A new fast point detector of FIR laser radiation

S.D. Ganichev*, K.Yu. Glooch, I.N. Kotel'nikov#,
N.A. Mordovets#, A.Ya. Shul'man#, and I.D. Yaroshetskii

A.F. Ioffe Physicotechnical Institute, Russian Acad.of the Sci., St. Petersburg, 194021, Russia
#Institute of Radioengeneering and Electronics, Russian Acad.of the Sci.,
Moscow, GSP-3, 103907, Russia
*Alexander von Humboldt Fellow,
Actual address: Uni.Regensburg, Institute für Angewandte Physik III, 8400 Regensburg.

ABSTRACT

A point fast room temperature detector for FIR laser radiation is proposed. Its operation is based on a new physical effect which consists of the stimulation of tunnelling during the plasma reflection of laser light in a Schottky-barrier tunnel junction.

2. GENERAL CONSIDERATION

Optically pumped FIR pulsed gas lasers are widely applied at present time[1]. One of the problems arising in developments and applications of such lasers is the investigation of laser beam space-time structure where cross-sections and time durations are of the order of a few millimeters and nanoseconds, respectively. What is reguired are single or matrix fast photodetectors of FIR radiation with high space resolution. Fast photodetectors which are based on the hot-carrier μ-photoconductivity[2], the photon-drag effect[3,4] and pyroelectricity are difficult to use for measurements of the space distribution of pulse radiation intensity in the narrow laser beams because of the large sizes of the sensitive area (typical diameters are a few millimeters or more). A new point fast room temperature photodetector of FIR laser radiation will be now described. The operation of this detector is based on the change in the resistance of the Schottky-barrier metal-semiconductor tunnel junction during the plasma reflection of the laser radiation at free carriers in the semiconductor[5-7].

A metal-semiconductor tunnel junction with a Schottky potential barrier is a structure in which the shape of potential barrier and therefore the tunnelling current depends significantly on the profile of the self-consistent distribution of electrons in the semiconductor. Under ordinary conditions this distribution is established by the electric fields generated by charged impurities and surface states at the semiconductor-metal interface. The equilibrium position of the boundary of the electron gas corresponds to the balance of forces acting on each element of volume of the electron plasma due to the presence in the plasma of a gradient of the electron pressure and of the electric field. A disruption of this balance by any external perturbation leads to a displacement of plasma boundary and changes of potential barrier shape[8,9]. Such external perturbation can be the radiation pressure force arising in the case of plasma reflection of light from the electrons in the semiconductor. When an electromagnetic wave is incident onto the tunnel junction at wavelengths

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

in the plasma reflection region of the semiconductor, an additional ponderomotive 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. The schematic diagram of schalar potential in the depletion layer of tunnel junction with a Schottky barrier is shown at Fig.1. The solid line corresponds to the case of the absent of radiation; x_0 is the distance from the boundary of the plasma to the surface of semiconductor. The dashed line corresponds to the case when plasma reflection of the radiation occurs; x_0^* is the new position of the boundary.

