TUNNELING IN SCHOTTKY-BARRIER METAL-SEMICONDUCTOR JUNCTIONS DURING PLASMA REFLECTION OF LASER LIGHT

S.D.Ganichev[+], K.Yu.Gluch[+], I.N.Kotel'nikov[*], N.A.Mordovets[*],
A.Ya.Shul'man[*], and I.D.Yaroshetskii[+]

[*]Institute of Radioengineering and Electronics, USSR Acad. of the Sci.
Moscow, GSP-3, 103907
[+]A.F.Ioffe Physicotechnical Institute, USSR Acad. of the Sci.
Leningrad, 194021
USSR

The change in n-GaAs/Au tunnel junction resistance caused by pulsed laser radiation under plasma reflection conditions was experimentally investigated and theoretically analysed.

1. INTRODUCTION

The Schottky potential barrier at a metal-semiconductor tunnel junction results from the self-consistent distribution of electrons of the semiconductor in the electric field of ionized impurities and of charge in surface states at the semiconductor-metal interface. The tunnel current in such a system can be largely affected by a change in the potential barrier shape [1,2]. When an electromagnetic wave is incident onto the tunnel junction at wavelengths in the plasma reflection region of the semiconductor, an additional force arises and acts on the electron subsystem of the semiconductor as a result of the reflection of the radiation. Thus the Schottky self-consistent potential barrier is distorted, and the junction resistance is changed [3,4] (see Fig.1).

2. SAMPLES AND EXPERIMENTAL TECHNIQUES

The GaAs/Au tunnel junctions obtained under vacuum conditions about 10^{-10}Torr by evaporating the metal onto the cleaned surface of n- and p-type GaAs wafers (free carrier densities $(2\div7)*10^{18}cm^{-3}$) were investigated. Reflectance spectra of n-GaAs wafers showed the sharp plasma minimum at the corresponding wavelengths λ_p, but in p-GaAs spectra the plasma minimum was absent . The thickness of the semitransparent gold electrodes was about 200 Å, and their diameter was 1 or .25 mm. Analysis of the tunnel spectra at liquid helium temperatures showed that the charge transfer from GaAs into Au is by the tunneling mechanism [2].

To realize conditions when the plasma reflection was present or not for the same n-GaAs sample, discrete laser lines in the range of 10÷400 μm were used in the study of the photoresponse. Radiation sources used were CO_2-lasers (Q-switch, duration time $\tau_d \simeq 500$ ns; TEA, $\tau_d \simeq 100$ ns) in the range of 9.2÷10.8 μm and the optically pumped by the TEA CO_2-laser submillimeter NH_3-or D_2O-laser providing lines at wavelengths 90.55 or 385 μm ($\tau_d \simeq 40÷100$ns) [5].

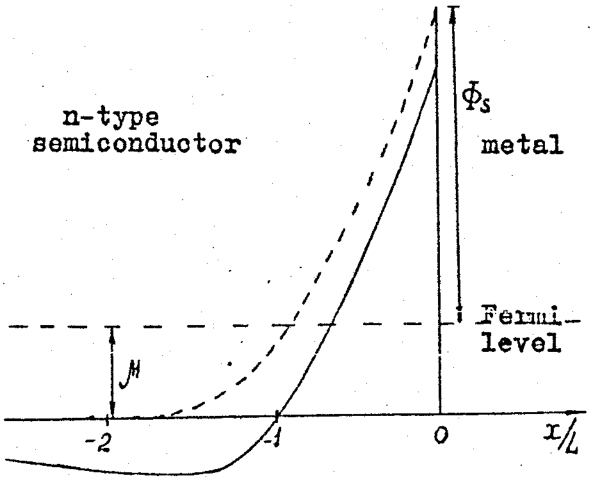

Fig. 1. Draft of the scalar potential in the Schottky depletion layer with (solid) and without (dashed) radiation.

Both the photo-emf and the photoresistivity effect of GaAs/Au tunnel structures were studied at T=300 and 78 K. The radiation was normally directed onto the sample surface from the side of the semitransparent gold electrode. The sample was set into the photoconductivity measuring circuit. In this case the change $\Delta\sigma$ in the junction conductivity $\sigma = I/V$ during the laser pulse has led to the change ΔV_L in the voltage V_L applied to the load resistance R_L. For small signal, the ΔV_L is related with $\Delta\sigma/\sigma$ under short-circuit conditions by the formula

$$\Delta\sigma/\sigma = (\Delta V_L/V_L)*(1 + R_L/R_d) , \qquad (1)$$

where R_d is the differential resistance of the junction.

The shape and the intensity of the laser pulse were always monitored by means of the fast photon drag detector [6].

