

***FeIn₂Se₄* layered magnetic semiconductor and heterojunction on its base**

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FeIn₂Se₄ crystals, having the layered structure and a magnetic component, have been grown by the Bridgman method. *N-InSe-p-FeIn₂Se₄* heterojunctions were produced on it base. A value of the potential barrier of heterojunctions was determined from the capacitance-voltage characteristics. Current-voltage characteristics and the temperature dependences of the forward branches of the current-voltage characteristics were measured too. A diode coefficient of the current-voltage characteristics is determined. A series resistance of heterojunctions determines a frequency dependence of the capacitance-voltage characteristics and decreases an exponential growth of the current with the voltage. The photoresponse spectra of heterojunctions have only the long-wave threshold at 1.25 eV and extend in an ultraviolet range with the increasing of the photocurrent quantum efficiency.

(Received September 25, 2007; accepted February 7, 2008)

Keywords: *FeIn₂Se₄*, *InSe*, Heterojunction, Photoelectric parameters

1. Introduction

The magnetic properties of semiconductors can be used for a control of a carriers' flow not only by magnitude and polarity of voltage but also by the magnitude and direction of the magnetic-field strength. Interest in layered magnetic semiconductors is due to a strong anisotropy of their properties and, as a result, possible inhomogeneous distribution of impurities in the lattice. Different states of a magnetic impurity can result in the formation of ferromagnetic domains that is of interest for practical applications. It results from the literature data, that crystals of *FeIn₂Se₄* type have been obtained as thin films by a vacuum evaporation method [1, 2], or as thin plates by the method of chemical reactions [3]. On the basis of these crystals Schottky barriers were produced and their diode properties were analyzed.

In the present work *FeIn₂Se₄* magnetic crystals were grown by the Bridgman method and the properties of *n-InSe-p-FeIn₂Se₄* heterojunction (HJ) with a Van-der-Waals contact on the interface were investigated.

2. Experimental

Large ingots of *FeIn₂Se₄* crystals were cut on disks and then they were cleaved by substrates with mirror-like surfaces appropriate for preparation of HJs by the Van-der-Waals contact method [4]. It is established from the Hall effect that the grown crystals had a *p*-type conductivity. Their basic electrical parameters are as follows: the carrier density and Hall mobility along the layers $p = (2-3) \times 10^{16} \text{ cm}^{-3}$ and $\mu_H = 10 \text{ cm}^2/(\text{V}\cdot\text{s})$, respectively.

N-InSe crystals were chosen as the second component of the HJs were also grown by the Bridgman method. Both undoped ($n=3 \times 10^{14} \text{ cm}^{-3}$) and doped with the germanium ($n=1 \times 10^{16} \text{ cm}^{-3}$) crystals were used for the HJs preparation. They were used as the frontal semiconductor and therefore were cleaved from the ingot with thickness of 20-50 μm .

The current-voltage and capacitance-voltage characteristics of the HJs were investigated on the „Schlumberger SI 1255” device with a computer interface. All the measurements were carried out at room temperature. Temperature dependences of the current-voltage characteristics were also investigated with the purpose to establish the current flow mechanism through the HJs.

The photoresponse spectra of the prepared HJs were investigated by means of a MDR-3 monochromator with a 2.6 nm/mm resolution. The all spectra were normalized in relation to the amount of the incident photons.

3. Results and discussion

From the measurements of the HJ capacitance-voltage characteristics one can conclude that the impurity distribution on the interface has an abrupt character. The C^{-2} vs. U linear dependence at reverse biases corresponds to that case. Additionally the capacitance-voltage characteristics show the frequency dependence. These frequency dependences differ the higher the higher is the series resistance of the HJ. For the HJ with a low-resistance *InSe* the capacitance-voltage characteristics do not show, in fact, the frequency dependence. The value of

the potential barrier of the HJ (ϕ_b) determined from the capacitance-voltage characteristics for different samples is in the range 0.42-0.52 eV. In Fig. 1 it is shown the capacitance-voltage characteristics of *n-InSe-p-FeIn₂Se₄*

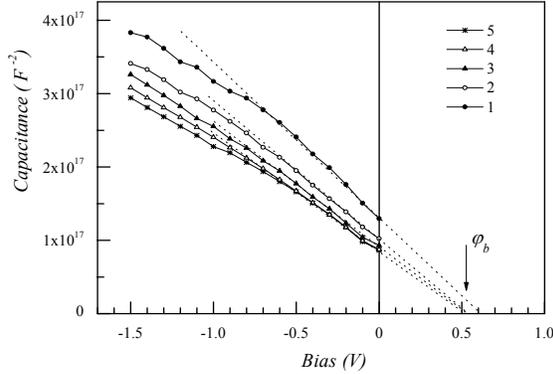


Fig. 1. Capacitance-voltage characteristics of *n-InSe-p-FeIn₂Se₄* heterojunction at different frequencies: 1-30; 2-20; 3-15; 4-10; 5-5 kHz.

HJ with a low-resistance frontal layer. For curves 2-5 in this Figure the extrapolation of the C^2-U dependence to the intersection with the voltage axis gives the same magnitude of cut-off voltage which corresponds to the value of the potential barrier of HJ [5]:

$$C^{-2} = \frac{2(\varepsilon_1 N_{D1} + \varepsilon_2 N_{A2}) \cdot (U_b - U)}{q N_{D1} N_{A2} \varepsilon_1 \varepsilon_2}, \quad (1)$$

where ε_1 , ε_2 are the permittivities of semiconductors forming HJ; N_{D1} , N_{A2} - concentrations of donors and acceptors; q is the electronic charge. The depletion with the majority carriers at the *p-n*-junction can be realized in both the semiconductors due to their approximately equal concentration.

