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Investigation of Electrical Signals Transmission through Light-Induced Conductive Channels on the Surface of CdS Single Crystal

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***Abstract*—Further development of information technologies hinges on innovations in the electronic components sector, particularly in enhancing electronic communication devices. This involves creating dynamic interconnects—electrically conductive channels that can be configured on-demand within chip circuitry to overcome the "tyranny of interconnects," which limits electronic systems due to the fixed nature of conventional interconnects.**

This paper presents experimental verification of transmitting information through photoconductive channels formed on a photosensitive cadmium sulfide (CdS) semiconductor single crystal using optical irradiation. By directing a focused light beam to specific areas of the CdS crystal, localized conductivity is induced, allowing for the dynamic formation of conductive channels. This method's efficacy in real-time signal transmission validates the theoretical framework and suggests new possibilities for semiconductor technology.

The integration of dynamic interconnects could revolutionize communication systems by enhancing device efficiency and processing capabilities. This technology could lead to more complex electronic architectures needed in high-speed computing and advanced telecommunications.

Additionally, this approach has potential applications in optoelectronics, improving device interaction with light. Dynamic interconnects could enhance solar cell efficiency, increase light sensor sensitivity, and aid in developing innovative visual displays.

The ability to control material conductivity through light not only advances existing device performance but also opens doors to new electronic designs and operations. This includes fully reconfigurable circuits that adapt in real-time, self-optimizing network components, and smart sensors that respond to environmental changes.

In summary, this research not only confirms the practicality of using photoconductive channels for information transmission but also emphasizes the significant implications for electronic and communication system advancements. As this technology evolves, it promises to significantly impact the design and functionality of future electronic devices, paving the way for more adaptable and powerful systems.

Keywords — photoconductivity; mobility of charge carriers; commutation; cadmium sulfide; gallium arsenide

I. INTRODUCTION

The modern world cannot be imagined without information technology, which has penetrated all spheres of human activity. In fact, the development of communication technologies has become one of the most important conditions for the sustainable development of society. Therefore, there is a need to constantly update both information technologies and their hardware. Data transmission channels are an important component of any communication device. Currently, wire channels, radio channels, fiber optic channels, etc. are used [1]. All of them have their advantages and disadvantages. For example, radio channels can be easily configured for any direction of data transmission, but require sufficiently high power to transmit a signal over long distances [2], and they are also quite vulnerable to external interference [3]. Wired and fiber optic channels have lower energy requirements and are more resistant to external interference, but they require a developed communication infrastructure and significant costs when it comes to reconfiguration [4]. To a certain extent, these problems are solved by using various combinations of wire, fiber, radio, and even plasma channels [5]. However, it is still not possible to completely circumvent the technological limitations caused by the physical impossibility of creating the required number of channels for transmitting information signals in a limited volume of the chip, which

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is called the "tyranny of interconnects" or "interconnect bottleneck" in English-language works [6, 7].

In our opinion, it is possible to expand the capabilities of information systems by reconfiguring semiconductor photosensitive switches by irradiating them. By illuminating the necessary areas of the semiconductor plate with radiation of a certain frequency, intensity, and polarization. Therefore, the aim of this work is to study the possibility of transmitting information signals through photoconductive channels formed on the surface of a semiconductor substrate made of single crystal cadmium sulfide.

II. Description of the experimental setup

The conductivity of a semiconductor material can be controlled using the internal photoelectric effect. The total electrical conductivity in a semiconductor can be described by equation [8]:

$$\sigma_{st} = \sigma_0 + \Delta\sigma_{st} = e\left((n_0 + \Delta n)\mu_n + (p_0 + \Delta p)\mu_p\right)$$

where σ_0 is the dark equilibrium conductivity, $\Delta\sigma_{st}$ is the stationary photoconductivity (caused by the light generation of charge carriers by intrinsic absorption), e is the electron charge, n_0, p_0 are the equilibrium concentrations of electrons and holes, respectively, Δn, Δp are the excess concentrations of electrons and holes caused by illumination, μ_n, μ_p are the mobilities of electrons and holes, respectively.

