1. Introduction

The mercury-cadmium-telluride (MCT, HgCdTe) solid solutions are within the most studied semiconductors and have found an important application in the infrared (IR) device technology. The physics and applications of the Hg$_{1-x}$Cd$_x$Te IR detectors and systems were summarized in a number of review papers and books (see, e.g., [1–4]). The mechanisms of the recombination of excess carriers in these semiconductors have an important influence on IR detectors and, to a large extent, control their performance [3, 5, 6]. Despite the fact that these mechanisms in Hg$_{1-x}$Cd$_x$Te ($x \sim 0.2$ and $x \sim 0.3$) materials, as well as in devices based on them, have been intensively studied by various experimental methods [7–9], the values of the lifetime published in the literature have ranged from micro- to nanoseconds. The fact is that the lifetime of excess carriers critically depends on the quality of materials prepared by different techniques, technology of IR devices on their base, and methods of its measurement.

Under the condition of weak excitation, the effective total lifetime of excess carriers is determined by several recombination mechanisms [1]:

$$
\tau_{\text{tot}}^{-1} = \tau_{\text{bulk}}^{-1} + \tau_{\text{surf}}^{-1} = \tau_{\text{A1}}^{-1} + \tau_{\text{A7}}^{-1} + \tau_{\text{rad}}^{-1} + \tau_{\text{SRH}}^{-1} + \tau_{\text{surf}}^{-1},
$$

(1)
Photocarrier lifetime is a fundamental parameter when designing mid- to far-infrared detectors. Among various methods for measuring the lifetime of excess carriers, the microwave reflection technique is the most frequently used. This method is based on the measurement of the decay time of the photocurrent after applying an external microwave field. The decay time is related to the lifetime of excess carriers through the equation:

\[ \tau = \frac{1}{\frac{1}{\tau_{\text{rad}}} + \frac{1}{\tau_{\text{SRH}}} + \frac{1}{\tau_{\text{surf}}} + \frac{1}{\tau_{\text{bulk}}}} \]

where \( \tau_{\text{bulk}} \) and \( \tau_{\text{surf}} \) are the recombination times in the bulk and at the surface of the semiconductor, respectively, \( \tau_{\text{rad}} \) and \( \tau_{\text{SRH}} \) are the Auger and Shockley–Read–Hall recombination mechanisms, respectively, and \( \tau_{\text{e}} \) is the interband radiative recombination mechanism.

The Auger processes play an important role in limiting the performance of HgCdTe infrared photodiodes, especially when the energy band-gap is decreased, and the temperature is increased. The Shockley–Read–Hall recombination mechanisms are most important at low temperatures. A number of deep levels of intrinsic defects and impurities, which may be responsible for this mechanism, were found for HgCdTe. With a sufficient decrease in the concentration of SRH recombination centers, this mechanism together with the radiative mechanism remain the fundamental limitation mechanism for the lifetime of minority carriers, which defines the upper feasible device parameters.

Among a large variety of methods for getting the lifetime of excess carriers, the different decay methods seem to be the most frequently applied. In these methods, the excess carriers are generated by a pulse of light with a turn-off time (falling time) shorter than the lifetime to be measured. The photoconductivity decay time can be measured by the direct observation of the resistivity or by the microwave method (reflection or absorption of decaying free carrier concentrations in a microwave spectral region) (see, e.g., [15–18]). The conductivity changes due to excess carriers excited by the microwave power were previously used for measuring the lifetime of excess carriers in n-type and p-type Hg\(_{1-x}\)Cd\(_x\)Te with \( x = 0.22 \) and 0.3 [19]. The photoconductivity decay was monitored by measuring the microwave reflection. The important advantage of this method is that the samples need no special preparation, and the contact-resistance effects are eliminated. The lifetime values obtained by the microwave reflection were found to agree well with those obtained by the conventional photoconductive decay on a wide range of lifetimes. However, the microwave reflection technique requires the prior application of surface passivation. In addition, it does not account for the influence of contacts on the value of lifetimes for the interband excitation.

The goal of this research is the investigation of the decay carrier lifetime \( \tau \) under the interband (the band-gap \( E_\text{g} < h\nu \), where \( h\nu \) is the energy of a photon under the excitation) and intraband (the band-gap \( E_\text{g} \gg h\nu \)) radiation excitations in HgCdTe photoconductors with various distances between the electrical contacts and various areas of contacts. In the case of the interband excitation, the decay of excess carriers is observed as a change in the voltage on the load resistance. In this work, the measurements were carried out in the photoconductivity mode in order to study the effect of metal contacts on the recombination mechanism. In the samples with small distances between large-area contacts, the increase in the recombination rates at contacts can arise leading to the shortening of the decay times. An investigation of the minority carrier lifetime in HgCdTe with different geometries of electrical contacts is of importance for the design of IR photodetectors, photodiodes, and THz detectors devices.

