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METHOD OF RESEARCH OF PHOTOELECTRIC PARAMETERS OF HIGH IMPEDANCE SEMICONDUCTOR FILMS

Abstract: *The method of measuring the electrical conductivity and photoconductivity of semiconductor films with high electrical resistance is described. The developed computer program providing automation of measurements, as well as registration and initial processing of data is presented.*

The photoelectric properties of CdTe semiconductor films are investigated depending on technological factors of their obtaining. The activation energy of the mobility was determined and it was shown that for the films obtained on fresh cleavages of mica, this energy is less than twice that of films obtained on polished glass substrates.

Keywords: *solar energy, electrical parameters, photoconductivity, automation, mobility.*

Introduction

In recent years, research has increasingly focused on renewable energy sources, in particular solar energy.

The second generation of photocells is promising, where such thin film materials are usually used: cadmium telluride (CdTe), a mixture of copper, indium, gallium, selenium. Typically, the thickness of the layer of a semiconductor that absorbs light is only 1 to 3 microns. The process of producing such photocells is more automated and has much lower cost. The main disadvantage of the second generation of elements is less efficiency, which varies depending on the technology from 7-15%. At present, the market share of film photocells is about 18%. There are constant searches for ways to increase the efficiency of the converters of solar energy into electric [1].

Also, compounds of the type $A^{II}B^{VI}$ are relevant and due to the prospect of their use for the creation of gamma and hard x-ray detectors and infrared filters [2]. Recently, interest in quantum dots based on CdTe is also growing.

In a polycrystalline film, for example, CdTe, photoconductivity is mainly determined by processes on the grain boundaries.

Typical values of the resistivity of these materials are 10^6-10^7 Ohm m [3], and the study of the electrical parameters of such samples requires conventional and expensive electrometric technology and is quite labor intensive. The problem of measuring electrical and photovoltaic parameters still remains relevant. The rapid development of microprocessor and computer technology opens up new possibilities for automation of technological processes and laboratory research. The emergence of new specialized microcircuits and microcontrollers with a large amount of memory, a widely developed periphery and a small price, combined with the simplicity of development, makes optimal use of them in automated measuring complexes, which also makes it possible to develop computer programs that enable to process and visualize data. already in the process of measurement.

This paper describes a method for measuring electrical conductivity, photoconductivity and volt-ampere characteristics of semiconductor films with an electrical resistance of up to 500 GOhm, and introduces and develops an installation and a computer program that provides measurements automation, registration and initial processing of the received data.

The photoelectric properties of CdTe semiconductor films obtained on different substrates were investigated. Photosensitivity and activation energy of mobility are determined.

Experimental method

CdTe films were prepared from the pre-synthesized material by the method of open evaporation in a vacuum of 10^{-5} Pa, and the vapor deposition on fresh cleavage of mica and polished glass. The evaporation temperature was 920 K, the precipitation temperature was 473 K. The initial components for the synthesis of ingots were purified 99.999.

Measurement of electrical parameters of semiconductor films was carried out on the developed automated installation according to the classical method, when a sufficiently high voltage is applied to the sample and the current flowing through the sample is measured. In measuring, the film samples were located in a holder of a typical construction [4], made on a fluoroplastic basis with four measuring probes and a built in reference resistor for measuring the current with a digital microwave. The holder via a demountable connection is fixed in the middle of the aluminum cylinder, which is equipped with a PT100 temperature sensor and a digital light meter VEML7700CT, as well as a light source of the corresponding frequency. The temperature range in the working area is 77-500 K. The accuracy of the temperature measurement was 0.5 K, the illumination ±3%, the conductivity ±10%.

The production of reliable omic contacts, which do not destroy the film and satisfy all the necessary requirements [4, 5], were carried out by methods of depositing silver in combination with gilded clamping contacts or soldering at $T < 400$ K. The choice of the main contact material was determined by its work output, temperature and mechanical properties. To reduce the overall electrical resistance of the film material, the contacts were sprayed in rectangles at a short distance from each other (fig. 1). Control of the properties of the manufactured contacts was carried out by analyzing the VAC samples [3]. The type of conductivity was determined by the term thermoelectric power [3]. The thickness of the thin films was determined by the optical method using the microinterferometer MII-4. This provided accuracy of ~0.02 μm.

