ON THERMOMAGNETIC TRANSDUCERS OF IR RAYS ON THE BASE OF $Cd_xHg_{1-x}Te$

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Thermomagnetic properties of the solid solution of $Cd_xHg_{1-x}Te$ ($0 \le x \le 0.3$) and possibilities of creation of non cooled trancducer on the basis of them using traverse effect of Nernst-Ettingsgausen are studied. The analysis of the influence of the main physical parameters of the sensitive element on the main characteristics of the thermomagnetic transolucers is carried out. It is established, that as the sensitive element of infrared receiver from the investigated solid solutions the more suitable is the composition $Cd_{0.2}Hg_{0.8}Te$. Moreover, it is observed that electronic irradiation (with the integral doze ~$5.6 \cdot 10^{17}$ El/cm^2) at 300K leads to the increase of the specific sensitivity in two times.

The solid solutions $Cd_xHg_{1-x}Te$ are widely used as the sensitive element of cooled phototransducers in infrared-range [1]. In this direction the big successes have been achieved, the kinds of the receivers of the infrared rays have been created and are used. Moreover, the perspective of he uncooled warm transducers and receivers of the infrared rays on the base narrow-band semiconductors and on the base of Cd mercury, telluride system (CMT) [1-2] takes place. The thermomagnetic receivers of the infrared rays are one of the differences of the warm receivers of the infrared rays, having the defined advantages in respect of others. The set of the unique properties of the CMT system promote to the creation the same transducers on their base. Particularly, he minor effective mass of the electron, and their high mobility, low lattice thermoconductivity as conscience are caused by this. Therefore, the necessity of the study of the thermomagnetic properties of CMT and observing the probability of the use them as the sensitive elements in the uncooled thermomagnetic transducers of the infrared rays, based on he transversal effect Nernst-Ettingsgausen (N-E) effect, appear.

The given paper is devoted to the technical development of the thermomagnetic infrared transducers and the methods of the improving their technical characteristics. Unlikethe photoelectric gauges the thermomagnetic transducers don’t ask for the additional power sources, and the cooling and thermostable systems also.

The action principle of thermomagnetic transducers is caused by the appearing of the temperature drop in the semiconductor in the direction of thermal radiation at the thermal absorption. At the action of the transversal magnetic field on the faces of the samples the N-E field appears, the value of which is caused by the thermal flux.

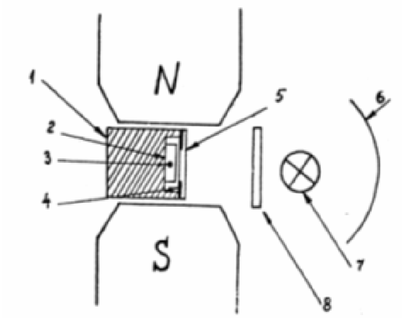

Fig.1. Construction of receiver of the infrared rays on N-E effect.

The most simple table of such transducers is given on the fig.1. This transducer includes the heat-eliminating core1, the sensitive element 2, the metallic contacts 3, screen 4, and the glass window 5. The sensitive element is situated between magnet fields before the radiation source. The filter 8, is situated between element situating in the focus of the mirror 6 and the calibration lamp 7.

The main characteristics of the thermomagnetic transducers on the base of N-E effect are:

specific sensitivity δ: $$\delta = \frac{\varepsilon_y}{\frac{W}{S}} = \frac{Q_\perp B}{\text{ж}} \qquad (1)$$

thermomagnetic quality $Z_{T\mu}$: $$Z = \frac{(Q_\perp B)^2}{\text{ж} S} \qquad (2)$$

factor of Quality *F*:

$$F = \frac{Q_\perp B}{\text{ж}^{3/4} c^{1/4} \rho^{1/2}} \qquad (3)$$

detective property *D:*

$$D = \frac{\delta \left(\frac{d}{4kT\rho}\right)^{1/2}}{\left(1+\sqrt{ZT}\right)^{-1}} \qquad (4)$$

