Non-Thermal Effect of FIR Radiation on Tunnel Conductance of Schottky-Barrier Junctions with Three- and Two-Dimensional Electron Gas

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Abstract

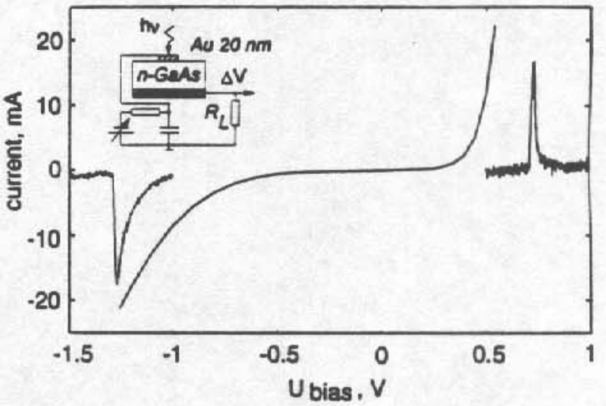
A fast change in the conductivity of tunnel Schottky-arrier n-GaAs/metal junctions due to far-infrared laser radiation has been detected. The observed photoresponse is hown to be due to ponderomotive forces of the electromagnetic field. These forces arise at plasma reflection of the radiation from 3D free carriers of the semiconductor and in case of 2D carriers in δ-doped GaAs due to the effect of the near field at the electrode edges.

3D-electron gas structures

The well-known application of the Schottky-barrier diodes as detectors of electromagnetic radiation of millimeter range is based on the use of nonlinearity of the static current-voltage characteristic and antenna coupling of the diode to the radiation. The transition to the submillimeter region or to even shorter wavelengths is accompanied by the reduction of the diameter of a metal electrode down to submicron sizes and by the complication of design of antenna structures. Here we show that in tunnel Schottky diodes yield a submillimeter response due to ponderomotive forces without need of antenna coupling.

As the doping level of the semiconductor increases, a transition to the tunneling transfer of charges through the Schottky-barrier occurs. The tunnel current depends not only on the height and the width of the barrier but it depends also significantly on the profile of the self-consistent spatial distribution of the free electrons in the semiconductor [3,4]. Under conditions of plasma reflection of radiation from the free electrons the radiation pressure can move the equilibrium position of the border of the depletion layer and change the width of the Schottky barrier, and, hence, the resistance of the tunnel junction [5]. A fast photoresponse due to this effect was found in n-GaAs/Au junctions. It has been shown that the response is not caused by electron heating due to free carrier absorption, but it is stipulated by a change in the tunnel junction resistance produced by deformation of the Schottky barrier [6].

In Fig. 1 the current-voltage characteristic of a tunnel junction n-GaAs/Au at T=300 K with the electron density of the order $2.5 \cdot 10^{18}$ cm^{-3} is shown as well as an example of the response to the radiation of pulsed FIR laser (λ =90 μm) at positive and negative bias voltages. In the inset a tunnel structure and the scheme of the measurement circuit is displayed. It is seen, that the current through the junction increases during a radiation pulse that corresponding to a drop of the tunnel resistance.



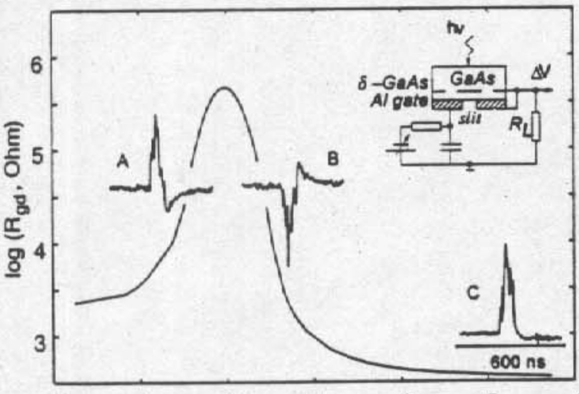
This sign of the photoresistive effect seems to contradict the assumption that the radiation pressures shifts the border of the free carrier plasma from the surface into the bulk of the semiconductor, increasing thickness of the Schottky barrier and, hence, the resistance of the tunnel junction. However, a detailed calculation taking into account the ponderomotive force through Maxwell stress tensor has shown, that a decrease of the resistance has just to occur due to the change of the electron density profile [6,7].

