Current-Voltage Characteristics of MDM and MDSCM Structures on Basis of Lithium Borates

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Abstract. *The results of investigations of current-voltage characteristics for metal-dielectric-metal and metal-dielectric-semiconductor-metal structures, where crystalline and glass lithium borates used as dielectrics, are presented.*

Key words: current-voltage characteristics, lithium borates, metal-dielectric-metal and metal-dielectric-semiconductor-metal structures.

I. INTRODUCTION

The scintillation method for detection of different types of radiation is the main among other methods. Nevertheless, in the last years there appeared a large interest to elaboration of completely solid-state detectors, which work by mechanism of direct recording of the current jump caused by the current carriers, excited by radiation, in the working substance of detector [1]. At development of such solid-state detectors of thermal neutrons by the current jumps one can use the metal-dielectric-metal (MDM) or metal-dielectric-semiconductor-metal (MDSCM) structures, where M – metal thin films, D – thin dielectric plates, SC – semiconductor thin films. But for this it is necessary to select the most optimal variant of such detector structure. Here can be helpful the investigations of the current-voltage characteristics (CVC) for these detector structures, which were fulfilled in the given work.

II. EXPERIMENTAL

Thin (0.5 mm) dielectric (D) plates had been cut from $Li_2B_4O_7$ or $Li_6GdB_3O_9$ single crystals grown by Czochralsky technique [2]. For formation of MDM structures thin metal (M) Cu films had been deposited on opposite surfaces of D plate by thermal method in vacuum. For formation of MDSCM structures, before M films deposition, on one surface of D plate there had been deposited semiconductor (SC) ZnO or Eu_3O_3 films with thickness 2 and 1μm, respectively, by magnetron (or thermal) method.

Recording of CVC had been performed at the room temperature in dynamic regime at rates of the voltage change from 10 to 1000 mV/s in the range from -15 V to +15 V. The voltage had been changed stepwise with step $\Delta U = 5$ mV. Conductivity of samples is very low ($R \approx 10^{10} - 10^{13}$ Ohm), therefore the measuring circuit had ensured the accuracy of the current value recording within the limits from 10^{-11} A to 10^{-12} A. CVC recording had been performed at multiple (to 10 times) passage of all voltage range.

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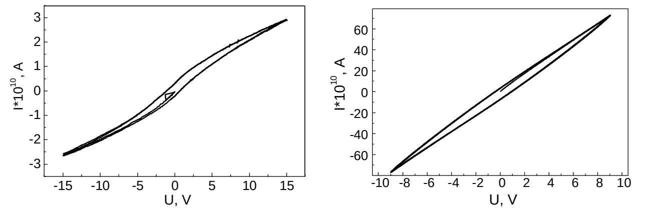
III. RESULT AND DISCUSSION

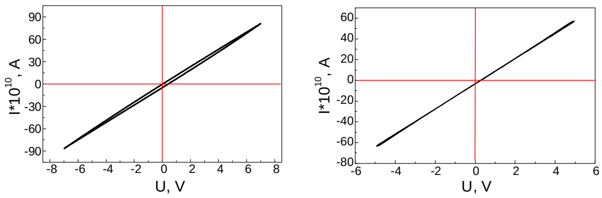
In Fig. 1–4 can to observe how the CVC shape depends on the structure types and electric voltage scanning rate on these. Presence of hysteresis is characteristic feature of CVC for majority of MDM and MDSCM structures.



a) b)

Fig. 1. CVC of detector structures: a) Cu-$Li_2B_4O_7$(X-cut)-Cu; b) Cu-$Li_2B_4O_7$(glass)-Eu_2O_3-Cu. Scanning rate 100 mV/s.

As it is seen in Fig. 1, CVC of MDM detector structures on basis of $Li_2B_4O_7$ single crystal and glass at scanning rate 100 mV/s have different shapes with noticeable hysteresis for some of these. The voltage scanning rate has an influence on the hysteresis width that is well illustrated in Fig. 2 for detector structure Cu-$Li_2B_4O_7$(glass)-ZnO(magnetr.)-Cu with deposited ZnO thin film by magnetron method.

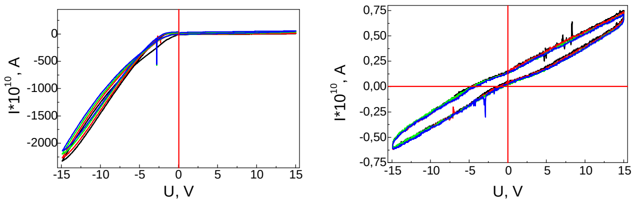


a) b)

Fig. 2. CVC dependence on the scanning rate: a) 100 mV/s; b) 1000 mV/s. Structure Cu-$Li_2B_4O_7$(glass)-ZnO(magnetr.)-Cu.

Fig.2 show that small hysteresis, observed at the scanning rate 100 mV/s, practically disappears at its increasing to 1000 mV/s.