inertialness τ:

$$\tau = \frac{0{,}4\ cd^2}{\text{ж}} \qquad (5)$$

where ε_y – N-E field; *W/S* is radiation power, adsorbed by the unit surface of the gauge; *d* is the thickness of the sensitive element; æ, ρ, *c* are coefficients of heat conduction, specific resistance and specific heat capacity accordingly. As it is seen, the main physic parameters of the semiconductor, defining the suitableness of the material for this purpose, are N-E coefficients, heat conduction and resistances. From the expression (1) it is followed, hat for the creation thermomagnetic transducer of the infrared rays with the high sensitivity it is necessary to choose the material with the low формула, with the big value of N-E coefficient. In [2] it is shown, that thermomagnetic force $Q_\perp B$ goes through minimum, the N-E coefficient achieves the big values in the materials with he high value of mobility ratio $U_n/U_p >> 1$ outside the area of the intrinsic conductivity. From the expression (2) it is followed that for the creation of the transducer with he high quality there are need the materials with the low thermoconductivity with he high value $Q_\perp$, and with the low resistance also. Thus, if $Q_\perp$ increases because of the participation of the carriers of II type in the conductivity, but ρ increases and Z falls. Sluggishness of the receivers is defined by the thermoconductivity and the thickness of the sensitive element (5). For the creation of the low inertial receivers it is need the sensitive element with the minimum thickness with the high æ. From the expression (4) it is followed, that detective property can be grown because of the high specific sensitivity δ and electroconductivity. Thus, the carried out analysis show, that demands to the materials for the thermomagnetic infrared transducers are different. The materials with the high δ, but a little bit worse exponents F, D, τ are used for the creation of the measurements of the thermal flux, with the high F are used for the creation of detectors of infrared rays, and with the high $Z_{T\mu}$ – for the energy transducers.

The solid solutions of CMT have the low lattice thermo-conductivity, small effective mass and high mobility of the electrons. The crystals of CMT can be obtained as by *n*-, so by *p*-type of conductivity and changed its parameters at external action (temperature, pressure, radiation, magnetic and electric field, e.t.c.). The unique properties of the CMT crystals are in the base of the using in the quality as the gauge of the thermomagnetic transducers of the infrared rays.

The investigation of the transversal N-E effect was carried out on the swarm of the samples with $x=0\div0.3$ at 300K with the purpose of the definition of the ways of the practical use of the solid solutions of CMT. Because of the mixed conductivity the temperature and magnetic-field dependences of the value $Q_{\perp}B$ have the maximums. The problem is the observing the conditions, when these maximums are equal to T room and not high B. The maximum $Q_{\perp}B$ can be shifted, changing the ratio of concentrations of the electrons and holes in the initial material. The dependence curve of the specific sensitivity δ of CMT samples from the composition (fig.2; B=1Tl) was obtained. As it is seen, the dependence achieves the maximum value at x=0,2. The obtained results show the probability of the use of CMT solid solutions ($0.15\leq x\leq0.25$) as the sensitive element in the devices on the detection of the radiation object, based on the N-E effect.

The comparison of the value of specific sensitivity of gauge on the base CMT with x=0,2 $\left(\delta = 9\cdot10^{-5}B\ \frac{M}{B_T}\right)$ with data on Cd_3As_2-NiA $\left(\delta = 1\cdot10^{-5}B\ \frac{M}{B_T}\right)$: JnSb-NiSb $\left(\delta = 2.7\cdot10^{-5}B\ \frac{M}{B_T}\right)$ [2, 3] shows the perspectivity of CMT ($0.15\leq x\leq0.25$) in the quality as the sensitive element in the installation on the detection of the radiation object.

