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HYSTERESIS EFFECTS OF FIELD INDUCED ELECTRON EMISSION PHENOMENON

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The study was carried out by using the Malter effect controlled by electric field. Due to the application of indium-tin oxide (ITO) layers deposited onto a glass substrate it was possible to obtain a relatively stable electron emitter. In order to study the electron emission the polarizing voltage was applied between the both ITO layers. One of the layers was the field electrode and another one, which was at the opposite side of the glass surface was treated as the electron emitter. The negative voltage U_{pol} was applied to the field electrode. The research was carried out in vacuum (10^{-7} Pa).

As a result of applying U_{pol} voltage and illumination, electrons and photoelectrons were released and enter electron multiplier. The electrons from the multiplier created voltage pulses, which were recorded in the multichannel pulse amplitude analyzer. It has been stated that the emission efficiency at the same inducing field is affected by the state in which the sample was just before the measurement, which means the history of the measurement course. It has been proved that the emission course during the increase of the U_{pol} voltage differs from that occurring when the voltage decreases. It means that the effect of electron emission shows the hysteresis properties.

Key words: indium tin oxide (ITO), electron emission, field effect, hysteresis effect, MIS structure.

Thin dielectric films can be low-macroscopic-field electron emitters, which are able to generate electrons when a macroscopic electric field in the order 1 MV/m is created. This phenomenon is known as a cause of pre-breakdown currents in high-voltage vacuum breakdown.

Investigation of electron vacuum emission from thin layers after creation a high electric field can provide an information concerning electron transport in layer devices of MIS type (metal-insulator-semiconductor). Injection and transport of hot electrons as well as electron processes of break down are important in microelectronic technology. Frequently the random effects when the local fields acts, lead to break down the devices or to occurrence of not expected effects. That is why the field effects should be used in a controllable manner for injection of charges and storing them in a device memory. In order to achieve it the wide studies are carried out [1, 2], where are determined the hot electron energies in SiO_2 by Monte Carlo method, and in the paper [3] were studied the field effects of electron heating in MOS samples by the electroluminescence methods,

transistor field effect and the field emission. In that studies it was necessary to deposit the thin metal electrode onto the oxide layer in order to create the electric field inside the sandwich structure. Malter [4, 5] was the initiator of the study of the anomaly electron emission effects in dielectrics. The electric field was created in Al_2O_3-Cs_2O, which was charged as a result of its bombardment by an electron beam. However, in Malter's work the electric field was created in uncontrollable way.

In certain conditions in some semiconductors the non-equilibrium conditions may appear. These effects can occur due to the charge carrier concentration fluctuation in different points of the volume and creation of the momentary variation space charge. During the investigation of the electric field influence on emission properties of these structures, hysteresis effects of this phenomenon were observed [14].

In our studies the sample consisted of a microscopy glass with ITO (indium tin oxide) films evaporated on the opposite sides of the glass of dimensions 0,2x16x16 mm. One of the film was rather thick while the film at the opposite side of the glass was thin emitting layer (<300 nm). The field electrode was 1 μm thick. Applying an appropriate the voltage to the layers one may create an inner electric field of a given direction and value. We call the above effect the field induced electron emission. The additional electron emission from the surface has been obtained by illumination and we call it the field induced photoemission.

Deposition of nanocrystalline indium thin oxide films was performed by reactive dc sputtering technique, with is the most widely used technique for the deposition of controlled high quality ITO films. This technique provides good film uniformity, excellent adhesion, precise thickness control, surface smoothness and less waste of expensive source material. Detailed account of the deposition system may be found elsewhere [6-8].The field electrode was of great transmittance which enabled to study the transmission photoemission of electrons. The surface resistance was varied within 10-100 Ω/cm. The doped ITO layers appear to be wide gap n-type polycrystalline semiconductors the conductivity of which depends among others on doping concentration. The gap was found to be 3.5 to 4 eV wide. At concentration of about $10^{25}m^{-3}$ the donor levels split and the semiconductor becomes degenerated [9]. The ITO layers on the glass substrate can be assumed to be degenerated if they are sufficiently thick so the substrate influence can be neglected. The remaining electrical and optical properties of ITO layers are given in the paper [10-12]. The measurements were performed at the pressure of about $2x10^{-6}$ Pa. The schematic diagram of the apparatus is shown in Fig. 1.

