Photon-drag photodetectors for the far-IR and submillimeter regions

S. D. Ganichev, Ya. V. Terent'ev, and I. D. Yaroshetskii

A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, Leningrad

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The development of optically pumped pulsed lasers which produce short, intense light pulses in the far-IR and submillimeter spectral regions requires the development of corresponding detectors with a high time resolution and a large dynamic range. These characteristics should be exhibited by detectors which operate by virtue of the drag exerted on electron by photons in semiconductors.[1,2] Photodetectors of the FP and FPU types, for example, working at wavelengths near 10.6 μm, have a short response time ($\sim 10^{-9}$ s) and are capable of detecting light over the intensity range from 10^2 to $5 \cdot 10^8$ W. The possibility of using the drag exerted on electrons by photons to detect radiation in the far-IR and submillimeter parts of the spectrum was studied in Refs. 3 and 4. In the present letter we describe photon-drag photodetectors wh which can detect laser pulses over the wavelength range from 9 to 500 μm.

The present experiments show that the most promising approach for developing detectors which can operate over a broad spectral range (from the mid-IR region to the submillimeter region) is to make use of the longitudinal drag effect accompanying indirect intraband transitions. The reason is that semiconductors with a complex band structure, e.g., p-type Ge, in which direct transitions between subbands of the valence band also occur, exhibit many spectral inversions of the sign of the drag current. These spectral inversions, studied in detail in Ref. 4, naturally complicate the development of photodetectors to operate over a broad spectral range. We have accordingly used n-type germanium to fabricate the photodetectors. To optimize the characteristics of the detectors, we have studied the drag emf as a function of the density. Figure 1 shows data for the two wavelengths $\lambda = 90$ and 385 μm. Also shown here are some corresponding theoretical predictions. Analysis of these results shows that the decay of the photosensitivity at high densities results from a significant decrease in the average light intensity in the sample due to an increase in the absorption by free carriers.

Our studies reveal the optimum photodetector to be an n-type Ge sample with $n = 1.5 \cdot 10^{14}$ cm^{-3}, with a length of 26 mm, and with contact stripes no wider than 1 mm. Figure 2 shows the sensitivity spectrum of this detector.

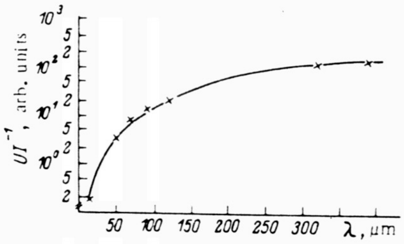

FIG. 1. Sensitivity of the photon-drag photodetector versus the density in n-type Ge at T = 300 K for various wavelengths. Points) Experimental; curves) theoretical. 1) 90 μm; 2) 385 μm.

TABLE I. Sensitivity of the Photon-Drag Photodetector at Three Wavelengths

λ, μm	Sensitivity, mV/kW	
	sensitivity area of 5 × 5 mm^2	sensitivity area of 10 × 10 mm^2
9.2	$3 \cdot 10^{-1}$	10^{-1}
90.5	$3.7 \cdot 10^1$	$1.1 \cdot 10^1$
385	$1.5 \cdot 10^3$	$4.7 \cdot 10^2$

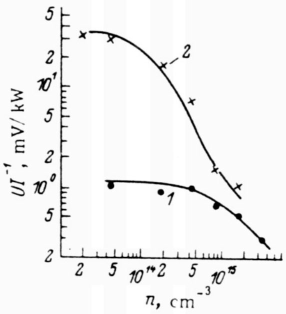

FIG. 2. Sensitivity spectrum of the n-type-Ge photon-drag photodetector (T = 300 K, $n = 3 \cdot 10^{14}$ cm^{-3}, 0.2 × 0.2 × 1.5 cm).

We studied the linearity of the detector at three wavelengths. At 9.2 μm the detector remains linear up to a light intensity ~30 MW/cm^2; at $\lambda = 90.55$ μm, the detector remains linear up to the maximum radiation power density at our disposal: 2 MW/cm^2 (no nonlinearity was observed).

At $\lambda = 385$ μm, unfortunately, the maximum possible power in these experiments was only 10 kW/cm^2, so that there was of course no nonlinearity. The resolving time of the detector is better than 10^{-9} s. This detector can operate over a broad temperature range, from T = 77 to 300 K.

This photosensitive element has been used to fabricate a photodetector including a wide-band amplifier (bandwidth of $1.5 \cdot 10^3$–$7 \cdot 10^7$ Hz) with a gain K = 150.

The sensitivities of the photodetector with two interchangeable heads are listed in Table I.

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