According to the theory the value of thermomagnetic force $Q_{\perp}B$ can increases, increasing the ratio between concentrations n/p [2]. There are several methods of the influence on the ratio n/p (thermal treatment, doping, inclination from the stoichiometric). In the case JnSb-NiSb and Cd_3As_2-NiAs the above mentioned methods of the treatment lead to the to a change for the worse of δ [4], that is connected with the high initial electron concentrations in them (~$2\cdot10^{17}$ and $6\cdot10^{18}cm^{-3}$). The longed temperature annealing of CMT crystals ($0\leq x\leq0.25$) at 180-200°C in the pores of mercury leads to the insignificant increase of δ [5, 6]. The later relieving, lightening, doping don't leads to the significant increase of δ. This is caused by the difficulty of the influence on the ratio of electrons and holes in it.

As it was mentioned in the work [7], the irradiation by the electrons at 10K and 20K don't influence of the significant influence on the parameters of the receivers of the infrared rays on the base $Cd_{0.2}Hg_{0.8}Te$. Such conclusion is the consequence of the influence of the small doze and low radiation temperature. It is no need to create the enough quantity of the radiation defects (RD), which are stable higher than radiation temperature that can lead to δ increase at such conditions. As it was shown in work [8] the electron irradiation leads of the increase of the electron concentration in the CMT crystals.

The results of the detailed investigation of the influence of the electron irradiation on the specific sensitivity δ are given on the fig.2, from this it is followed, that ($\Phi=5.6\cdot10^{17}cm^{-2}$) goes through maximum at $0.15\leq x\leq0.25$ at the electron radiation. These results show that the irradiation by electrons at 300K by the energy 4MeV in the doze interval $(4\div7)\cdot10^{17}cm^{-2}$ of CMT crystals with $p>>n$ and $pU_p\geq nU_n$, used earlier in the photo- and thermomagnetic receivers, as the sensitive element in the installations on the detection of radiation object, based on the N-E effect, leads to the increase of δ in 2 times.

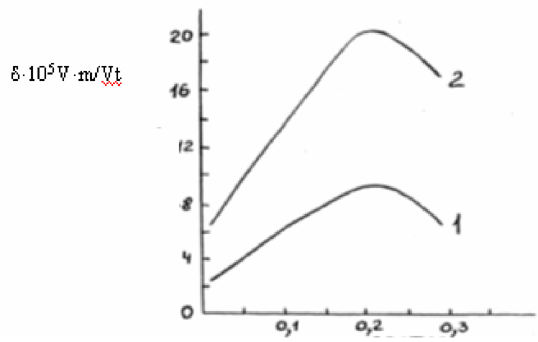

Fig.2. The dependence of specific sensitivity on composition of thermomagnetic transducer on the base CMT. The doze of irradiation 1 – 0; 2 - $5{,}6\cdot10^{17}$ el/cm^2.

The obtained results are explained that CMT in the conductivity always participate holes and electrons with the different concentrations and mobility at the same time.

The electron irradiation leads to the increase of n, which is followed by the according increase of N-E coefficient. Indeed, the last leads to the increase, as the phonon spectrum isn't sensitive to the electron irradiation.

It is known the several types of the thermomagnetic transducers on the base of N-E effect. The most simple from them it was described in the work [4]. This receiver includes the heat-conducting core, sensitive element, metallic contacts, screen and glass window.

The sensitive element is situated between magnet poles before radiation source. The filter is situated between calibration lamp and element, situating in the focus of the mirror. The most original construction of N-E receiver is used for the detection of the location of the radiation source. The construction of this receiver is ipresented on the figure 3. The front surface of the element turns back and closes by the thin glass (or quartz) window 8. The sensitive element 1 is situated between 4 and 5 magnet poles. The electromotive force of N-E appearing on the side faces of the sensitive element, is taken by the contacts 6 and given on the focusing installation. The action principle of this receiver of heat radiation is based on the temperature drop, appearing in the sensitive element at the decrease of the infrared rays. The N-E electric field appears at the action of magnetic field *B*. The fall point of the infrared beam on the working solid moves from the area of the one magnet to the area of another at the moving of the radiation source. Moreover, the output signal changes the polarity going through «dead point– *O* » (where *B*=0), but the signal value increases with the increase of the inclination of the fall point of the radiation in respect of «dead point» of the sensitive element. The output signal changes and thus the transmission of the radiation source is fixed with the inclination of source beam in respect of «*O*» point. Such devices can be used in the industry, for example, in the control systems with the help of the infrared beams, especially on the heat tube mill.