Applying polarizing voltage U_{pol}, from the interval from -2 kV to 0 V, to the field electrode made an internal field, which favored electron emission into vacuum. Appropriate operational conditions for the electron multiplier were received by acceleration of electrons between the emitting film and the multiplier, i.e. voltage U_p =–200V at the emitting film and grounded entrance of the multiplier (EM). Depending on the kind of performed measurements, grids 3 and 4 of the electron energy analyzer (EEA) were either grounded or polarized by negative analyzing voltage U_a. The electrons accelerated to the energy eU_p create voltage pulses in the multiplier, which are recorded in the multichannel pulse amplitude analyzer (MPAA). The multiplier is joined to preamplifier, which adjusts its parameters to the pulse analyzer. The multichannel analyzer registers pulses, which are amplified. The pulses are recorded in channels of the pulse analyzer according to their height, creating so-called voltage pulse amplitude

spectrum. The amplitude spectra (for various U_b) were measured for not illuminated samples and illuminated by a quartz lamp (UV).

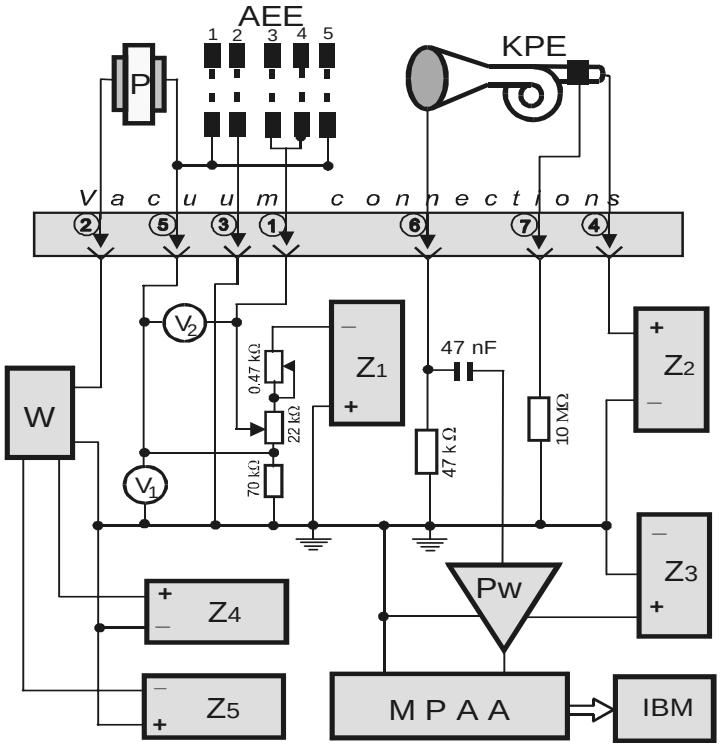

Fig. 1. Experimental arrangement used to study field induced electron emission UV-quartz lamp, S-sample, EEA-energy electron analyzer (1, 2, 3, 4, 5-grids), KPE-channeltron, ①-⑦ – vacuum connections, W-high voltage switch, Z_1(U_p–accelerating voltage, U_a–analyzing voltage), Z_2 (HV=2,9 kV –channeltron's voltage), Z_4(+U_{pol}), Z_5(-U_{pol}), voltmeters V_1, V_2 (U_p,U_a), MPAA – multichannel pulse amplitude analyzer, IBM- computer

As a result of field creation in the glass-ITO structure it is possible to observe a vacuum emission of electrons. Multichannel pulse amplitude analyzer recorded the amplitude spectra of voltage pulses, which were created by electron incident at the multiplier. The pulse number N (with amplitudes within a certain interval around the mean value) appears to be proportional to the electron number emitted from the sample. The spectrum maximum reflects the pulses of the mean energy of about 200 mV. The spectra for different polarizing voltage U_{pol} are shown in Fig. 2. If the U_{pol} voltage increases (that means the increase of the field inside the sample) then also increases the recorded pulse number (which correspond to the increase of the electron emission intensity). So the amplitude spectra illustrate the phenomena of field induced vacuum emission of electrons and show the field impact on the emission efficiency.

