A Room Temperature High Sensitivity Fast Detector of FIR Radiation

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ABSTRACT

A highly sensitive fast room temperature FIR detector is proposed. The detector operation is based on intraband photoconductivity in semiconductors. It has a time resolution of 100 ps and operates in the spectral range from 50 μm to 500 μm. Its sensitivity (at λ= 90 μm is 30 μV/W without and 6 mV/W with a 300 MHz bandwidth amplifier) increases with wavelength as λ^2. This is at least by two orders of magnitude higher than the sensitivities of fast pyroelectric or photon drag detectors.

2. GENERAL CONSIDERATIONS

In this paper we report the development and construction of a fast room temperature semiconductor photodetector for pulsed FIR laser beams. It operates over a broad spectral range, from 50 μm to 500 μm. Detection is based on the change in the carriers mobility as a result of intraband absorption of light in the semiconductor.

The linear absorption of IR and FIR radiation ($h\omega<E_g$, $h\omega$ is the photon energy, E_g is the band gap) in semiconductors at comparable high temperatures, when impurity levels are ionised, is determined by the nondirect (Drude) intraband transitions and the absorption on the lattice. In p-type semiconductors direct heavy-to-light hole intraband transitions also play an essential role. The absorption of light leads to an increasing of the photoexcited carriers energy and, as a result of their energy relaxation by electron-electron collisions, to the increasing of the electron temperature, T_e, of the electron gas in whole. The value of electron heating is determined by the absorbed energy and the value of energy losses by the energy relaxation of carriers with emission of optical and acoustical phonons. The electron heating leads to a change of the electrons mobility and so of the materials conductivity. For the condition $T_e-T_0 < T_0$ (T_0 is the lattice temperature) the relative photoconductivity $\Delta\sigma/\sigma$, T_e and the carriers mobility μ are connected by the relation:

$$\frac{\Delta\sigma}{\sigma}=\frac{1}{\mu}\frac{\delta\mu}{\delta T_e}\Bigg|_{T_e=T_0}(T_e-T_0)$$

0-8194-1234-1/93/$6.00

The characteristic time of this effect is determined by the energy relaxation time of carriers due to collisions with optical and acoustical phonons. For germanium at room temperature it is of the order of 10^{-12} s.

The effect described above has been used previously for the design of a radiation detector for the spectral range of the CO_2 laser, where a p-Ge sensitive element was connected in a photoconductivity circuit with a high-voltage pulsed power supply[1]. This detector permits the measurement of very short IR radiation pulses with time duration up to 100 ps but has rather low sensitivity. The value of its sensitivity is determined by relatively small electron gas heating due to the presence of a fast and strong mechanism of energy losses. This is the emission of optical phonons of energy $h\omega_0$, in a case of IR radiation absorption ($h\omega > h\omega_0$). The choice of p-Ge for the detectors element was determined by weak absorption of nondirect (Drude) transitions and the essentially higher value of direct heavy-to-light intraband absorption in p-type materials.

For the excitation of Ge by radiation of FIR range, where photon energies are relatively small and energies of photoexcited carriers are lower than optical phonon energy, emission of optical phonons is absent. This leads to higher value of electron heating. At the same time, with increasing wavelength the Drude absorption by free carriers increase and, consequently, absorbed energy increase. Both factors lead to an increase (by 10-10^3 times in comparison with 10 μm range) of the relatively change in mobility normalised to the light intensity, I. The increasing of the value of electron heating in the FIR range permits us to develop a high sensitivity fast FIR detector based on the above principal.

3. SAMPLES, EXPERIMENTAL TECHNIQUES AND RESULTS

Investigations were carried out on n- and p-type Ge samples with densities 10^{12}-10^{16} cm^{-3} at T=300 K inserted in the usual photoconductivity arrangement. The radiation sources used were FIR NH_3 or D_2O lasers optically pumped by TEA CO_2 laser providing lines at the wavelengths λ= 66, 90.5, 120, 150, 290 and 385 μm with pulse duration ~40 ns.