2. Experiment and Discussion

The Hg\(_{1-x}\)Cd\(_x\)Te \( (x \approx 0.2) \) compensated single crystal films used for measuring the decay lifetimes were grown by the molecular beam epitaxy (MBE) on GaAs (013) substrates (see Fig. 1, a) [20].

The thickness of the infrared (IR) photosensitive layers with the composition \( x \approx 0.2 \) (0.20–0.22) was \( d \approx (2.5–9.0) \, \mu m \) between ZnTe (0.01 \( \mu m \)) and CdTe (5–7 \( \mu m \)) buffer layers and a thin intermediate layer with changing the chemical composition to...
For measuring the decay time under the interband radiation excitation, we used the samples with long distance between the electrical contacts to exclude their influence on the carrier lifetime. For measuring the decay recombination time in the THz or microwave spectral regions (intraband excitation), only small-width sensitive layers (d ≈ 10 μm) with metal contacts in the form of bow-tie antennas to introduce the radiation into the samples were used. To study the influence of electrical contacts on recombination times, the large-area contacts (antennas, Mo/In or Mo/Au) were deposited on the active layers. To introduce an electromagnetic radiation in THz and microwave spectral ranges (E_0 ≫ hν), cap dielectric layers were deleted by the wet etching in a bromine-methanol solution.

### 2.1. Decay carrier lifetime at the intraband excitation

In the decay lifetime experiments, we used the samples with bow-tie antennas with the spacing between blades d ≈ 10 μm (Fig. 1, b). Blades were obtained by the dc magnetron sputtering of thin (d ≈ 700 Å) molybdenum adhesive layers and the subsequent evaporation of d ≈ 1 μm indium or gold contact blade layers on MCT sensitive layers obtained by the wet chemical etching of cap protective graded band layers (Fig. 1, a). The dimensions of blade layers were about 2 mm in length used as antennas to let the microwave radiation (ν ≈ 70.05 GHz) or THz radiation (high-power THz molecular lasers pumped by a transverse excited atmospheric TEA-CO_2 with hν = 0.617 and 1.07 THz), to be introduced in the MCT sensitive layers of the area A ≈ 10 × 50 μm.

For the excitation we used the microwave IMPATT (impact ionization avalanche transit-time) diode source with the radiation frequency ν ≈ 70.05 GHz (hν ≈ 2.9 × 10^{-4} eV ≪ E_0) and the impulse duration of (80–100) ns, with the rise and falling times of not more than 5 ns. We applied bow-tie antennas designed for the frequency range ν ≈ 300 GHz the gain of which for this radiation frequency range is G ≪ 1. This means that only a small part of the power P ≈ 3.8 W from the microwave emitter was introduced into the samples. The distribution of the power density I in the sample plane is close to the Gauss one and can be approximated by

\[
I(r) = I_0 \exp\left(-\frac{r^2}{\tau^2}ight),
\]

where r is the radial distance,
The decay time can be well described by the equation
\[ y = y_0 + A_1 e^{(t-x_0)/\tau}, \]  
(2)
where \( y_0 = 0.00062, \) \( x_0 = -59.5 \) ns, \( A_1 = 25.02835, \) and \( \tau = 32.9 \) ns is the decay time.

As it was shown in [23, 24], the electron heating by electromagnetic waves in bipolar Hg\(_{1-x}\)Cd\(_x\)Te can be used for the designing of THz/sub-THz detectors. The free-carrier photoresponse in the THz and microwave spectral ranges of MCT layers is related to several mechanisms [24, 25]: the Dember effect (photodiffusion effect) contribution, the thermoelectromotive contribution, and the contribution associated with free carrier concentration changes.

At the intraband excitation, the observed lifetimes are changing within the different ranges of several tenths ns with the mean, over 8 samples, \( \tau \approx 43 \) ns. This value of the lifetime explains the form of a response of such samples showing a reiteration of the impulse duration, which, for example, for a laser operating at \( \lambda = 280 \) μm (1.07 THz) was at least of \( \tau \approx 100 \) ns. The data on the response time under the gas laser excitation at the wavelengths \( \lambda = 280 \) μm (1.07 THz) and \( \lambda = 486 \) μm (\( \nu = 0.617 \) THz) were obtained for samples at \( T = 300 \) K (see Fig. 3).