3. EXPERIMENTAL RESULTS AND COMPARISONS WITH THE THEORY

At wavelengths λ = 90.55 and 385 μm ($\lambda > \lambda_p$) two types of photoresponse have been found in n-GaAs/Au junctions: the fast photoresistive response due to an irradiation-induced change in the resistance of the junction and the photo-emf. The former reproduces the shape of the laser pulse, and the latter, on the contrary, does not. The sign of the photoresistive response corresponds to a decrease in the junction resistance, and the magnitudes of the response are roughly equal at both the wavelengths. In

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the absence of the plasma reflection conditions only a slow (30÷300μs) photothermal response was observed both in p-GaAs junctions at all wavelengths used and in n-GaAs in the 10-μm range.

The dependence of $(\Delta\sigma/\sigma)/J$ on the bias voltage V is shown with circles in Fig.2 (T=300 K, λ=90.55 μm, $J \simeq (30 \div 50)$ kW/cm^2) for the one of n-GaAs/Au tunnel junctions. Here J is the power density of the incident radiation in kW/cm^2 and the $V>0$ corresponds to the electron tunneling from GaAs to Au. The dependence showed in Fig.2 keeps its form within the experimental errors at others T and $\lambda > \lambda_p$ (i.e. T=78 K or λ=385 μm). This dependence is almost uneffected by free carrier concentrations, too.

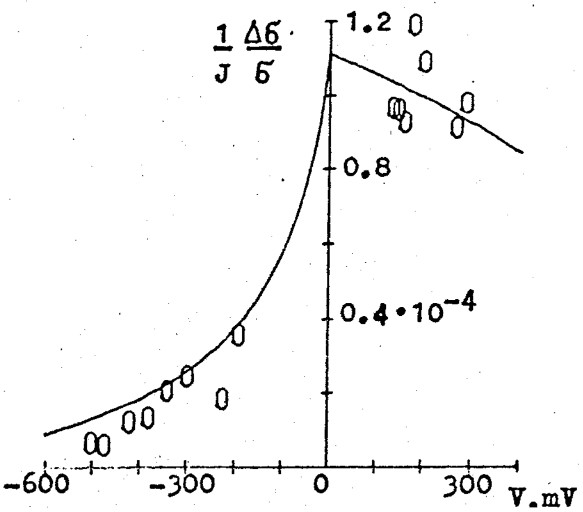

Fig. 2

To estimate theoretically the Schottky barrier distortion due to the appearance of the ponderomotive forces, acting on the free carrier plasma of semiconductor from the electromagnetic field of the radiation, we have solved the kinetic equation for electrons and Maxwell equations for scalar and vector potentials. The expression thus obtained for the change $\Delta D(E,V)$ in the barrier tunnel transparency $D(E,V)$ at the electron energy $E \geq \mu$ and at the applied bias V has the form

$$\frac{\Delta D}{D} \propto k_F L \frac{|\mathbf{E}|^2/4\pi}{N\Phi_s} \varphi(E,V) , \qquad (2)$$

where

$$\varphi(E,V) = \ln \frac{\sqrt{\Phi_b - E} + \sqrt{\Phi_b - (2/5)\mu}}{\sqrt{E - (2/5)\mu}} - \sqrt{\frac{\Phi_b - E}{\Phi_b - (2/5)\mu}} . \qquad (3)$$

Here k_F is Fermi wavevector of the electrons, $L = \sqrt{\varkappa\Phi_s/(2\pi Ne^2)}$ is parabolic barrier length, $\Phi_b = \Phi_s + \mu - eV$, Φ_s is the barrier height measured from Fermi level of the metal (see Fig.1), $|\mathbf{E}|^2/4\pi$ is the energy density of the incident electromagnetic wave.

The Equ.(2) shows the increase in barrier transparency caused by the radiation, the independence of the response on the radiation frequency, and weak dependence of the response on the bulk free carrier density N ($\propto 1/N^{7/6}$). To estimate theoretically the dependence of the response $\Delta\sigma/\sigma$ on the bias V we assumed $(\Delta\sigma/\sigma) \propto (\Delta D/D)$ and calculated Equ.(3) at the energy $E=\mu$ in the case of the positive bias $V>0$ or at $E=\mu-eV$ for the negative bias $V<0$, i.e. at the Fermi level of the semiconductor or the metal, respectively. The result is drawn in Fig.2 with solid line and shows an acceptable coincidence with the experimental points.

The alternating-sign nature of the response at $V=0$ and significant changes in the shape and the amplitude of the signal from pulse to pulse which are observed in this case are explained on the basis of a phenomenological approach as manifestation of a time-dependent photo-emf, resulting from a redistribution of the charge between the metal and the semiconductor due to changing the capacitance of the depletion layer. Analysis of this effect shows that the shape and the height of the pulse of the time-dependent photo-emf should depend strongly on the relations among the RC time of the circuit, the duration of the radiation pulse, the small departures of the bias from zero, and the rise and decay times of this pulse - in accordance with the experimental observations.

Thus,Equs. (2)-(3) describe all the qualitative features of the observed effect. In particular, the tunnel transparency increase is explained by the decrease in the depletion layer thickness due to the negative charge transfer from surface states into the quasineutral region of the semiconductor, and the same phenomenon is the cause of the change in the capacitance.

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