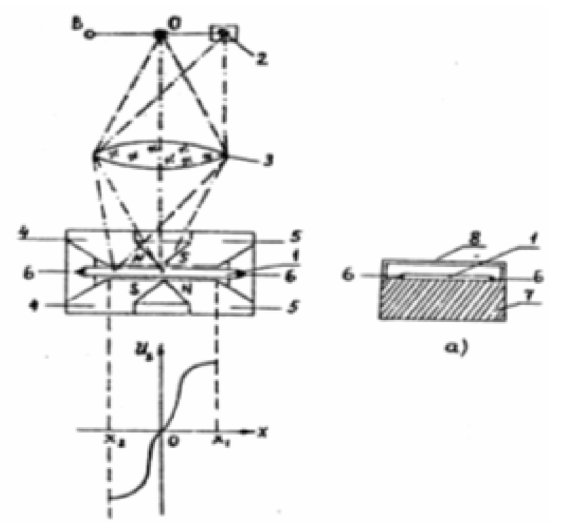

Fig.3. Construction of receiver IR radiation on the N-E effect for detection of the location of source radiation. 1- sensitive element (working body); 2 – source of IR radiation; 3 – lens; 4,5 – magnet; 6 – contacts; 7 – heat conducting core; 8 – glass window.

The thermomagnetic N-E effect is used for the creation of the amplifier of the direct current also. For this it is used the hybrid thermoelectric-thermomagnetic transducer of the intensity on the Peltie and N-E effects, including Peltie thermoelements of *n* and *p* branches Bi_2Te_3 and the sensitive thermomagnetic element from JnSb-NiSb. The action principle of the transducer is: the constant voltage of such polarity, that the heat will generate on the contact, is given on the thermoelement. The generating heat creates the temperature gradient on the sensitive element in the direction of *y* axe. The field N-E appears at the appearing of the magnetic field on the sensitive element in the direction, transversal to *dT/dy*. Moreover, the ratio of the output signal to the input signal can be estimate by the ratio:

$$\frac{V_2}{V_1}=\frac{\left(\frac{QB}{\alpha_1}\right)\left(\frac{\ell}{d}\right)}{1+Z\cdot T\left(1+\frac{ж_2}{ж_1}\right)}$$

where α_1 is the electromotive force of the thermoelement, $æ_1$ is its thermal conduction, *Z* is thermoelectric quality, *l* is common length of the sensitive element in the direction of the output signal, *d* is thickness in the direction of heat flux.

Because of α, æ and *Z* aren't almost depend on *B*at the room temperature till *B=1Tl*, so output intensity becomes proportional to *QB*. That's why the one more important demand to the such devices is the linear change of thermomagnetic force *(QB)* of the sensitive element from the *B* induction, which leads to the line changing V_2 from *B*.

As it was above mentioned, the specific sensitivity δ for CMT crystals have linear character. The creation of the sensitive element from the semiconductor solid solution $Cd_xHg_{1-x}Te$ ($0.15\le x\le 0.25$) allows to increase significantly of the amplification factor in the hybrid transducers on Peltie's and N-E effects (fig. 3), consideringly. Such transducers can be used in the measuring technics for the amplify of the weak electric signals.

Thus, it is established, that $Cd_xHg_{1-x}Te$ (with x=0.15÷0.25) can be used as in the sensitive element in the thermomagnetic receivers of the infrared rays. The electronic irradiation (with the integral doze ~$5.6\cdot10^{17}$el/cm^2) of CMT crystals (with x=0.15÷0.25) at 300K leads to the increase of the specific sensitivity of the receivers of the infrared rays in two times.