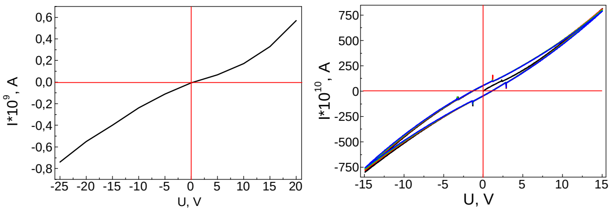
The detector structures on basis of $Li_2B_4O_7$ and $Li_6GdB_3O_9$ single crystals with deposited Eu_3O_3 thin films, and also thermally deposited ZnO thin film (Fig. 3 and 4) are much more complex CVC. Firstly, one can pay attention to sharply defined CVC with rectification (diode type) for structure Cu-$Li_2B_4O_7$(Z-cut)-Eu_2O_3-Cu (Fig. 3,a) that indicates existence of the energy barrier, at least on one of interfaces. Nevertheless, for analogous structure on basis of $Li_2B_4O_7$ crystal with other crystallographic orientation, CVC does not demonstrate such sharply defined barrier, but it has much more strongly defined hysteresis. Since Eu_2O_3 thin films had been deposited on both samples simultaneously, it becomes evident that such difference of CVC is connected with crystallographic orientation. It is also necessary to note that in CVC of Cu-$Li_2B_4O_7$(X-cut)-Eu_2O_3-Cu structure one can observe noticeable inflections in neighborhood of U = 0, which are characteristic for varistors (Fig. 3,b).



a) b)

Fig.3. CVC of detector structures: a) Cu-$Li_2B_4O_7$(Z-cut)-Eu_2O_3-Cu; b) Cu-$Li_2B_4O_7$(X-cut)-Eu_2O_3-Cu. Scanning rate 100 mV/s.

More clearly the varistor type of CVC is defined for detector structures Cu-$Li_2B_4O_7$(X-cut)-ZnO(therm.)-Cu and Cu-$Li_6GdB_3O_9$(001-cut)-Eu_2O_3-Cu (Fig. 4). And as it is seen in Fig. 4,a, for structure with thermally deposited ZnO film on $Li_2B_4O_7$ crystalline plate with orientation perpendicular to polar axis (X-cut) the hysteresis is not observed.



a) b)

Fig. 4. CVC of detector structures: a) Cu-$Li_2B_4O_7$(X-cut)-ZnO(therm.)-Cu; b) Cu-$Li_6GdB_3O_9$(001)-Eu_2O_3-Cu. Scanning rate 100 mV/s.

Therefore, one can note that for absolute majority of investigated structures the CVC have nonlinear character. Only for one structure Cu-$Li_2B_4O_7$(glass)-ZnO(magnetr.)-Cu the CVC can be considered as completely linear that indicates the ohmicity of contacts and absence of energy barriers on the way of the current carriers. Since at magnetron deposition the ZnO films usually have n-type of conductivity, the ohmicity of contacts indicates that in $Li_2B_4O_7$ glass also dominates the electron conductivity, and the work function of electrons for all components of the given structure is very close or coincides. Analogous situation takes place for structure Cu-$Li_2B_4O_7$(glass)-Eu_2O_3-Cu (Fig. 1,b), if to neglect hysteresis. But at thermal deposition in vacuum the deficiency of oxygen contributes to increasing of the oxygen vacancies concentration in ZnO films, and this leads to p-type conductivity in these. If to take into consideration that n-type conductivity is proper for $Li_2B_4O_7$ single crystals [4 and 5], then from our results one can make a conclusion about serious problematical character of formation of p-n transitions in our structures. This can be explained by too large difference in forbidden gaps: borates are dielectrics with large forbidden gap, for example, E_g = 7.5 eV for $Li_2B_4O_7$ crystal, whereas for high energy-gap semiconductor ZnO E_g = 3.3 eV.

As it is seen from results, nonlinearity of CVC for investigated structures is cased, possibly, by different mechanisms. In structure Cu-$Li_2B_4O_7$(Z-cut)-Eu_2O_3-Cu (Fig. 3,a) there is, without doubt, contact with rectification effect, but now it is impossible to determine its localization. For neutron detector the best localization of this rectifying contact will be on interface $Li_2B_4O_7$ – Eu_2O_3. In the rest structures: Cu-$Li_2B_4O_7$(X-cut)-Cu (Fig. 1,a), Cu-$Li_2B_4O_7$(X-cut)-Eu_2O_3-Cu (Fig.3,b), Cu-$Li_2B_4O_7$(X-cut)-ZnO(therm.)-Cu and Cu-$Li_6GdB_3O_9$(001-cut)-Eu_2O_3-Cu (Fig. 4,a and b) there are nonrectifying contacts with symmetrical CVC. One variant of appearance of such CVC is examined in publication [6] for structures Cu-ZnO-Pt, when Cu film is an anode. The main mechanism, which works in such structures, in [6] authors judgment, is diffusion of active Cu^{Z+} ions in external electric field through the film of solid ZnO electrolyte with the next crystallization on cathode, and, respectively, formation of conductive nanochannels for conductivity electrons. In our case, the width of working $Li_2B_4O_7$ plates seems to be too large for realization of such mechanism, but to be sure in this it is necessary to record CVC for some our structures with application of inert electrodes (Au, Pt or Ir). Such investigations will be to conduct in the near future.

IV. Conclusions

From above presented results of CVC investigations for MDM and MDSCM structures one can make provisional conclusion that the best variant for preparation of neutron detector can be structure Cu-$Li_2B_4O_7$(Z-cut)-Eu_2O_3-Cu, connected to electric voltage in the barrier direction.

Acknowledgment

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