.

Temperature Dependence of Electrical Characteristics

The electrical conductivity and the shape of the $\mathrm{I}-V$ characteristics were very sensitive function of temperature after the sandwiches had been electrically formed and significant conductivity had been established at room temperature. As the temperature was lowered to $238K$, the maximum circulating current and the general current level decreased gradually. The current including the peak value increased considerably as the temperature was raised to $333K$. Figure.3 shows the temperature dependence of specimen conductivity at three different temperatures for a freshly made $Au-CeF_3-Au$.sample. Electron emission into a vacuum was observed as conductivity developed in the insulator later and this emission current was also temperature dependent.

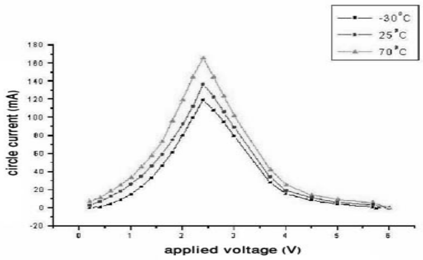

Figure 3: Variations of circulating current versus the applied voltage at three different temperatures.

Attenuation Length Measurements

Figure 4. shows $\log\alpha = \log {}^{I_e}\!/_{I_c}$ as a function of thickness of the CeF_3 layers for different values of applied voltage. The slopes of the lines are striper for electrons emitted at lower applied voltages and indicate that the electrons of lower energy are more heavily attenuated than those of higher energies. Experimental evidence for the energy loss is provided by the fact that in general the transmission ration increases with increase of the applied voltage. Form the slopes of the graphs in Figure .4 an attenuation length was derived for each value of applied voltage in the range 7-15 volts. The values of λ_{CeF_3} are approximately constant $\left(1200A^\circ\right)$ in the range 7-13 volts and then rise with increasing voltages to a value of $1800A^\circ$ at 15 volts applied.

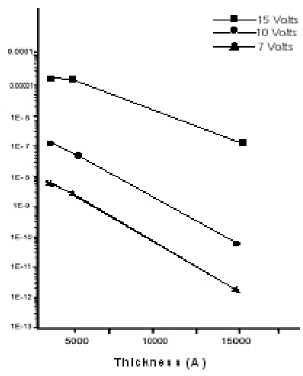

Figure 4: Variations of transfer ratio ($\alpha = I_e/I_c$) versus the thickness of CeF_3 layers.

Discussion of Conclusions

Reason ally good electron emission properties are found and hot electron attenuation lengths are determined .The general electrical properties of $Au - CeF_3 - Au$ sandwich structure are similar to other metal – Insulator – metal structure [1-4] and point to the existence of a barrier layer near the cathode which can cause the free electrons to be accelerated to very high energies sufficient penetrate the reminder of the insulator, the top metal electrode and to be emitted into vacuum. The increase in circulating and emission currents at a given bias voltage observed at high temperature is expected since more thermal energy is available for transfer to the total energy of the electrons. The reduction density observed is of the order $1 \times 10^{-6} A.cm^2$. The poly filamentary model of gold seems to indicate that a practical level of emission level of emission current has been achieved.

The mechanism of electron transport through thin insulating films sandwiched between metal electrodes has been the subject of a number of investigations and a variety of theories to explain the current – voltage and related characteristics has been given. One of the model which successfully explains the observed phenomena was put forward by Dearnaly et al in 1970 [1] .Their model explains the conduction mechanism on the basis of the formation of field – induced Metallic filaments between two electrodes thereby providing low – resistance path for the current, and electron emission is from the ends of filaments at the top positive electrode.[1-2].The transport and energy loss mechanism of hot electrons in metal films have been extensively studied bout studied theoretically and experimentally. To study the energy loss mechanism in these samples, the transfer ratio α is measured as a function of the thickness of top or the insulator layers. The transfer or transmission ratio is defined as the ratio of electron emission current I_e to the circulating current I_c for a given voltage applied across the sandwich. Results of such experiments indicated a strong attenuation of electrons in the top metal and also provided evidence of inelastic interaction of the injected electrons in the top layer [3-4]. R E Thurstans and D P Oxley described a new model is presented of the electroformed metal–insulator–metal structure which explains its various properties including electron emission, electroluminescence, memory effects and, for the first time, a complete account of the differential negative resistance. [5-6] Measurements of the relative numbers of electron transmitted though the thin layer as a function of thickness of the layer, yield a direct measurements of the attention length. By extending the range of insulator thicknesses measured, it is possible to find out the values of attenuation length of hot electrons in the insulator. [7]

In the present paper, measurements are reported on $Au - CeF_3 - Au$ Sandwiches and the usual phenomena of electroforming, negative resistance and electron emission into a vacuum are observed for CeF_3 layer.[8]

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