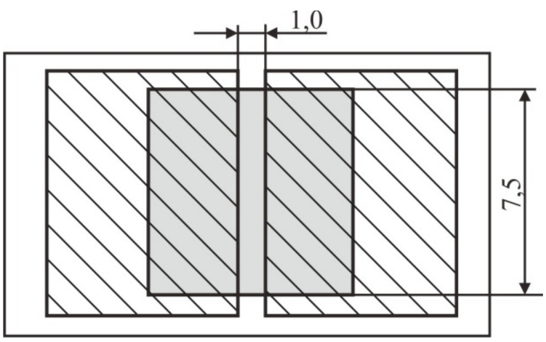

***FIGURE 1.** The configuration of the sample for measuring the electrical parameters of thin films*

The basis of the measuring complex is the digital multimeter UNI-T UT804, which supports the output of data to the computer and in the mode of a voltmeter of constant voltage provides a resolution of 0.01 mV with accuracy of 0.05% and has a mode of automatic selection of measuring range. Microcontroller STM32F152C8 is selected as control device, which is characterized by a widely-developed periphery. The program for the microcontroller is written in C. The block diagram of the measuring unit is shown in figure 2.

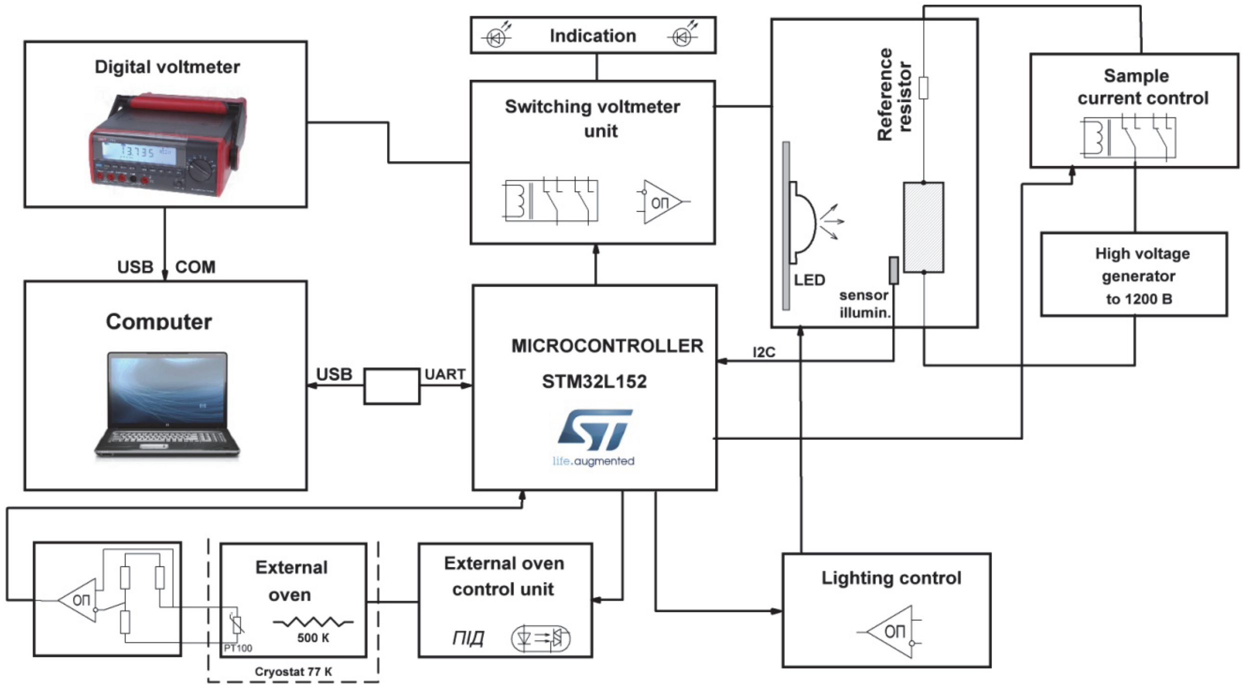

FIGURE 2. Functional block diagram of the device of automated measurements of photoelectric parameters of high impedance semiconductor films

The high voltage generator is assembled on a standard chip OZ960 and is configured such that, when loaded on a 4-resistor chain, a total resistance of 200 kOhm gives a voltage of 1200 V, different voltages are removed from the outlets of the resistors, rectified by a high-voltage fast diode, smoothed by a capacitor, and via a switching node are fed to sample.

Turning on the LED and setting the given illumination is carried out by the DAC of the microcontroller through the current stabilizer on the operational amplifier.