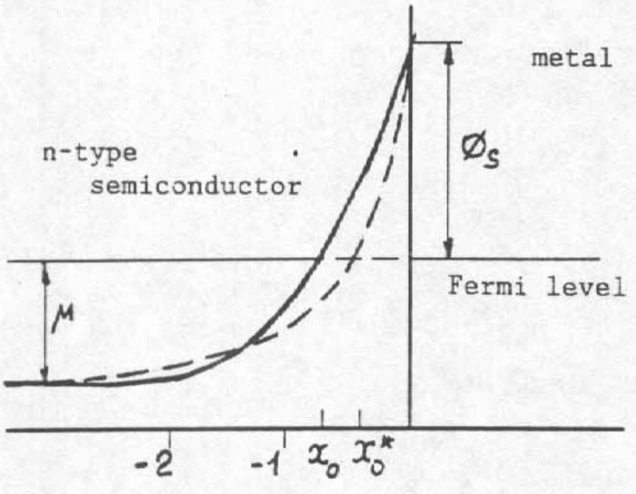

Fig.1

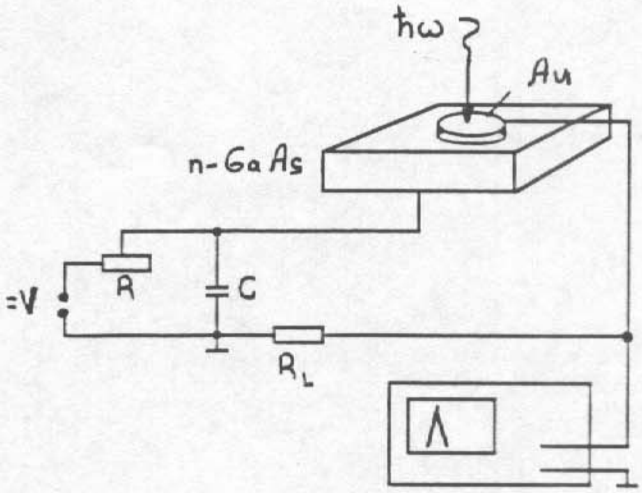

Fig.2

In the considered case the physical limitations on the response rise time result from the speed of the non-equilibrium charge redistribution among the metal electrode and the semiconductor depletion layer. This is determined by the parameter *RC*, where *R* is the resistance and *C* is the capacity of the junction. For *n-GaAs/Au* junction a response time of order 10^{-9} - 10^{-11} s can be attained with the junction diameter and doping reasonable selected. Such an operating speed, the sizeable magnitude of the response[6,7], and also the possibilities of modern technology in making the junctions with small diameter (up to a few microns) and a matrix of the junctions raise our interest in the analysis of the Schottky-barrier tunnel junction as photodetector in the FIR range.

3. SAMPLES, EXPERIMENTAL TECHNIQUES AND RESULTS

The detectors element that were investigated were made of the *n-GaAs/Au* tunnel junctions obtained under ultra-high vacuum conditions by evaporating the metal onto the cleaned surface of n-type *GaAs* wafers (free carrier densities N between $(2\text{-}7)\cdot 10^{18}$ cm^{-3}, with corresponding plasma reflection minimum wavelengths λ_p between 20 μm and 11 μm). The thickness of the semitransparent gold electrodes was about 200 A, and their diameter was 1 mm (Fig.2). The transparency of the gold electrode has been checked by phototermal spectroscopy. 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= 90.5 μm or 385 μm with pulse duration ~40 ns.

A *n-GaAs/Au* junctions were inserted in the usual photoconductivity arrangement (Fig.2). Under the plasma reflection conditions, $\lambda>\lambda_p$, a fast response of the photoresistive type is found that reproduces the shape of the FIR laser pulse. The sign of the photoresistive response corresponds to a decrease in the tunnel junction resistance, i.e. stimulation of the tunnel current takes place.