In the case of intrinsic absorption, $\Delta n = \Delta p$, so:

$$\sigma_{st} = \sigma_0 + \Delta\sigma_{st} = e\left(n_0\mu_n + p_0\mu_p\right) + e\Delta n\left(\mu_n + \mu_p\right)$$

In practice, it is necessary to fulfill the condition that the total conductivity is dominated by photoconductivity: $\Delta\sigma_{st} >> \sigma_0$. Thus, neglecting the dark equilibrium conductivity, we have:

$$\sigma_{st} \approx \Delta\sigma_{st} = e\Delta n\left(\mu_n + \mu_p\right)$$

To realize this goal, an experimental study of the possibility of forming a conductive channel on the surface of a semiconductor by the optical method, suitable for transmitting information signals through it, was carried out.

Cadmium sulfide (CdS) with a hexagonal structure was chosen as the semiconductor material under study from the $A^{III}B^{V}$ class, since it is one of the most common materials for the manufacture of photoreflectors. Also, the wavelength of the peak sensitivity of cadmium sulfide is in the range of 530...580 nm, which corresponds to the visible part of the spectrum (Fig. 1). For the study, cadmium sulfide plates with dimensions of 5 x 5 x 1 mm^3 (Fig. 2) and 10 x 5 x 1 mm^3 were made. The main parameters of the material under study are given in Table 1 [9].

Table 1 Table styles

Name	Value
The width of the prohibited zone along the (001)-optical axis (T = 300 K):	2,55 eV
Own resistivity CdS:	10^{10} Om
Concentration of intrinsic charge carriers	10^{17} m^{-3}

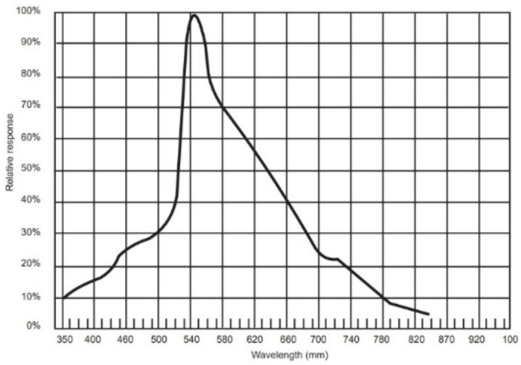

Fig. 1. Spectral sensitivity of CdS [10]

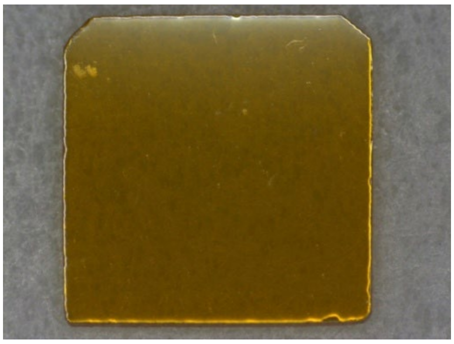

Fig. 2. Cadmium sulfide substrate with dimensions of 5 x 5 x 1 mm ^{3}

a *b*

Fig. 3. Exterior view of the laser (a) and cylindrical laser optics for forming orthogonal laser lines (b)

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The irradiation was carried out with a red laser with a wavelength of 650 nm and a power of 5 mW (Fig. 3). The wavelength of 650 nm is within the spectral sensitivity of CdS (Fig. 1).

To connect the wafer under study to the measuring devices, 500 nm thick aluminum contact areas with an intermediate 10 nm thick titanium adhesive layer were sputtered onto the wafer. The substrate was mounted on a breadboard (Fig. 4). The distance between the ohmic contacts for each of the channels was 0.5 mm.

The connection diagram of the breadboard to the measuring devices is shown in Fig. 5.

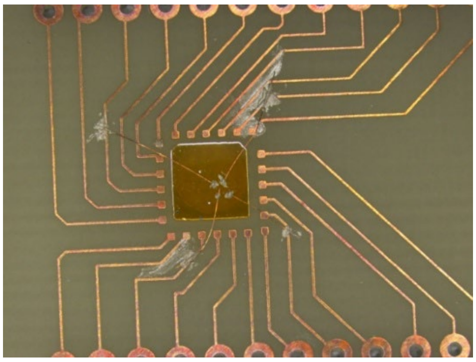
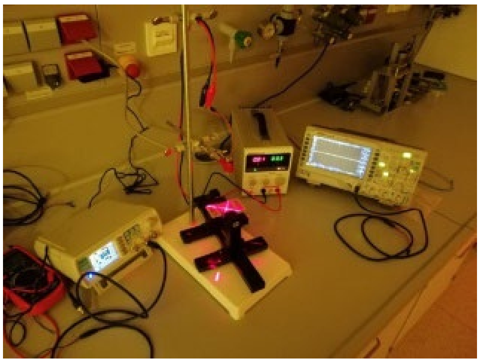
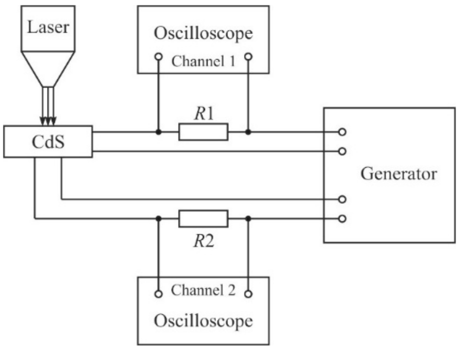


