It can thus be concluded that the observed ESR spectra belong to surface paramagnetic recombination centers which are oriented perpendicular to the surfaces of the crystal along ⟨111⟩ axes.

We also carried out some experiments in which the silicon crystals were bombarded with 50-keV x rays. Bombardment of the silicon crystals in this manner for several days increased the intensity of the observed ESR spectrum of the surface centers by a factor of three to five, depending on the particular sample. Furthermore, yet another new ESR spectrum appears after the x-ray bombardment in n-type silicon crystals with a resistivity of 1-5 Ω • cm. Lines c and d of this spectrum are shown in Fig. 1b, while their angular dependence is shown by the dashed lines in Fig. 2. The symmetry of the g tensor of this spectrum is also approximately axial, with a ⟨111⟩ symmetry axis, and with $g_{\parallel} = 1.993 \pm 0.001$ and $g_{\perp} = 2.002 \pm 0.001$.

The spectrum which arises during x-ray bombardment also belongs to surface recombination centers, since it disappears after the samples are etched.

In summary, the use of the effects of spin-dependent recombination significantly improves the sensitivity of the standard ESR procedure and expands the possibilities of this technique for studying various phenomena at the surfaces of semiconductors.

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Fast uncooled detector for far-IR and submillimeter laser beams

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Optically pumped tunable pulsed lasers with output wavelengths from 10 to 1000 μm and pulse lengths 10^{-7}-10^{-9} s have recently found use in several applications (plasma diagnostics, research on solids, etc.). There is accordingly an urgent need to develop radiation detectors with a high time resolution for this wavelength range.

In this letter we report the development and construction of a fast-response uncooled photodetector of a new type for pulsed laser beams. It operates over a broad spectral range, from 50 to 500 μm. The detector operates by virtue of the change in the mobility of charge carriers in semiconductors during intraband absorption of light by free charge carriers. The effect is caused by (first) a change in the mobility of the carriers which are directly involved in the elementary photon-absorption event and (second) a change in the mobility of all of the free carriers because of an increase in their temperature during the energy relaxation of photoexcited carriers through electron–electron collisions. The effect described here has been used previously in radiation detectors for the spectral range of the CO_2 laser, where a p-Ge semiconductor detector is connected in a photoconductivity circuit with a high-voltage pulsed power supply.[1]

To evaluate the possibility of fabricating similar photodetectors for use at longer wavelengths (up to 500 μm), we experimentally studied the heating of charge carriers in Ge at T = 300 K in this spectral range. As the light source we used pulsed NH_3 and D_2O lasers with optical pumping by a CO_2 laser.[2] The experiments were carried out in a standard photoconductivity arrangement.

The experimental results show that the relative photoconductivity referred to a unit light intensity, $(\Delta\sigma/\sigma)(1/T) = \Sigma$, which determines the sensitivity of the detector, is greater by a factor of 10-10^3 (depending on wavelength) over the interval from 50 to 500 μm than for the spectral range of a CO_2 laser (10^{-5} cm²/kW, according to Ref. 1). This result is explained on the basis that as the wavelength of the radiation is increased there is an increase in the coefficient of intraband optical absorption by free carriers, while on the other hand there is an increase in the fraction of the energy which is expended on heating the bulk of the carriers during the energy relaxation of the photoexcited carriers. Figure 1 shows the experimental results on $(\Delta\sigma/\sigma)(1/I)$ versus the carrier density in n-type and p-type germanium for two typical wavelengths in the submillimeter range ($\lambda = 90.55$ μm and $\lambda = 385$ μm). We see that the value of Σ in n-type germanium is twice that in p-type germanium and essentially independent of the carrier density n. In order to achieve the maximum sensitivity in practice, however, it is necessary to satisfy the condition that the attenuation of the light as it propa-

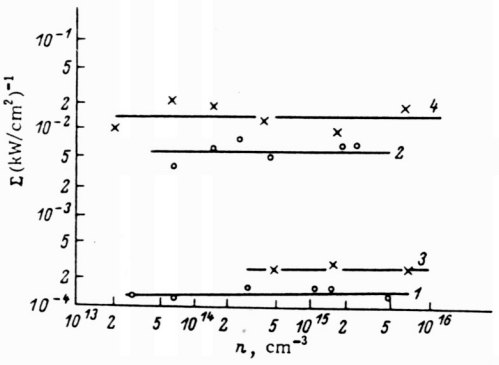

FIG. 1. Relative photoconductivity referred to a unit intensity of the incident radiation, $(\Delta\sigma/\sigma)I^{-1} = \Sigma$, versus the current carrier density in n-type and p-type germanium at two wavelengths, $\lambda = 90.55$ μm and $\lambda = 385$ μm, at T = 300 K. 1) p-Ge, $\lambda = 90.55$ μm; 2) p-Ge, $\lambda = 385$ μm; 3) n-Ge, $\lambda = 90.55$ μm; 4) n-Ge, $\lambda = 385$ μm.