The measurements course in one case was performed when the applied voltage changed from 0 V to –2 kV and in the second case in reverse direction, from –2 kV to

0 V. Exemplary spectra at same selected U_{pol} are given in Fig. 3 and Fig. 4. Both spectra have been found to be different at the same U_{pol}. They differed by the total number of pulses as well as by the mean amplitude connected with the mean energy of the emitted electrons. When U_{pol} changes in the reduction direction the total pulse number was always found to be larger than in the rise direction. The shift effect has been also found during the repeated measuring the spectra at the same applied voltage.

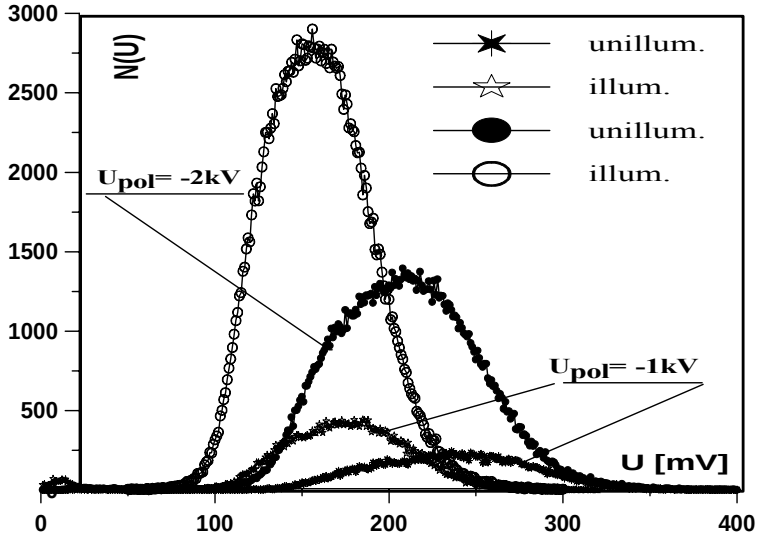

Fig. 2. Some pulse amplitude spectra for different U_{pol} as a parameter (with and without illumination)

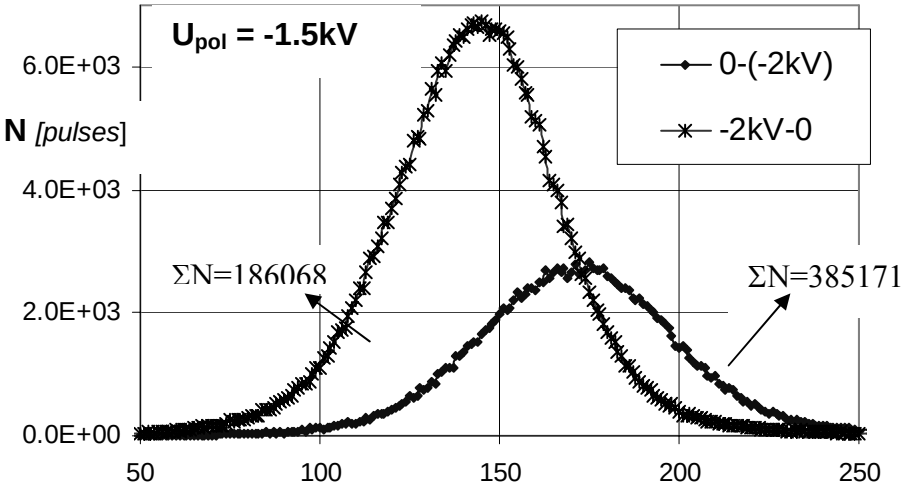

Fig. 3. Pulse amplitude spectra for U_{pol} = -1,5 kV. 0-(-2kV) – variation of U_{pol} in direction from zero to –2kV, (-2kV) -0 - variation of U_{pol} in direction from –2kV to zero