Fig. 4. Prototype board with cadmium sulfide substrate installed



a



b

Fig. 5. The test bench (a) and a schematic representation of the alternate connection of channels to measuring devices (b)

III. Measurement Results

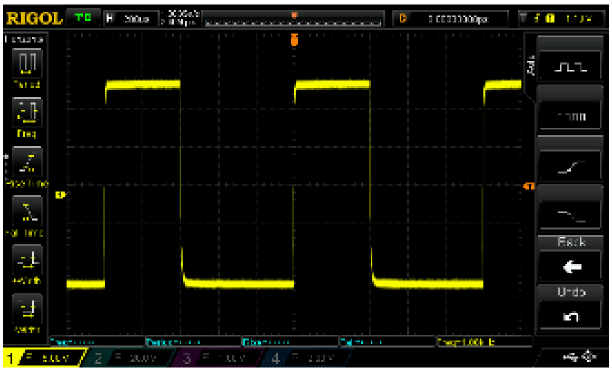
Two crossed conductive channels were formed on the surface of the cadmium sulfide plate using laser radiation. The resistance of each of the formed channels was on average 470 ohms. Rectangular signals from a signal generator were passed through the formed channels. The parameters of the input signals are shown in Table 2.

Table 2 Input signal parameters

Signal parameter	Channel 1	Channel 2
Amplitude	5 V	5 V
Fullness (duty cycle)	40%	20%
Signal type	pulse	pulse
Pulse frequency	1 kHz – 500 kHz	1 kHz – 500 kHz

After passing through the optically formed conductive channels, the signals were transmitted to the load resistors connected in series with them with a resistance of 47 kΩ and 51 kΩ for the first and second channels, respectively. An oscilloscope was connected to the load resistors, the screen of which displayed the output signals.

The passage of signals through each of the channels separately (in the absence of signals on the other channel) was investigated. The results are shown in Fig. 6.



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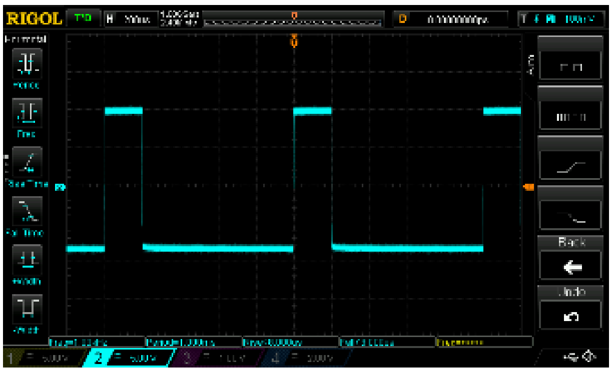

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Fig. 6. Output signals of channel 1 (a) and channel 2 (b) in the time division mode.

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When the frequency increased to 500 kHz, signal dispersion was observed, which manifested itself in signal distortion. At a frequency of 1 MHz, the signal distortion no longer allowed the transmission of signals of a given shape due to the low mobility of charge carriers and the diffusion capacity of the semiconductor, therefore, the maximum bandwidth of the rectangular pulse transmission channel is less than 1 Mb/s. Using *N* information transmission channels, you can increase the bandwidth of the data bus to *N* Mb/s.

It is possible to significantly improve the frequency characteristics due to the use of semiconductor material with greater mobility of charge carriers. For example, such a material could be gallium arsenide, since it has a much higher mobility of charge carriers than cadmium sulfide (Table 3).

TABLE 3 PARAMETERS OF SEMICONDUCTOR MATERIALS AT ROOM TEMPERATURE [11].

