# Photoresistive effect in n-GaAs/Au tunnel junctions during plasma reflection of laser light

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A fast-rising photoresistive effect has been observed in $n$-GaAs/Au tunnel junctions during the application of a pulse of laser light in the region of the plasma reflection from free carriers in $n$-GaAs.

The potential barrier at a metal-semiconductor tunnel junction is concentrated in the semiconductor. It forms as a result of a self-consistent distribution of electrons in the field of ionized donors and of the charge in surface states. When an electromagnetic wave is incident on an electron plasma of a semiconductor, an additional force arises and acts on the electron subsystem as a result of the reflection of the radiation. As a result, there is a change in the shape of the Schottky potential barrier, which in turn changes the transparency of this barrier and thus the resistance of the junction. This photoresistive effect was predicted by Kotel'nikov *et al.*,[1] who also offered some estimates regarding the possibility of observing it.

In an effort to observe the photoresistive effect, we studied the response of an $n$-GaAs/Au tunnel system to pulsed laser radiation at a wavelength, $\lambda = 90.55\ \mu$m, greater than $\lambda_p$, where $\lambda_p$ is the wavelength corresponding to the plasma minimum in the reflection spectrum of $n$-GaAs. The $n$-GaAs/Au tunnel junctions were fabricated by the method described in Ref. 2 on $n$-GaAs substrates with electron densities $N$ of $2\times10^{18}$, $3.7\times10^{18}$, and $6.5\times10^{18}\ \text{cm}^{-3}$. The measured values of $\lambda_p$ were 20, 16, and 11.5 $\mu$m, respectively. The thickness of the gold electrodes was 200 Å, and their diameter was 1.0 or 0.25 mm. Analysis of the current-voltage characteristics at liquid-helium temperatures showed that the charge transfer is by a tunneling mechanism at the fabricated junctions.[2]

For the measurements we used a pulsed submillimeter $NH_3$ laser, optically pumped by a $CO_2$ laser.[3,4] In the experiments we used both focused radiation and unfocused radiation, with respective intensities $\simeq 400$ and $\simeq 100\ \text{kW/cm}^2$. The radiation ($\lambda = 90.55\ \mu$m, pulse length $\tau_{\text{pulse}} = 40$ ns) was directed onto the sample from the side of the gold electrode in such a manner that the plane of the $n$-GaAs/Au junction was perpendicular to the optical axis of the apparatus. An electrical signal was taken from a load resistor $R_L = 50\ \Omega$; the time resolution of the measurement circuit was better than $7\times10^{-9}$ s.

Figure 1 shows oscilloscope traces of the photoresponse measured at $T = 77$ K at $n$-GaAs/Au junction with $N = 3.7\times10^{18}\ \text{cm}^{-3}$. Also shown here is a curve of the differential resistance $R_d$ of the same junction versus the bias voltage across it, $V$. We

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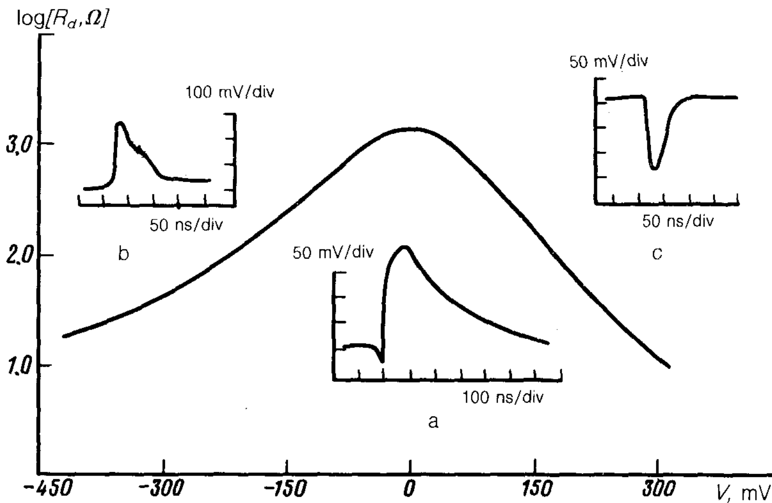


FIG. 1. The differential resistance $R_d = dV/dI$ versus the bias voltage $V$ across the $n$-GaAs/Au tunnel junction [$N = 3.7 \times 10^{18}$ cm$^{-3}$; diameter of 1 mm; capacitance $C(0) = 4300$ pF]. Oscilloscope traces of the response of the junction to focused pulse radiation with $\lambda = 90.55$ $\mu$m $> \lambda_p$ ($T = 77$ K). a—$V = 0$; b—$V < 0$; c—$V > 0$.

see that there are two types of photoresponse: a photo-emf (Fig. 1a, $V = 0$) and a response due to an irradiation-induced change in the resistance of the junction (Fig. 1b, $V < 0$; Fig. 1c, $V > 0$). The latter reproduces the shape of the laser pulse, and its sign does not change when the polarity of the connection of the sample in the circuit is reversed, as we would expect in the case of a photoresistive effect. Furthermore, these results show that the observed response is not due to an ordinary rectification by a nonlinearity of the I–V characteristic of the $n$-GaAs/Au junctions. A similar behavior of the photoresponse was observed for all the other junctions both at $T = 300$ K and at $T = 77$ K.

The alternating-sign nature of the response at $V = 0$ and the significant changes in the shape and amplitude of the signal from pulse to pulse which are observed in this case can be explained as manifestations of a time-varying photo-emf, which results from a redistribution of charge between the metal and the semiconductor. Analysis of this effect shows that the shape and height of the pulse of the time-varying photo-emf should depend strongly on the relations among the $RC$ time of the circuit, the duration of the radiation pulse, and the rise and decay times of this pulse—in accordance with the experimental observations. The negative nature of the first phase photo-emf pulse corresponds to a percolation of electrons from the metal into the semiconductor through the resistance $R_L$.