[1] Infrared Detectors. (Ed. By *R.D.Hadson*- New-York). A Division of J.Wiley and Sons Inc. 1975, 392 p.

[2] *S.A. Aliyev, D.G. Arasli*. Fizicheskiye ocnovi termomagnitnikh preobrazovateley IK izlucheniya. Baku, 1981-27 s. (Preprint № 42 Instituta fiziki AN Azerb. SSR) (in Russian).

[3] *H.J. Goldsmid, K.R. Sydney*. A thermal radiation detectors employing the Nernst effect in Cd_3As_2-NiAs.- J.Phys. Appl. Phys., 1971, v.4, №6, p.869-875.

[4] *E.I. Zulfugarov*. Vliyaniye elektronnogo oblucheniya na elektrofizicheskiye svoyctva tvyerdikh rastvorov $Cd_xHg_{1-x}Te$ (0 *x* 0,25). Diss. kand. fiz.- mat.nauk. Baku, 1985- 132 p. (in Russian).

[5] *G. Dittmaz, B. Forbrig, F. Schubert.* Tempern von $Cd_{0.2}Hg_{0.8}Te$ im Quecksilberdampf., Krist. Und Techn/ 1978, v.13,N 7,p.817-821

[6] *B.M. Askerov*. Kineticheskiye effekti v poluprovodnikakh. Nauka, L., 1970, 303 p. (in Russian).

[7] *C.E. Mallon, B.A. Green, R.E. Leadon, J.A. Nabar*. Radiation effects in $Hg_{1-x}Cd_xTe$. e EEE, Trans. Nucl. Sci., 1975, v.22, №6, p.2283- 2288.

[8] *S.A. Aliyev, T.G. Gadzhiyev, E.I. Zulfugarov, R.I. Selim-zade*. Vliyaniye elektronnogo oblucheniya na parametri nositeley zaryada v tvyordikh rastvorakh $Cd_xHg_{1-x}Te$ tezisi dokl. Vsecoyuz. konf. «Radiacionnaya fizika poluprovodnikov I rodstvennikh materialov». Tashkent, 1984, s.66. (in Russian).

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$Cd_xHg_{1-x}Te$ KRİSTALLARI ƏSASINDA İQ ŞÜALARIN TERMOMAQNİT ÇEVİRİCİLƏRİ

Məqalədə $Cd_xHg_{1-x}Te$ kristalları əsasında düzəldilmiş İQ (infraqırmızı) şüaların termomaqnit qəbulediçilərinin düzəldilməsi və onların iş prinsipindən danışılır.

$Cd_xHg_{1-x}Te$ kristallarının 300K temperaturda eninə *N-E* (Nernst-Ettinqsqauzen) effekti ölçülmüşdür. Müəyyən olunmuşdur ki, $Cd_{0.2}Hg_{0.8}Te$ kristalları İQ qəbulediciləri üçün daha yararlıdır. Belə ki, $Q_{\perp}B$ maksimumu məhz x=0,2 kristallarında ən çox olur.

Məqalədə hərəkətdə olan obyektləri aşkar edən İQ qəbuledicinin quruluşu və iş prinsipi haqqında da məlumat verilir.

Э.И. Зульфугаров

О ТЕРМОМАГНИТНЫХ ПРЕОБРОЗОВАТЕЛЯХ ИК ИЗЛУЧЕНИЯ НА ОСНОВЕ $Cd_xHg_{1-x}Te$

Исследованы термомагнитные свойства твердых растворов и возможности создания на их основе неохлаждаемых преобразователей ИК излучения, основанных на поперечном эффекте Нернста-Эттингсгаузена. Проведен анализ влияния основных физических параметров чувствительного элемента на основные характеристики термомагнитных преобразователей. Установлено, что в качестве чувствительного элемента ИК приемника из исследованных твердых растворов наиболее подходит состав . Наряду с этим выявлено, что электронное облучение (с интегральной дозой) при 300К приводит к возрастанию удельной чувствительности ИК приемника в два раза.

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