2D-electron gas structures.

A two-dimensional electron gas (2DEG) in the potential well of a δ-doped semiconductor represents a similar system with a self-consistent potential. The properties of this system depend on the redistribution of free carriers in the direction perpendicular to the plane of the δ-layer. In this case the condition of plasma reflection is not fulfilled because of the small thickness of the electron plasma in the δ-layer.

The investigated samples consist of MBE grown GaAs with one δ-layer, 5 mm long and 1 mm wide, at a distance of 20 nm from the semiconductor surface. The donor atoms are Si with a density of $6 \cdot 10^{12}$ cm^{-2}. The 2DEG density is $3 \cdot 10^{12}$ cm^{-2} due to the spatial redistribution of carriers between the surface states and the δ-layer. The samples used were coated with an split aluminium gate of 200 nm thickness, the width of the slit was 20 μm (see inset in Fig. 2). The current through the Schottky barrier between the gate and the channel (δ-layer) is carried by tunneling electrons.

In Fig. 2 the dependence of the tunnel resistance R_{gd} of a structure on the voltage bias U_{gd}, measured at 77 K according to the circuit shown in the inset, is plotted. Two distinct regions may be recognized: a sharp and a slow change of R_{gd} with bias voltage. The first region, where R_{gd} drops exponentially, corresponds to the case when the tunnel resistance exceeds resistance of the channel. In the second region the complete resistance of the structure is determined by the voltage drop along the channel. In this case the resistance depends on the bias voltage only because of the change of density of 2DEG in a channel. It explains observed asymmetry of the R_{gd}-U_{gd} curve at large values of positive and negative biases, where accumulation and depletion of electrons in the channel occurs for $U_{gd} > 0$ and for $U_{gd} < 0$, respectively.



In addition, Fig. 2 shows three signal pulses (A, B, C) obtained at λ = 250 μm (duration of the laser pulse: 100 ns, the same results were obtained for λ = 90.55 μm). The position of the pulses on the voltage scale corresponds to the applied bias voltage.

In the region of the bias, where R_{gd} is determined by the tunneling process, the sign of the response indicates an increase of the resistance due to irradiation. In the region where the channel conductance determines R_{gd}, the sign of the response is opposite, i.e. the resistance of the structures decrease (Fig. 2, C). This can be explained by heating of the 2D electrons and the generation of non-equilibrium longitudinal optical phonons [9]. However in the region, where the tunnel resistance of the Schottky barrier prevails, the observed response cannot be explained by electron heating because the tunnel resistance decreases with rising temperature whereas it increases by irradiation.

Thus the sign of photoresistive effect in 2DEG structures is opposite to that in 3D Schottky-barrier structures (cf. Fig. 1 and 2). The reason for this difference can be the distinction of the two structures from an electrodynamics point of view. The semitransparent gold electrode of 3D structures transmits the radiation (power transmission about 50%) with tangential polarization of the electric field. The conductance of the Schottky-junction is affected by reconstruction of the potential barrier profile due to plasma reflection. In the case of 2D electron gas structures the aluminium gate is opaque. Thus, boundary conditions require the tangential component of an electrical field on a surface of gate to vanish. The response of the 2D structures did practically not change when the sample was irradiated from the semiconductor side (opposite as shown in Fig. 2). Therefore the response must be caused by the near-zone field generated by diffraction of incident radiation at edges of the metal gate and, especially, in the region of the slit of the electrode. In the given geometry of the 2D structures the electrical field of the near zone in the area under the gate, where the tunnel current flows, has almost only a component normal to the surface and, hence, normal to δ-layer while in 3D structure the tunnel current is affected by tangential electrical field.

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