The shown in Fig. 2 current-voltage characteristic of the HJ have a well expressed diode character.

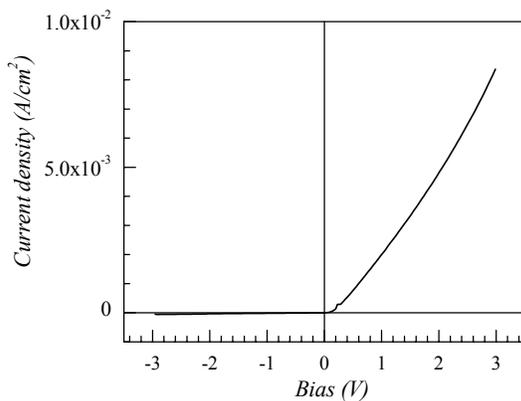


Fig. 2. Current-voltage characteristics of *n-InSe-p-FeIn₂Se₄* heterojunction at room temperature.

even at low direct biases the current-voltage characteristics essentially differ from a linear dependence. It is caused by the redistribution of the applied voltage drop between the depletion region and the series resistance which involves all the quasi-neutral regions of the HJ. The analogical deviations of current-voltage characteristics are practically observed in all the diodes [6]. The influence of the series resistance is also confirmed by the fact that the current-voltage deviation from the linear law increase with decreasing temperature because the resistance of quasi-neutral regions becomes higher. The diode coefficient of the current-voltage characteristic at currents below 2×10^{-5} A/cm² is close to unit. In this case the diffusion mechanism of charge transfer through the HJ takes place.

The room temperature spectral dependences of the photocurrent quantum efficiency are showed in Fig. 4

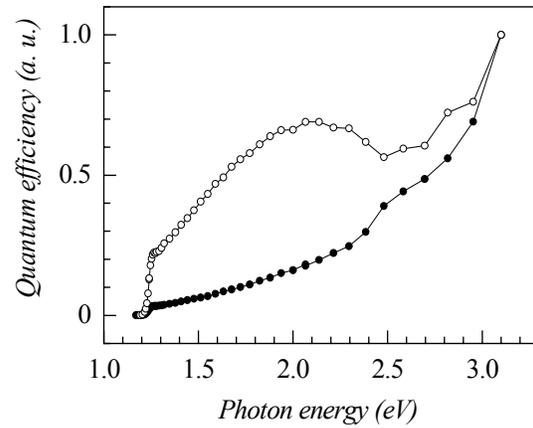


Fig. 4. Spectra of the photocurrent quantum efficiency of *n-InSe-p-FeIn₂Se₄* heterojunctions at room temperature for two different samples.

for *n-InSe-p-FeIn₂Se₄*. The photocurrent was measured in the mode of short-circuit current. The HJ samples contained the layer of undoped *InSe* of different conductivity. The energy gaps of *InSe* and *FeIn₂Se₄* are practically the same at $T = 295$ K: $E_g(\text{InSe}) = 1.25$ eV and $E_g(\text{FeIn}_2\text{Se}_4) = 1.15$ eV. The spectrum has the long-wave To establish the charge transfer mechanism through the barrier it is necessary to carry out temperature measurements of the direct branches of the HJ current-voltage characteristics from which it is possible to determine the diode coefficient n [5]:

$$J = J_o \left[\exp\left(\frac{qU}{nkT}\right) - 1 \right], \quad (2)$$

where J_o is the saturation current density; k – the Boltzmann constant; T – temperature. Such current-voltage characteristics were measured in the temperatures range 233-323 K with a 30 K step. They are shown in Fig. 3 in semilogarithmic scale in order to obtain a linear

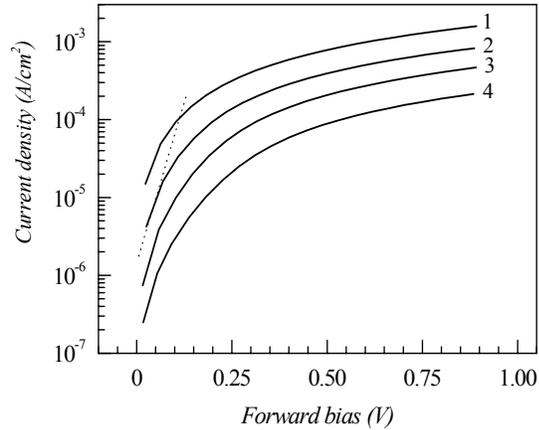


Fig. 3. The temperature dependences of the current-voltage characteristics of *n-InSe-p-FeIn₂Se₄* heterojunction: 1-323; 2-291; 3-262; 4-233 K. The dashed line is the theoretical current-voltage characteristics at room temperature.

connection between the current and voltage. In the same place the room temperature theoretical dependence of the current-voltage characteristic is shown. As one can see, threshold of photo-response at 1.25 eV. It indicates on the fact that all the depletion region of the HJ and separation of photocarriers takes place only in the frontal semiconductor. The role of the base semiconductor consists in the creation of the built-in-potential between the semiconductors. Light absorption in the near-surface region and diffusion of the carriers to the *p-n*- junction interface provide the photoresponse of the HJ in the ultraviolet spectral region.

4. Conclusions

FeIn₂Se₄ crystals grown by the Bridgman method have layered structure and high-quality mirror-like cleaved surfaces. *N-InSe-p-FeIn₂Se₄* heterojunctions were produced by the Van-der-Waals contact method with other *InSe* layered semiconductor. The measured electric characteristics (capacitance-voltage, current-voltage and their temperature dependences) testify to satisfactory quality of the obtained HJ. The magnitude of the potential barrier, i. e. the diode coefficient of the HJ current-voltage characteristics is determined. The HJs have a wide spectrum of photoresponse, limited only from the long-wave side.

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