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gates through the sample must be very slight: $\alpha d < 1$, where α is the absorption coefficient and d is the thickness of the sample. In the spectral range under study here, this condition is met for the samples with $n \leq 10^{14}$ cm^{-3} (d = 1 mm). Working from these conditions, we have developed a prototype photodetector, whose basic characteristics are described below.

At wavelengths from 50 μm to 500 μm, the sensitivity of this detector is 0.1–10 mV·cm²/kW (for a supply voltage of 4.5 V). According to Ref. 1, the use of a high-voltage pulsed power supply increases the sensitivity by several orders of magnitude and sets the stage for the achievement of high output voltages (above 10 V), so that single light pulses with lengths as short as 10^{-11} s can be displayed directly on an oscilloscope. The response time of the detector is no worse than $2 \cdot 10^{-10}$ s, and in principle it is limited only by the energy relaxation time of the photoexcited carriers, which amounts to (for n-type germanium at T = 300 K, for example) 10^{-11}–10^{-12} s. An upper limit on the dynamic range of the detector is set by the nonlinearity in the dependence of the carrier mobility on the light intensity, which is seen as a substantial increase in the carrier temperature. The experimental results show that at a light wavelength λ = 90.55 μm a 10% nonlinearity of the photoresponse is reached only at $I \sim 1$ mW/cm². The ability to reduce the thickness of the detector while retaining its basic characteristics makes it possible to work effectively in a spectral region where the optical absorption coefficient of the detector material is high. This ability also eliminates the restriction on the speed imposed by the time required for the light to propagate over the thickness of the sample.

The fundamentally new, fast, uncooled detector for the spectral range 50–500 μm which we have described here has several specific advantages, which would appear to make this detector a good complement to the existing detectors.

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Effect of nanosecond laser pulses on indium phosphide

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The laser processing of III–V semiconducting compounds, which have a high internal quantum yield of radiative recombination, has recently attracted much interest. In the very first experiments carried out with GaAs, however, it was found that laser processing under conventional conditions seriously degrades the emission properties of the material.[1–4] An effort has accordingly been undertaken to seek III–V semiconducting compounds which are more resistant to laser radiation and also new types of laser processing, which do not degrade the luminescence properties of a semiconductor.

In the present letter we report a regime for nanosecond laser processing of InP at an energy density above the threshold for melting of the material which does not result in a degradation of its luminescence properties. This laser-processing regime is reached in a comparatively narrow energy interval.

The samples are mechanically polished (111) n-InP substrates (Sn; $1 \cdot 10^{18}$ cm^{-3}) grown by the Czochralski method. The samples are bombarded by single pulses from a ruby laser (λ = 0.694 μm, $\tau \sim 50$ ns). We wish to stress that it is ineffective to use the common laser-processing procedure which involves the use of a square intensity distribution in the beam and a discrete set of bombardment energies to study the behavior of the luminescence because the energy intervals in which the emission properties of the material may change are very narrow. We use laser beams with a smooth intensity distribution, so that it is possible to obtain a spatial sweep of the change in the luminescence properties of the materials as a function of the bombardment energy density. In order to change the geometric dimensions of the zones corresponding to different energy intervals, we varied the density of the radiant energy at the maximum from 0.3 to 1.5 J/cm².

Each processed region at the surface of the sample is a spot ~1.5–2 mm in diameter with a clearly defined annular structure. Some of the rings (including the bright outer ring) have sharp boundaries. Over the entire processed region, all the way to the outer boundary of the bright ring, we observe a melting of shallow cracks and also a sharp decrease in the diffuse-scattering background which stems from the original surface roughness of the semiconductor. At the centers of some of the spots bombarded at high energy densities, regions of surface damage to the material are found.

The photoluminescence measurements are carried out after a layer of material ~15 nm thick is removed from the surface of the sample. We study the photoluminescence spectra and also the intensity distribution of the photoluminescence (at the maximum of the edge band) over the cross section of the processed region and over depths in the sample. The photoluminescence is excited with an Ar^+ laser, whose beam is focused to a size ~50 μm. A scanning system allows us to measure the photoluminescence distribution over the cross section of the

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