In no case does the photoresistive response in the photo signal have an alternating-sign component. The sign of the response corresponds to a decrease in the resistance of the tunnel junction, $R_T$, by an amount $\Delta R_T$, caused by the radiation. Figure 2 shows $\Delta R_T/R_T$ versus the bias voltage $V$ according to measurements without a focusing of the radiation. At $V > 0$ the measured values, $\Delta R_T/R_T \simeq 6 \times 10^{-3}$, are seen to

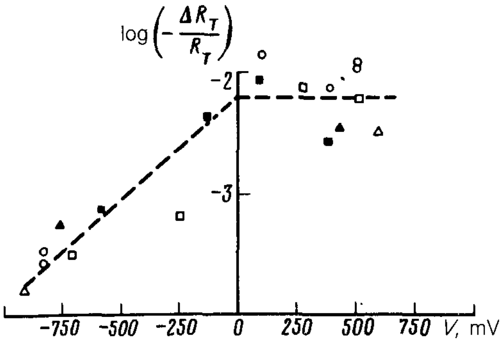


FIG. 2. Relative change in the resistance, $\Delta R_T/R_T$, versus the bias voltage $V$ for unfocused radiation ($\lambda = 90.55\ \mu m$). △, ▲—Junctions with $N = 2\times10^{18}$ cm$^{-3}$; ○, ●, □, ■—$N = 3.7\times10^{18}$ cm$^{-3}$. Open symbols—$T = 77$ K; filled symbols—$T = 300$ K.

depend only weakly on $V$. With increasing magnitude of the negative bias voltage, $\Delta R_T/R_T$ falls off by a factor of about 50 (at $V = -0.9$ V). When the radiation is focused, the response increases to a significantly greater extent than the intensification of the radiation.

Analysis of the response time of the observed photoresponse shows that this time is determined by the time resolution of the measurement circuit, when allowance is made for the $RC$ time of the junction.

To determine how important the presence of the plasma reflection is for the existence of the observed effect, we carried out measurements at $\lambda < \lambda_p$. For this purpose we used the radiation from a $Q$-switched $CO_2$ laser ($\lambda = 10.2\ \mu m < \lambda_p$, $\tau_{pulse} = 500$ ns, intensity of 5 kW/cm$^2$). In this case, in contrast with the effect described above, we observed a slow photoresponse, with a scale time $\simeq 500\ \mu m$ (Fig. 3). There was no fast photoresponse.

The calculations show that in the case of the $CO_2$ laser, the photoresponse is due to a heating of the lattice near the tunnel junction due to the absorption of radiation by

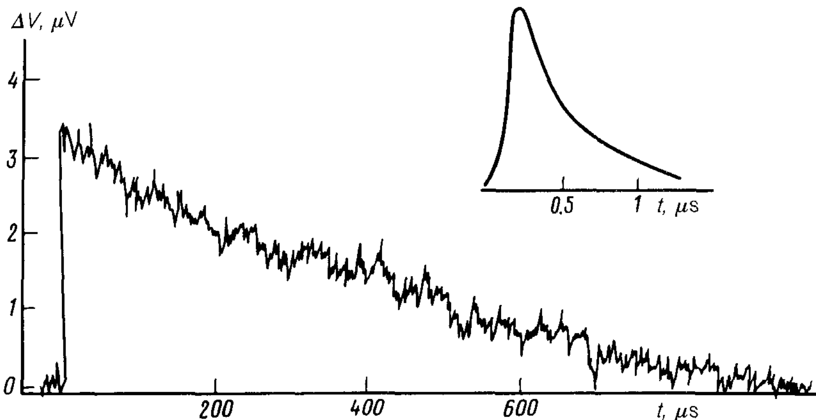


FIG. 3. Response of an $n$-GaAs/Au junction to pulsed radiation from a $CO_2$ laser ($\lambda = 10.2\ \mu m < \lambda_p$); oscilloscope trace of the pulse from the $CO_2$ laser.

free carriers in the GaAs. An estimate of this heating found from a solution of the heat-conduction equation yields a response which is close to that observed. In the experiments with $\lambda = 90.55\ \mu$m, heating effects lead to a signal two or three orders of magnitude smaller than the measured fast photoresponse, because of the slight absorption of the light at the plasma reflection.

It follows from these results that under plasma-reflection conditions a new photoresponse mechanism of tunneled structures with a Schottky barrier operates. This new mechanism involves a redistribution of charge in the depletion layer as a result of the irradiation. A qualitative explanation of the observed effect and, in particular, the decrease in $R_T$ during illumination can be found from the theory of Ref. 1, when the contribution of the rf potential is taken into account more accurately.

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[1]I. N. Kotel'nikov, N. A. Mordovets, and A. Ya. Shul'man, Conference Digest of Ninth International Conference on IR&MM Waves, Takarazuka, Japan, 1984, p. 137.
[2]I. N. Kotel'nikov, I. L. Beĭnikhes, and A. Ya. Shul'man, Fiz. Tverd. Tela (Leningrad) **27**, 401 (1985) [Sov. Phys. Solid State **27**, 246 (1985)].
[3]S. D. Ganichev, S. A. Emel'yanov, and I. D. Yaroshetskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **35**, 297 (1982) [JETP Lett. **35**, 368 (1982)].
[4]S. D. Ganichev, S. A. Emel'yanov, E. L. Ivchenko, E. Yu. Perlin, and I. D. Yaroshetskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **37**, 479 (1983) [JETP Lett. **37**, 568 (1983)].

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