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Study of Fast Switching Processes in Cadmium Telluride Based Structures

M.V. Kirichenko, A.N. Drozdov, D.S. Shkoda, R.V. Zaitsev, G.S. Khrypunov, K.O. Minakova, V.O. Nikitin

National Technical University «Kharkiv Polytechnic Institute», 2, Kyrpychova St., 61002 Kharkiv, Ukraine

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One of the main requirements for modern radio electronic equipment is the issue of electromagnetic (EM) stability, which means the ability to maintain operating parameters during and after the action of pulsed EM radiation of various origins. The problem of ensuring EM stability is due to the fact that under the influence of EM pulses, overvoltage pulses appeared in the circuits, which is particularly prone to the destruction of semiconductor devices due to both the properties of the *p-n* junction and the specific thermal conductivity of semiconductor materials. At the same time, the effects of resistive switching are actively used in modern electronics, in particular, the work of memristors is based on resistive switching in oxides of transition metals. This effect of resistive switching has long been observed in CdTe, both on thick (more than 100 μm) single-crystal layers and in thin polycrystalline films. The novelty of the proposed work consists in the fact that switching processes between low and high conductivity states in CdTe films depend on various factors, such as the film thickness, its initial structure, the power of the switching pulse, and the contact properties. Thin film CdTe based structures were prepared by using vacuum deposition methods. The study of fast switching processes in manufactured Mo – cadmium telluride – Mo structures was carried out by measuring and further analytical processing of their amplitude-time characteristics under the action of EM pulses of nanosecond duration. It was found that the prototypes with a metallization diameter of 0.5 mm and 6 mm, made using the planar technology, have similar parameters: the switching time is at the level of 1-2 ns, similar values of the cutoff voltage and the course of its dependence on the pulse amplitude. The geometry of the contact metallization does not affect the switching parameters of structures, and in the manufacture of protection elements against EM pulses on their basis, an industrial technology for the formation of metallization can be used without the need for its excessive miniaturization.

Keywords: Planar technology, Geometry, Impulse.

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1. INTRODUCTION

One of the main requirements for modern radio electronic equipment (REE) is the high reliability of its operation under the influence of external factors. Recently, more and more attention has been paid to the issue of electromagnetic (EM) stability, which means the ability to maintain operating parameters during and after the action of pulsed EM radiation (EMR) of various origins [1]. The problem of ensuring EM stability of REE is due to the fact that under the influence of pulsed EMR, overvoltage pulses appear in the circuits, amplitude values, rise times and duration of which can vary within wide limits due to many factors. EMR-induced pulse overvoltage can have a serious negative effect on elements of equipment (especially input devices), and it should be noted that semiconductor devices are especially susceptible to destruction under the action of EMR [2, 3]. This is due to both the properties of a *p-n* junction and the specific thermal conductivity of semiconductor materials. When the reverse bias voltage of the junction is sufficient to realize an avalanche breakdown, the junction may release large amounts of thermal energy due to the progressive accumulation of which the temperature can reach values equal to the melting point of semiconductor materials, which causes shunting of a *p-n* junction [4-6]. As the size of semiconductor devices decreases, the level of energy required for their destruction decreases and for integrated circuits is from 10^{-3} to 10^{-7} J.

At the same time, the effects of resistive switching are actively used in modern electronics, in particular, the work of memristors is based on resistive switching in oxides of transition metals. This effect of resistive switching has long been observed in CdTe, both on thick (more than 100 μm) single-crystal layers and in thin polycrystalline films. In [7], the use of the switching effect under the influence of optical high-frequency generation is proposed. This gives hope for the development on the base of these films of optically controlled super-fast THz devices, such as THz switches and THz modulators for microwave photonics [8-11]. Another important application of devices with switching effects is the prospect of creating on their basis elements of REE protection from pulsed EMR. In [11-16], the effects of switching in CdTe films under the action of EM pulses were studied and it was experimentally established that CdTe layers with a thickness of 3 to 7 μm can be used to create protection elements with a switching time of several nanoseconds. Unlike existing protection elements, based mainly on the use of diodes, structures with CdTe film do not have a *p-n* junction, so they are more reliable and cheaper to manufacture. CdTe film structures can be easily implemented on flexible substrates. In addition, the technology of obtaining high-quality CdTe films has been developed at a high industrial level in the production of CdS/CdTe based solar cells [17], which allows us to hope for the rapid introduction of new protection elements based on these films.