Material	CdS	CdSe	ZnS	GaAs	Ge	Si	AlAs	GaP
$\mu_n, \frac{cm^2}{V \cdot s}$	340	720	140	9500	3900	1400	280	190
$\mu_p, \frac{cm^2}{V \cdot s}$	110	75	5	450	1900	500	-------	120

Since the mobility of own charge carriers in gallium arsenide is about 28 times greater than the mobility of own charge carriers in cadmium sulfide, the use of gallium arsenide as a conductive medium can increase the bandwidth of the data bus up to 28**N* Mb/s.

The obtained results confirm the fundamental possibility of transmitting information signals through photoconductive channels formed on the surface of semiconductor materials.

The simultaneous transmission of signals through channels 1 and 2 demonstrates their interaction according to Ohm's law. Separation of these channels by height in the near-surface layer of the photovoltaic semiconductor is theoretically possible using appropriate optical elements and polarization effects [12].

CONCLUSIONS

A preliminary study of one of the modes of transmission of rectangular information signals through orthogonal conductive channels formed by laser irradiation that interact with each other in accordance with Ohm's law was carried out in this work. It was found that for a single crystal of cadmium sulfide, the maximum bandwidth of the rectangular pulse transmission channel is less than 1 Mb/s, which is not a significant value compared to traditional approaches. The advantage of this method is the ability to transmit signals across the surface of a semiconductor between its different points at different times, which simulates neural-type interconnections. The simultaneous parallel transmission of information using *N* channels can increase the bandwidth of the data bus to *N* Mb/s. At the same time, the use of other photosensitive materials would allow to increase the bandwidth of the data bus. For example, the use of gallium arsenide as a conductive medium can increase the bandwidth of the data bus to 28**N* Mb/s. Depending on the workload of communication systems, it is potentially possible to dynamically redistribute the bandwidth of communication buses, which is not possible in the case of using metal or fiber optic interconnections.

Further development of the above research involves a deeper study of the interaction of conductive photoinduced channels, their dynamic and static parameters, time and energy characteristics.

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Дослідження передачі електричних сигналів в ортогональних напрямках через фотопровідні канали на поверхні монокристалу CdS

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Анотація—Подальший розвиток інформаційних технологій залежить від інновацій у секторі електронних компонентів, зокрема у вдосконаленні електронних комунікаційних пристроїв. Це передбачає створення динамічних з'єднань — електропровідних каналів, які можна конфігурувати за потребою в схемі мікросхеми, щоб подолати «тиранію з'єднань», яка обмежує електронні системи через фіксований характер звичайних з'єднань.

У статті представлено експериментальну перевірку передачі інформації через фотопровідні канали, сформовані на фоточутливому напівпровідниковому монокристалі сульфіду кадмію (CdS) за допомогою оптичного опромінення. Направляючи сфокусований промінь світла на певні ділянки кристала CdS, індукується локалізована провідність, що дозволяє динамічно формувати провідні канали. Ефективність цього методу в передачі сигналу в реальному часі підтверджує теоретичну основу та пропонує нові можливості для напівпровідникової технології.

Інтеграція динамічних з'єднань може революціонізувати системи зв'язку шляхом підвищення ефективності пристрою та можливостей обробки. Ця технологія може призвести до більш складних електронних архітектур, необхідних для високошвидкісних обчислень і передових телекомунікацій.

Крім того, цей підхід має потенційне застосування в оптоелектроніці, покращуючи взаємодію пристрою зі світлом. Динамічні з'єднання можуть підвищити ефективність сонячних елементів, підвищити чутливість датчика світла та допомогти в розробці інноваційних візуальних дисплеїв.

Здатність контролювати провідність матеріалу за допомогою світла не тільки підвищує продуктивність існуючих пристроїв, але й відкриває двері для нових електронних конструкцій і операцій. Це включає повністю реконфігуровані схеми, які адаптуються в режимі реального часу, самооптимізуючі мережеві компоненти та розумні датчики, які реагують на зміни навколишнього середовища.

Таким чином, це дослідження не тільки підтверджує практичність використання фотопровідних каналів для передачі інформації, але також підкреслює значний вплив на прогрес електронної та комунікаційної систем. Оскільки ця технологія розвивається, вона обіцяє суттєво вплинути на дизайн і функціональність майбутніх електронних пристроїв, відкриваючи шлях для більш адаптивних і потужних систем.

Ключові слова — фотопровідність; рухливість носіїв заряду; комутація; сульфід кадмію; арсенід галію