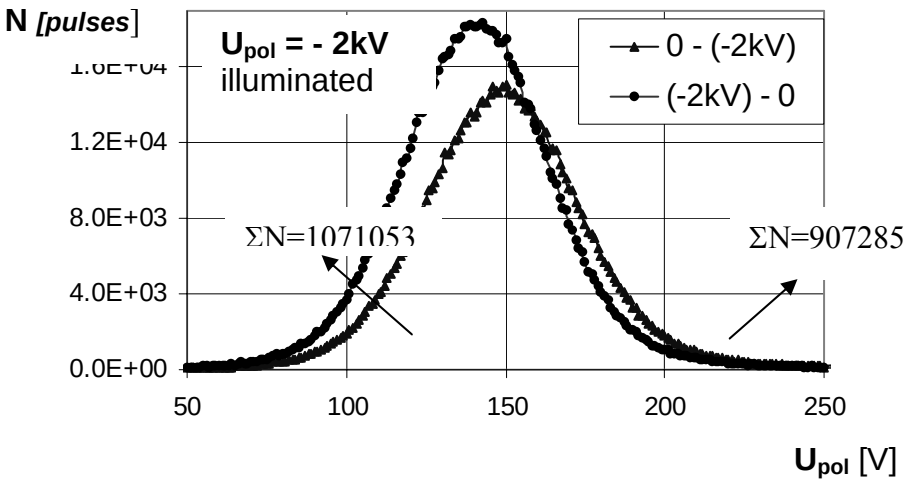

Fig. 4. Pulse amplitude spectra for U_{pol} = -2kV. 0-(-2kV) – variation of U_{pol} in direction from zero to –2kV, (-2kV)-0 – variation of U_{pol} in direction from –2kV to zero

In the previously performed studies of field induced secondary electron emission from ITO layers some anomalies have been noticed as well [13]. One of them was the field modification of energy distribution in the secondary electrons. The modification concerned the certain applied voltages at which there has been observed a shift of the elastic pike, which is related to the primary electrons. The shift in direction of energies lower than E_p (primary electron energy) has been noticed. The change in the primary pike position in the energetic spectrum can be related to the reduction in the number of elastically reflected electrons from the emitter surface. This means that the majority of the electrons is subjected to the energy reduction (below than E_p) and this occurs at the surface zone of ITO. The above discussion leads to the conclusion that the field induced electron emission from ITO layers shows the hysteresis effect. This follows from the fact that the emission phenomena was found to be different depending on either U_{pol} voltage is growing or lowering during the measurement process. In order to examine the effect the pulse frequency n has been measured for different U_{pol} voltage and different directions of its variation and the diagrams $\Sigma N = f(U_{pol})$ have been drawn for the both series of measurements. Figure 5 shows the total the number of counts ΣN as a function of voltage U_{pol} for ITO layers without UV illumination as well as under illumination. Due to the existence of hysteresis, its examination shows that the applied field results rather weak irreversible changes in the electron emitting ITO layer. Irreversibility of the emission effect shows a probable occurrence of the self-maintaining emission resembling the well-known Malter emission [4, 5].

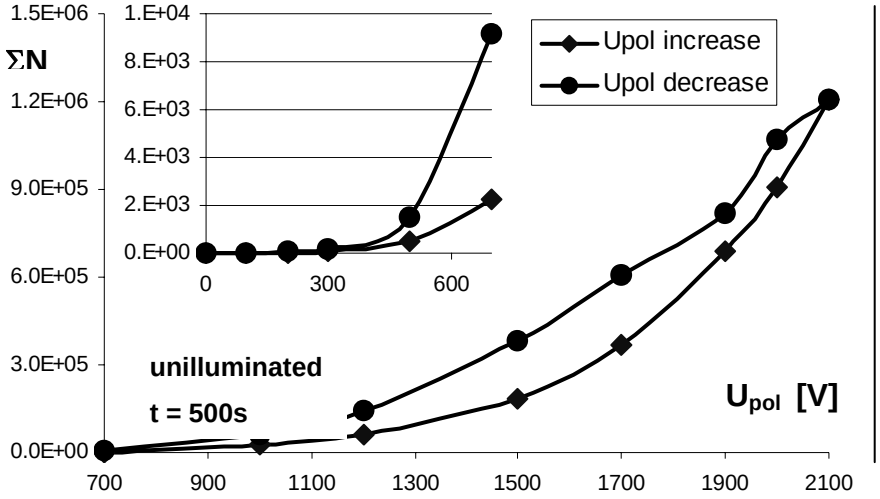

Fig. 5. The electro-emission hysteresis $\Sigma N = f(U_{pol})$. Increase – variation of U_{pol} in direction from zero to $-U_{pol}$, decrease – variation of U_{pol} in direction from $-U_{pol}$ to zero

In order to explain the observed phenomena we should consider two basic effects: the influence of the applied electric field and the illumination.