The switching processes between low and high conductivity states in CdTe films depend on various factors, such as the film thickness, its initial structure, the power of the switching pulse, and the contact properties. Establishing the laws of these dependences will supplement the theory of switching and bistable states in CdTe films. Additional interest in the question of the influence of the properties (including geometric) of contacts is added by the transition in modern electronics [18] from the body edition design of elements to planar technology, when all devices that are part of REE are made on a printed circuit board. In this case, the ability to perform contact metallization by well-established industrial technologies will be an additional advantage.

The goal of the paper was to study the influence of the contact metallization geometry on the amplitude-time characteristics of the switching processes in thin-film structures based on cadmium telluride layers.

2. CdTe BASED SAMPLES PREPARATION TECHNIQUE

Two groups of thin-film samples will be investigated in this research. A general manufacturing step was the formation of CdTe base layers. An industrial vacuum unit and a method of thermal vacuum deposition of 99.999 % pure powder with a particle size of 10 mm were used to deposit the cadmium telluride base layers on substrates made from electrolytically polished molybdenum foil with a size of 10 cm × 10 cm. The initial vacuum was $6 \cdot 10^{-6}$ mm Hg, the working pressure in the vacuum chamber during deposition was kept at a level of $1 \cdot 10^{-5}$ mm Hg. For thermal evaporation of cadmium telluride, a graphite crucible with indirect heating from two electrically insulated heaters was used.

The deposition temperature of CdTe was monitored using a thermocouple installed in the heater, the heating time of the crucible to an operating temperature of 750 °C ranged from 260 to 275 s. The accuracy of crucible temperature control was not less than 5 °C. The thickness of the deposited layers of cadmium telluride, determined by the deposition time, was 3-10 μm. A quartz thickness meter KKT-40 was used to control the thickness of cadmium telluride films.

The control of the initial electrical resistance of the cadmium telluride film was carried out at a temperature of 20 °C using a digital ampere-voltmeter MS8040. Along with the initial electrical resistance of the samples at direct current, their electrical capacity was also investigated using a capacitance meter L2-28 at a frequency of 10^7 Hz and at a temperature of 20 °C.

Samples of series 1 and 2 represented a transitional type from the body edition design of the samples, previously studied in [10, 15], to an attempt to implement a planar technology, which will place REE protection elements directly on printed circuit boards. For samples of series 1 and 2, after the formation of a CdTe layer by magnetron sputtering method, contact metallization layers with a thickness of 2 μm were formed. Metallization was formed through a metal mask with holes of such size that the diameter of the electrodes was 5 mm (series 1) and 0.5 mm (series 2).

To minimize parasitic capacitance and inductance, a clamp-type contact device with a conductor length no more than 1-2 cm was specially made.

3. SAMPLES TESTING TECHNIQUE

To study the switching processes in the test samples, a research complex consisting of a nanosecond pulse generator [16, 18, 19] made by the charge line scheme [20-25], a Siglent SDS 1202X-E digital oscilloscope and a laptop were assembled, as shown in Fig. 1. A pulse generated by it has the following parameters: the pulse duration is about 30 ns, due to the length of the charge line (5 m, about 5-6 ns per meter) and the pulse growth front is about 2.2-2.4 ns, which is sufficient for planned research. Volt-second characteristics of the switching process in test samples were based on experimental oscillograms obtained on a digital oscilloscope Siglent SDS 1202X-E. Experimental volt-second characteristics obtained by this method were transmitted in the form of tables on a laptop connected to the oscilloscope, and then their analytical processing using Microsoft Excel was carried out.

Fig. 1 – General view of the research complex

4. RESULTS OF ELECTROMAGNETIC PULSE INFLUENCE

Fig. 2 shows a typical view of an oscillogram: a volt-second characteristic recorded after passing through the investigated samples of the EM pulse.