The computer program is written in the Delphi environment and provides the registration of data from a digital voltmeter, manual and automated control of the measurement process, pre-processing and data visualization. Communicate with the computer on the hardware level through the built-in USB interface of the microcontroller, and on the software using the interpreter of the text commands, which provides two-way data exchange between the control program on the computer and the microcontroller.

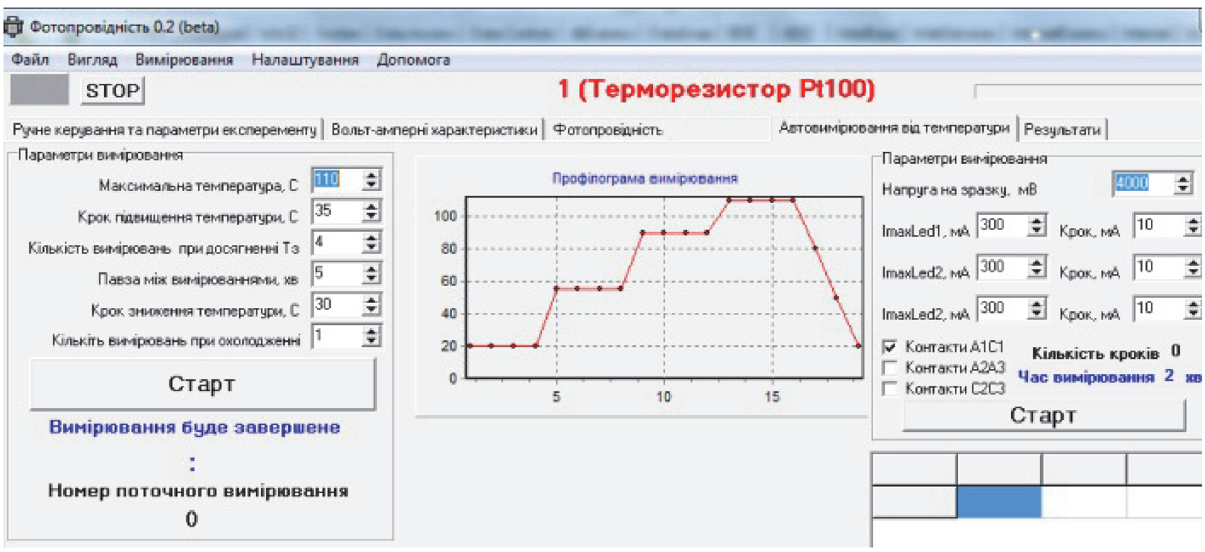

FIGURE 3. General view of the installation window for automated measurements of the control program for the photovoltaic parameters of semiconductor films

In the automated mode, the program allows both single measurements of electrical parameters and a series of measurements from time or temperature with the construction of the temperature-time diagram of the planned measurements (fig. 3). In the process of measurement, visualization of the time or temperature dependencies of the selected parameters can be visualized. In addition, in manual mode, the program allows you to control individual function blocks independently, which allows you to perform debugging and perform a non-standard experiment with automatic or manual recording of results.

Various filters are implemented and the ability to select specific data for export to MS Exel for further processing. For a series of samples of different thicknesses it is possible to automatically filter data and build profiles of electrical parameters from the thickness.

Results of the research and their discussion

A series of measurements was carried out for films obtained on the substrates of polished glass and fresh cleavages of mica. The volt-ampere characteristics of the CdTe films are the measured in the dark and in the illumination, are ohmic up to a voltage of 600 V. The temporal specific conductivity does not depend on the thickness of the film and the type of substrate and is about 10^{-6} $Ohm^{-1}m^{-1}$. The photoconductivity measurement results are shown in figure 4. It is evident that for all samples, the conductivity in the light increases significantly, and the thinner the film, so this dependence is stronger.

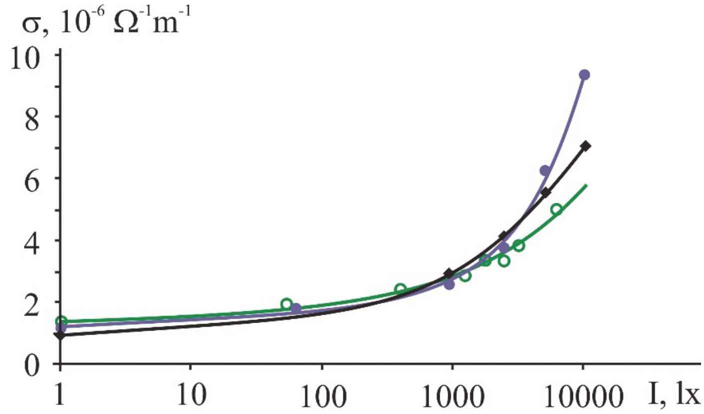

***FIGURE 4.** Dependence of specific electrical conductivity on illumination for thin films of CdTe of different thickness:*
● – thickness 200 nm, lining - mica; ♦ – thickness 320 nm, lining - polished glass; ○ – thickness 540 nm, lining - mica