### 2.2. Decay carrier lifetime at the interband excitation

For the interband excitation of MCT sensitive structures, we used a GaAs laser diode operating at the wavelength \( \lambda = 0.88 \) μm (\( h\nu = 1.41\) eV \( \gg E_g \) (MCT) \( \sim 0.1 \) eV at \( T = 80 \) K) with a pulse width of \( \approx 70 \) ns and the full time duration to the level 0.1 of \( \sim 20 \) ns. The typical decay photocconductiv curve is showing Fig. 4. The decay curves were measured by an oscilloscope with a bandwidth of 50 MHz (rise time 10 ns).

The temperature dependences of the decay lifetime of nonequilibrium charge carriers in the \( n- \) and \( p- \) type samples of MBE grown Hg\(_{1-x}\)Cd\(_x\)Te with a large distance between the contacts were measured. The interband low-intensity excitation levels (\( \Delta n = \Delta p \ll n_0 \) (\( \Delta n \) and \( \Delta p \) are the concentrations of nonequilibrium electrons and holes, respectively, and \( n_0 \) and \( p_0 \) are the concentrations of equilibrium electrons and holes) was used with a GaAs semiconductor laser (\( h\nu \approx 1.4 \) eV). For the \( n- \) type MCT materials, the
Auger recombination rates are determined by A1 process (involving two electrons and one heavy hole) [10].

In n-type MBE-grown layers (x ≈ 0.20–0.22) with the electron concentration \( N \approx (1–10) \times 10^{14} \text{ cm}^{-3} \) with large distances between the small-area metallic contacts at the temperature range \( T = 80–300 \text{ K} \), the well-known recombination mechanisms take place. The CHCC (A1 Auger process) and SRH recombination (trap concentration \( N_t \sim 1.5 \times 10^{14} \text{ cm}^{-3} \)), are shown to be the basic recombination mechanisms. The estimations were made for the carrier concentration \( N(80 \text{ K}) \approx (1.2–0.2) \times 10^{14} \text{ cm}^{-3} \) for the bandgap \( E_g \approx (0.85–0.11) \text{ eV} \), and \( N(300 \text{ K}) \approx (2–4) \times 10^{16} \text{ cm}^{-3} \) for the band-gap \( E_g \approx (0.15–0.18) \text{ eV} \). At \( T \leq 140 \text{ K} \), the recombination times were within \( \tau \approx (1–2) \times 10^{-9} \text{ s} \) quickly falling down to \( \tau \approx 10^{-7} \text{ s} \) at \( T \sim 250 \text{ K} \) in n-type samples. Calculations of the radiative recombination give much higher recombination times and were not taken into account.

In the p-type MBE-grown samples with the concentration of holes in the layers \( P = (2–8) \times 10^{16} \text{ cm}^{-3} \), the estimated decay lifetimes at \( T = 80 \text{ K} \) are \( \tau \approx 2 \times 10^{-8} \text{ s} \). The CHLH Auger recombination (light hole, heavy hole, and electron involved, A7 Auger process) and the SRH recombination via defect states at the concentration of recombination centers \( N_t \sim 3 \times 10^{15} \text{ cm}^{-3} \) are the principal recombination mechanisms. At temperatures \( T > 120 \text{ K} \), mainly the Auger-7 process prevails. The radiative recombination plays almost no role at any temperature.

The decay lifetimes \( \tau \) for samples with a short distance between the metallic contacts-antennas (Fig. 1, b), which were cut from the same MBE wafers, can be evaluated only approximately as the values of \( \tau \) obtained in 10 samples (\( \tau \sim (25–40) \text{ ns} \)) are approximately of the same order as the pulse width of a GaAs laser (\(~30 \text{ ns} \)). They are significantly lower than the decay lifetimes (~1000 ns) in samples with long distances between the contacts. Therefore, in samples with a short distance between contacts, the recombination at contacts defines the recombination processes. The recombination lifetime estimated from (1) is at most ~30 ns at the interband excitation. The mean decay lifetime measured over 10 samples is \( \tau \approx 31 \text{ ns} \).

3. Conclusions

The photoconductive decay carrier lifetime measurements in the narrow-gap \( \text{Hg}_{1-x}\text{Cd}_x\text{Te} \) (\( x \approx 0.2 \)) compensated single-crystal films with short distances between large-area metallic contacts (\(~10 \mu\text{m} \)) under the interband and intraband excitations (\( E_g \gg h\nu \)) are measured. These experiments have shown a significant lowering of the decay times in photoconductive compensated single-crystal films compared with those with long distances between the electrical contacts. The results obtained assume that, in the samples with short distances between the large-area (bow-tie antennas) contacts, the decay carrier lifetimes are influenced by the surface recombination at contacts, giving the decay times ~30 times shorter compared to the samples with long distances between the contacts. The obtained results concerning an establishing lifetimes and the ratio between them for interband and intraband excitations are important for creating the dual-spectral detectors based on HgCdTe for the IR and THz spectral ranges.

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