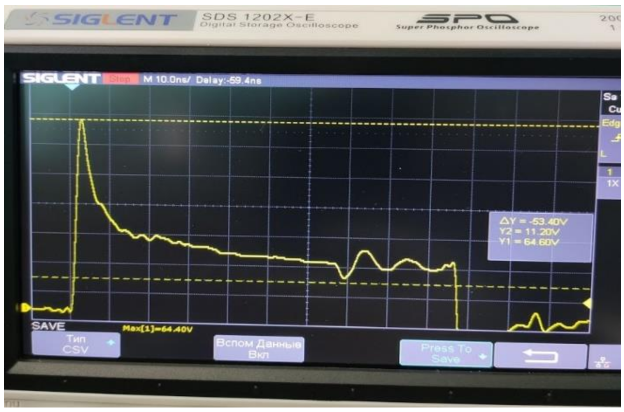

Fig. 2 – Volt-second characteristic of the switching process in a cadmium telluride film

Such volt-second characteristics, in digitized form, were the original data sets for the analytical study of the switching processes features in cadmium telluride thin films.

Generalized results of analytical processing of experimental data for the investigated samples are shown in Fig. 3.

According to the results of the analysis of experimental amplitude-time characteristics shown in Fig. 5, it can be seen that for the investigated samples, the switching voltage, independent of the pulse value, changed arbitrarily with increasing pulse amplitude, and the switching voltage did not exceed 40 V, i.e., did not exceed 1/5 of the pulse amplitude, and there was a significant reduction in the residual voltage to 1.5-4 V. Apparently, the increase in the switching voltage is due to the time of injection processes in CdTe, and its increase with increasing pulse amplitude due is to the fact that a pulse with a very steep front of 1-2 ns was realized during the experiment. In this case, the steepness of the pulse remains unchanged with increasing amplitude and therefore we observe an increase in the switching voltage because for the same time about 2 ns pulse with a larger amplitude has time to grow to a larger value.

In the study of samples made by planar technology, in which electrical contact with a layer of CdTe is realized by deposition of a molybdenum layer with a thickness of 2 μm and a diameter of several millimeters, contact before metallization was carried out in a specially made clamp-type contact device with a conductor length of no more than 1-2 cm to eliminate the parasitic effect of capacitance and inductance in the conductor.

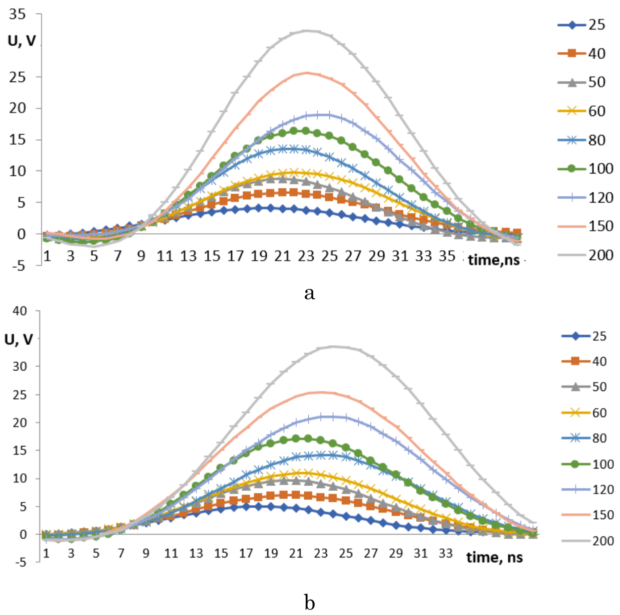

Fig. 3 – Typical amplitude-time characteristics of switching for samples of series 1 (a) and 2 (b) when changing the maximum amplitude of a pulse from 25 to 200 V

Studies of samples with a contact diameter of 5 mm using such a contact device showed a reduction of switching time to values of about 1.8 ns and a significant reduction in the amplitude of the pulse that has time to pass into the circuit before switching in comparison with body edition design samples studied in [11, 16].

Detailed studies on series 1 samples with a large area electrode found that they have a very short switching time of the order of 1 ns, and the cut-off voltage, after which the switching is quite small and varies from 5 V, when applying 25 V pulse, to 33-34 V, when applying 200 V pulse. It was also found that the cut-off dependence on the pulse magnitude is linear. All samples are very close to each other in terms of the cut-off voltage and show good stability in this parameter, as well as in the switching time. Also, these examples are characterized by a very small (1-2 V) residual voltage after switching, which also does not depend on the magnitude of the applied pulse.