Measurements of the relative photoconductivity $\Delta\sigma/\sigma$, in the range 50-500 μm, normalised to the light intensity I, which determines the sensitivity of the detector, have shown that this value is greater by a factor of 10-10^3 (depending on wavelength) than the same value in the spectral range of a CO_2 laser (10^{-5} cm^2/kW)[1]. Investigations of dependencies of $(\Delta\sigma/\sigma)(1/I)$ on carriers type, density and light frequency have shown that the value is in n-type germanium two times higher than in p-type germanium, independent of the carrier density and that it increases with wavelength as λ^2.

On the base of these investigations, n-type germanium has been used in a design of photodetector. The detector element of size 2x2x5 mm^3 has been made from n-Ge with

$n=6*10^{14}$ cm^{-3}. The resistance of it is 50 Ω for electrical impedance matching. The detectors element was connected to a metal cooler to provide temperature stabilisation and was included in a photoconductivity circuit (a load resistance R_l =50 Ω and bias voltage 9V). For increasing of a sensitivity, a high frequency amplifier with 300 MHz bandwidth and voltage gain coefficient 200 has been used.

The detector has been investigated in wide spectral and intensities ranges. It has been shown that the time resolution of the detector, which from physical side is limited by the energy relaxation time (for n-Ge at T=300 K of the order of 10^{-12} s), is better than 100 ps. The detectors time resolution has been checked by registration of FIR pulses with pulse duration 200 ps. It has been shown that signals from the detector repeat the pulses shape. As it was mentioned above the detectors sensitivity, S, rise with wavelength due to the frequency dependence of the Drude absorption coefficient. In Fig.1 the dependence of S on the wavelength is shown. The detectors sensitivity (at λ=90μm it is 30μV/W without and 6 mV/W with 300 MHz bandwidth amplifier) is much higher than the same values of FIR photon drag detectors or pyroelectric detectors with the same time resolution.

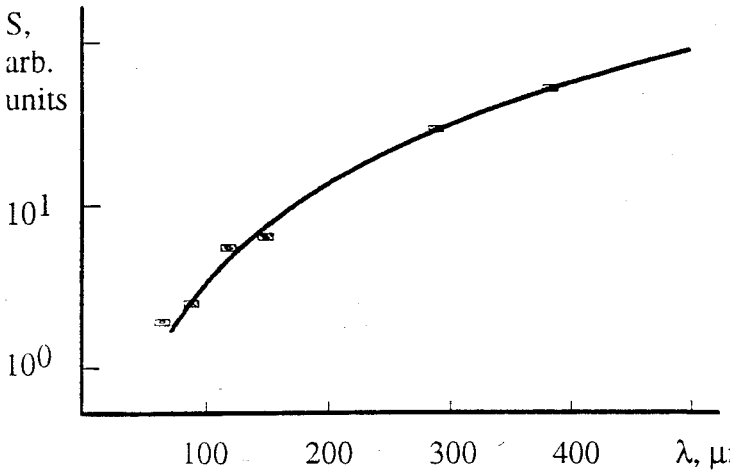

Fig.1

The dependence of the response on the radiation intensity was studied in the whole region of intensities which we could obtain (at λ=90μm up to 1MW/cm^2, at λ= 385 μm up to 30 kW/cm^2). It was found that in the whole investigated region the signal linearly depends on the light intensity. At the same time it is necessary to mention that at even higher intensities the signal could saturated due to the simple saturation of the photoconductivity signal for $\Delta\sigma/\sigma \sim 1$ or due to nonlinear dependence of the carriers mobility on the electron temperature.

4. ACKNOWLEDGEMENTS

One of the authors (S.D.G.) thanks Alexander von Humboldt Foundation for support of his work.

5. REFERENCES.

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Volume 1985