The photosensitivity is an effective parameter in determining photoconductivity. The photosensitivity largely depends on natural and external imperfections, which can act as capture centers or as centers of recombination. The polycrystalline film contains a large number of grains and grain boundaries. At the boundaries of the grains there is a large number of defects and torn atomic bonds that form additional energy states that effectively capture the charge carriers, thereby creating a potential barrier on the grain boundary. Given the uniform structure of the intergranular boundary with the average height of the E_{bd} barrier, the dark conductivity in the film is expressed as [6]:

$$\sigma_D = N_C e \mu_0 e^{-(\Delta E + E_{bd})/kT} = N_C e \mu_0 e^{-\Delta E_D/kT} \tag{1}$$

where:

N_C – the density of states in the conduction band;

μ_0 – mobility of carriers in grain.

In the case of illumination, the conductivity of the film may increase due to the increase of excess media and also due to the decrease of the barrier height, depending on the energy of the incident photon. In [6] it is established that the change in conductivity due to the carrier generation is insignificant in relation to thermally generated carriers, and the conductivity in the light increases mainly due to increased mobility of carriers at the boundaries of the grains (activation of mobility). Total photoconductivity in films under illumination can be expressed as [6]:

$$\sigma_L = N_C e \mu_0 e^{-(\Delta E + E_{bl})/kT} = N_C e \mu_0 e^{-\Delta E_L/kT} \tag{2}$$

Here $\Delta E_L = (\Delta E + E_{bl})$ – photoactivation energy, where E_{bl} is height of the barrier under illumination.

Reducing the barrier height or the energy of activation of mobility can be expressed as

$$\Delta E_\mu = (\Delta E_D - \Delta E_L)$$

The activation energy of mobility ΔE_μ depends on the lifetime of the charge carriers, which in turn depends on the intensity of the light, as well as on the temperature. The relationship between photoconductivity and the activation energy of mobility will be written from equations (1) and (2) as

$$\frac{\sigma_L}{\sigma_D} = e^{\Delta E_\mu/kT} \tag{3}$$

The photosensitivity S is defined as $S = (\sigma_L - \sigma_D)/\sigma_D$ and, using (1) and (2), photosensitivity can be expressed as a function of the activation energy of mobility

$$S = e^{\Delta E_\mu/kT} - 1 \tag{4}$$

In figure 5 dependences of the calculated energies of activation of mobility from illumination are shown.

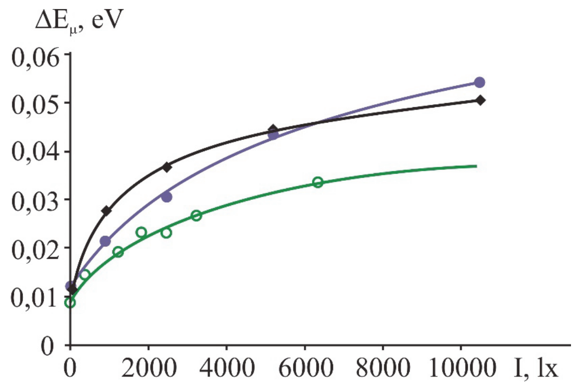

***FIGURE 5.** Dependences of the calculated energies of activation of mobility from illumination for thin films of CdTe of different thickness: ● – thickness 200 nm, lining - mica; ♦ – thickness 320 nm, lining - polished glass; ○ – thickness 540 nm, lining - mica*

It should be noted that for films obtained on polished glass substrates, the received energy is close and varies within 0.012-0.05 eV, and for films obtained on fresh cleavages of mica, much smaller values of the energies of activation of mobility are obtained 0.009-0.03 eV.

Conclusions

1. An operating system was developed and constructed and a computer program was created that provides automation of measurements of electrical and photovoltaic parameters of high impedance semiconductor films, as well as registration and primary data processing.

2. It is shown that the effect of grain boundaries is determinant in the photoconductivity mechanism of thin polycrystalline films CdTe.
3. The activation energy of the mobility was determined and it was shown that for the films obtained on fresh cleavages of mica, this energy is less than twice that of films obtained on polished glass substrates.

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