The investigated samples were made on a single substrate (Fig. 2) and for research were not divided into separate elements, while no mutual influence of the samples was detected. Also, repeated relocations of the contact device probe from one sample to another, their movement, providing additional pressure on the probe did not have a destructive effect on their properties and no significant degradation of the samples was detected.

In the next stage, samples of series 2 with a contact electrode with a diameter of 0.5 mm in another similar to those previously studied with an electrode with a diameter of 5 mm were investigated to accurately establish the presence or absence of contact electrode size influence on the properties of protection element. According to the results of series 2 samples study, it was found that they are similar in properties to samples with a large area electrode: switching time at 1-2 ns, similar values of the cut-off voltage and the course of cut-off voltage dependence on pulse amplitude.

Thus, it is shown that in principle the size of the contact metallization electrode does not affect the switching parameters of devices, which is a very important conclusion both from the point of view of physics and for future adaptation of such REE protection elements into existing technology of modern electronic devices.

The next step in the development of the investigated samples should be the transition from a molybdenum electrode, which, due to the characteristics of the material, is difficult to solder or weld, to two-layer Mo/Cu metallization, which will allow commutation of protection elements in REE devices by soldering or welding their contacts.

5. CONCLUSIONS

The presented paper is devoted to the investigation of two groups of thin-film cadmium telluride structures with different geometrical parameters of contact metallization under the action of nanosecond duration EM pulses.

According to the results of experimental data analytical processing, it was found that test samples with a metallization diameter of 0.5 mm and 5 mm made by planar technology have similar parameters: switching time at 1-2 ns, similar values of the cut-off voltage and cut-off voltage dependence on pulse amplitude. The geometry of contact metallization does not have a decisive influence on the switching parameters of the investigated structures, and in the manufacture of protection elements against EM pulses, an industrial technology of metallization formation can be used without the need for excessive miniaturization.

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Дослідження процесів швидкого перемикання в структурах на основі телуриду кадмію

М.В. Кіріченко, А.М. Дроздов, Д.С. Шкода, Р.В. Зайцев, Г.С. Хрипунов, К.О. Мінакова, В.О. Нікітін

Національний технічний університет «Харківський політехнічний інститут», вул. Кирпичова 2, 61002 Харків, Україна

Однією з головних вимог до сучасного радіоелектронного обладнання є питання електромагнітної стійкості, що означає здатність підтримувати робочі параметри під час і після дії імпульсного електромагнітного випромінювання різного походження. Проблема забезпечення електромагнітної стійкості пов'язана з тим, що під впливом ЕМ-імпульсів у ланцюгах виникають імпульси перенапруги, що призводять до руйнування напівпровідникових приладів внаслідок як властивостей *p-n* переходу, так і питомої теплопровідності напівпровідникових матеріалів. У той же час ефекти резистивного перемикання активно використовуються в сучасній електроніці, зокрема, робота мемристорів заснована на резистивному перемиканні в оксидах перехідних металів. Цей ефект резистивного перемикання вже давно спостерігається в CdTe, як на товстих (понад 100 мкм) монокристалічних шарах, так і в тонких полікристалічних плівках. Новизна запропонованої роботи полягає в тому, що процеси перемикання між станами з низькою і високою провідністю в плівках CdTe залежать від різних факторів, таких як товщина плівки, її початкова структура, потужність імпульсу перемикання, властивості контакту. Тонкоплівкові структури на основі CdTe були виготовлені методами вакуумного осадження. Вивчення процесів швидкого перемикання в виготовлених структурах Mo – телурид кадмію – Mo проводилося шляхом вимірювання та подальшої аналітичної обробки їх амплітудно-часових характеристик під дією електромагнітних імпульсів наносекундної тривалості. Встановлено, що прототипи з діаметром металізації 0,5 мм і 6 мм, виготовлені за планарною технологією, мають подібні параметри: час перемикання на рівні 1-2 нс, близькі значення напруги відсікання та хід її залежності від амплітуди імпульсу. Геометрія контактної металізації не впливає на параметри перемикання конструкцій, а при виготовленні елементів захисту від електромагнітних імпульсів на їх основі можна використовувати промислову технологію формування металізації без необхідності її надмірної мініатюризації.

Ключові слова: Планарна технологія, Геометрія, Імпульс.