Higher level of electron emission efficiency as well as the shifting of the mean amplitude position toward the lower values (Fig. 3 and 4) can be explained in the following way:

- with increasing U_{pol} voltage the number of electrons penetrating the enhanced zone of ITO rises but part of them are enable to go outside the film. This results in a dynamic widening the enhanced zone. So if we apply the field once again we do not obtain the same conditions in the emitting layer. Carrier concentration as well as the enhanced layer width appears to be changed;
- in the enhanced zone the field acts on electrons in a weaker way than in the depleted one, due to it electrons obtain the energy sufficient only to surmount the surface energy barrier. Thus these electrons posses the lower kinetic energies, which reflects in the lower mean amplitude, however theirs number appears to be higher due to the increased electron concentration at the surface region [14].

Taking into account in the considered effects the second term – the optical one, we should conclude that under UV illumination the most likely process is the excitation of electrons from the valence into conduction band. This can be supported by the fact that the gap and the photon energies are comparable. Due to In and Sb mixtures in SnO_2 and In_2O_3 oxides the essential is also electron transition from the donor levels to the conduction band. Those electrons due to interaction of applied field can obtain a sufficient energy to be emitted into vacuum. Of course the created field should accelerate the electrons toward the surrounding vacuum and the electron energy should be sufficient to surmount the surface barrier. We believe that this effect is connected with

generation of the free electrons by the strong field and after some avalanche effects they are emitted with a delay into vacuum.

1. The applied voltage creates the field in the ITO layer and this results the electron emission into vacuum.
2. Direction of applied field variation has been found to affect the field controlled electron emission from ITO layers. The effect is called electro-emission hysteresis.
3. The similar effect has been found in the case when measurements were carried out under additional UV illumination of ITO layers. The effect is called photoelectro-emission hysteresis.
4. The mechanism of photoelectro-emission hysteresis was found based on the field and optical terms (the field term is more significant).
5. A phenomenological model of the zones takes into account also the self-maintained Malter emission, which explains the occurrence of high electron emission efficiency.

The hysteresis effects are connected with a lack of stability due to the fluctuations of the electric field in the surface layer as well as in the glass-ITO interface. The fluctuations occur as a result of creation of the domain structure that diminishes very slowly. The existence of the hysteresis proves that the electric field causes some nonreversible changes in the emitting ITO layer. Usually the variation in electron emission is connected with the occurrence of additional charge at the surface of emitting sample or with the effect of self-supporting emission like in the case of the Malter emission [15]. It is possible that electrons enter the surface layer of ITO where their concentration is high (accumulation effect by the applied voltage). Electrons in order to escape into vacuum suffer the loss in energy due to the larger amount of collisions with other electrons and the atoms. Due to it the emitted electrons show reduced mean energy. These effects occurs because the dielectric and semiconducting film is, or becomes, an electrically nanostructured heterogeneous material, with quasi-filamentary conducting channels between its surfaces [16]. Defect channels produce hysteresis appearance and make characteristics $N = f(U_{pol})$ irreversible. So we have shown the hysteresis effect in the field induced electron emission phenomena.

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ЕФЕКТИ ГІСТЕРЕЗИСУ В ЯВИЩІ ЕЛЕКТРОННОЇ ЕМІСІЇ, СПРИЧИНЕНОЇ ЕЛЕКТРИЧНИМИ ПОЛЯМИ

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Дослідження проводили з урахуванням ефекту Малтера, контрольованого електричним полем. Використання шарів плівок оксиду індію, напилених на скляну підкладку, дало змогу отримати відносно стабільний емітер. Для дослідження електронної емісії постійне поле було прикладене між обома шарами плівок оксиду індію. Один з шарів відслугував електродом, тоді як інший, що був розміщений з протилежного до скла боку, слугував емітером електронів. До електродів було прикладено від'ємну напругу U_{pol}. Усі дослідження проводилися у вакуумі (10^{-7} Па).

Унаслідок прикладання напруги U_{pol} та під дією освітлення отримували сигнал з фотоелектронного помножувача, який записували за допомогою мультиканального імпульсного аналізатора амплітуди. З'ясовано, що ефективність емісії за тієї самої величини індукуючого поля залежить від стану зразка безпосередньо перед вимірюванням, тобто, відбувається вплив попередніх вимірювань. Було виявлено відмінність у залежності струму емісії від U_{pol} під час підвищення спаду напруги, тобто відстежено ефект гістерезису.

Ключові слова: плівки оксиду індію, електронна емісія, ефект поля, гістерезис, структура „метал–діелектрик–напівпровідник".

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