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ON THE NATURE OF THE SPEED OF RESPONSE OF RADIATION DETECTORS MADE OF $Cd_xHg_{1-x}Te$ BASED ON THE PHOTORESISTIVE EFFECT

(Presented by Academician A. M. Prokhorov, January 29, 1970)

The solid solution of cadmium and mercury tellurides has made it possible to obtain a wide range of photodetectors. Of primary interest are detectors for the atmospheric window of 8-13 μ, in which CO_2 lasers operate. Such detectors have recently been developed in France, the USA, and in our country ([1–5]). This article sets forth some aspects of the operation of CdHgTe photoresistors in the generation region of a CO_2 laser.

It is obvious that the choice of the composition of the solid solution is important. At a given temperature, the edge of the fundamental absorption λ_g of the intrinsic (pure) material is determined by the band-gap width E_g.

However, the presence of residual impurities and deviations from stoichiometry lead to a shift of the absorption edge, and thereby of the intrinsic photosensitivity, toward higher frequencies, mainly through the Burstein effect. The position of the absorption edge in a sufficiently narrow-gap material can be estimated by the quantity

$$\lambda_g(\mu) \approx 1.24/(E_g + F) \text{ (eV)},$$

where F is the Fermi level, located in the energy band and measured from the extremal value of the energy.

An increase in the concentration of charge carriers, leading to an increase in F, leads to a shift in the wavelength of the absorption edge. The presence of defects determines the position of the absorption edge and indirectly affects the value of the effective mass at the bottom of the band, and thereby also the Fermi level.

The position of the Fermi level is related to the value of the effective mass and, for narrow-gap semiconductors, is determined by Kane' s model.

Thus, the choice of the composition of the solid solution for producing a photoresistor with sensitivity in a specified spectral interval is connected with taking into account the defectiveness of the material. The problem becomes more complicated when it is necessary to operate over a certain temperature range. The change in the photosensitivity spectrum with changing temperature is due both to a change in the band-gap width and to a change in the position of the Fermi level as a result of changes in the concentration of charge carriers and in the density of states.

The solid solution of the specified composition was synthesized from starting components with a residual-impurity content of less than 10^{-5} wt.% with subsequent crystallization by the vertical zone-melting method.

The preliminary selection of samples cut from a single crystal for the manufacture of photodetectors was carried out on the basis of the results of galvanomagnetic studies, which, in the temperature interval 77-330° K, provided an estimate of the concentration and mobility of the charge carriers.

The selected samples were subjected to additional heat treatment, making it possible to change both the concentration of charge carriers and the type of conductivity either throughout the entire volume or locally.

Measurements of the photosensitivity spectra were carried out on an apparatus assembled on the basis of an IKS-21 spectrometer, including a synchronous detector and a resistance transformer for matching low-resistance samples with the high-resistance input of the recording circuit. Figure 1 presents, in relative units, the photosensitivity spectra S_λ, reduced to equal values of the radiation energy in the recorded spectral interval. As the temperature is lowered, the maximum of the photosensitivity spectrum shifts toward longer wavelengths. The temperature coefficient of the shift of the maximum is $(2—4) \cdot 10^{-4}$ eV/deg. Analysis of the temperature dependence of the position of the Fermi level on the basis of results from studies of galvanomagnetic effects makes it possible to assert that a positive temperature coefficient of the shift of the maximum of the spectral sensitivity by no means signifies that the temperature coefficient of the band-gap width is positive. Apparently, the inversion of the sign of the coefficient of the temperature dependence observed at $x < 0.5$ is due not to an inversion of the sign of the temperature coefficient of the band-gap width, as is usually believed, but to a change in the position of the Fermi level. The temperature coefficient of the band-gap width remains negative, apparently down to $x = 0$. This conclusion makes it possible to explain not only the spectral properties of the material, but also the temperature dependences of the current-voltage characteristics of $p—n$ junctions in this material, for which, as the temperature is lowered, the cut-off voltage also increases at $x < 0.5$.

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Since it is not possible to obtain a strictly homogeneous distribution of cadmium over the length and cross section of the ingot ([6]), the sample contains a volume electric field that leads to an asymmetry of the output signal with respect to the polarity of the bias voltage. The nonuniform distribution of cadmium also explains the presence of a fine structure in the photosensitivity.

To estimate the frequency properties of detectors obtained in this way, a CO_2 laser was used with a discharge tube 50 mm in diameter and 3 m long. The resonator length was varied within the range 3–6 m.

The Fresnel number for the resonator used was sufficiently large for the generation of a large number of transverse oscillation modes.

The use of the detectors under study made it possible to observe beats at frequencies up to 30 MHz on an S4-8 spectrum analyzer and an S1-11 oscilloscope.

The pulse characteristic of the detector can be found from the solution of the equation describing the process of establishment of the voltage V_R across a resistance and capacitance connected in series with the detector, in co-

through which a current $i(t)$ flows. Under the zero initial condition the solution has the form:

$$V_R(t) = \frac{1}{c} e^{-t/RC} \int_0^t e^{\xi/RC} i(\xi)\, d\xi.$$

We regard the contacts as nonrectifying; then in the detector circuit, under a δ-shaped light pulse, a current $i(t) = i_0 e^{-t/\tau_f}$ flows, where τ_f is the lifetime. As a result:

$$V_R(t) = \frac{i_0}{C} \frac{\tau_f \tau}{\tau_f - \tau} \left(e^{-t/\tau_f} - e^{-t/\tau} \right),$$

where $\tau = RC$.

The leading edge of the pulse response is determined by the smaller, and the trailing edge by the larger, of the times τ_f and τ; the width of the pulse response is determined by their sum. The experimentally obtained values of $\tau + \tau_f$ apparently do not exceed $3 \cdot 10^{-8}$ sec. Measurements of the lifetime in the material studied, based on the Kikoin–Noskov effect, showed that this quantity varies within the range from 10^{-10} to 10^{-8} sec., in good agreement with the value given above. It is interesting that the lifetime can be varied by heat treatment of the material, which indicates the possibility that intrinsic defects act as recombination traps.

To obtain pulse-response widths smaller than τ_f, it is necessary to use photodiodes.

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Note: Figure translations are in progress. See original paper for figures.