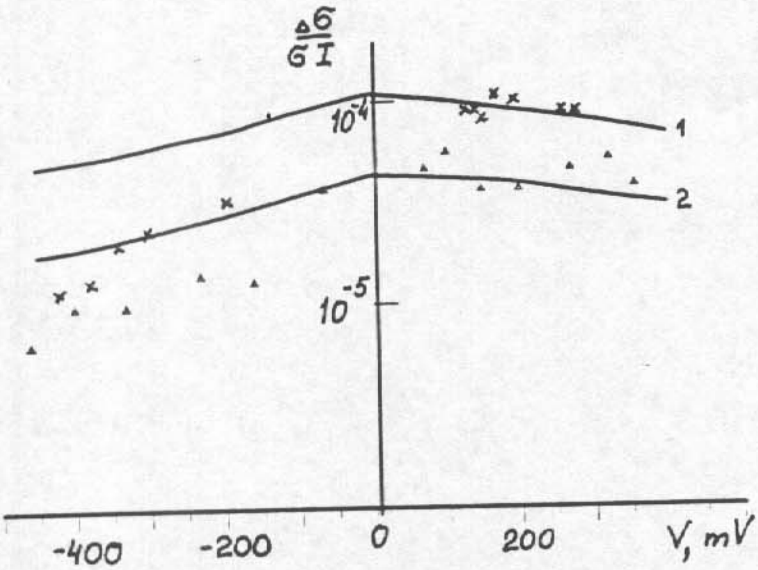

Fig. 3

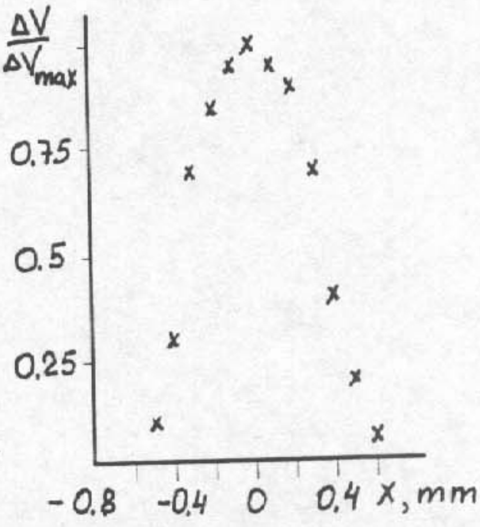

Fig. 4

In Fig.3 the relative change in the junction conductance $\Delta\sigma/\sigma$ normalised to the radiation intensity I in kW/cm^2 is shown as a function of the bias voltage. This dependence has been obtained on *n-GaAs/Au* junctions at T=300K with: x-N=$2\cdot10^{18}$ cm $^{-3}$, Δ-N= $3.7\cdot10^{18}$ cm $^{-3}$ with the excitation by light of λ= 90.5 μm. Solid lines are calculation of $\Delta\sigma/(\sigma I)$ as a function of bias voltage (1-N=$2\cdot10^{18}$ cm $^{-3}$, 2-N= $3.7\cdot10^{18}$ cm $^{-3}$) for the model described above. The same values of photoresponce have been obtained at λ= 385μm, which shows, in accordance with theoretical consideration, the absence of a photoresponce frequency dependence.

The described photosensitive element had been used in a design of photodetector consisting of a tunnel *n-GaAs/Au* junction at T=300K with N=$2\cdot10^{18}$ cm $^{-3}$ included in a photoconductivity circuit (a load resistance R_l =50 Ω and bias voltage ≈ 0.5 V) and a high frequency amplifier with bandwidth 250 MHz and voltage gain coefficient 200. It is shown that the detector sensitivity is roughly independent on the radiation wavelength in the range $\lambda > \lambda_p$ ~ 20μm and is about 30mV/kW.

The dependence of the response on the radiation intensity I was studied in the region from 10 to $2\cdot10^3$ kW/cm^2 , and a weak nonlinearity behaving as $I^{1.5}$ was observed.

To investigate the coordinate sensitivity of the detector, a scan of the focused laser beam was carried out across the gold electrode. The diameter of the focal spot was about 0.7 mm. The result is shown in Fig.4. It is seen that the response drops quickly as the irradiated domain leaves the range of the gold electrode. This measurements are too imprecise, to provide the limit of spatial resolution as the detector is scanned across the laser beam. However, it seems to us that the obtained results are already interesting from a practical point of view.

4. ACKNOWLEDGEMENTS

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

5. REFERENCES.

1. Th. de Temple: in "Infrared and millimeter waves," ed. by K.J.Button. N-Y., 1979, v.1, Ch.3, pp. 129-185 .

2. S.D.Ganichev, E.V.Beregulin, I.D.Yaroshetskii, "Room temperature high sensetive fast detector of FIR radiation" Int. Symposium on Physical Concepts and Materials for Novel Optoelectroni Device Applications II, 1985-61, Trieste, Italy, 1993

3. S.M.Ryvkin and I.D.Yaroshetskii: in "Problems in modern physics "(in Russian)- Leningrad, 1980,pp.173-185.

4. A.F.Gibson and M.F.Kimitt: in "Infrared and millimeter waves", ed. by K.J. Button, N-Y., 1980, v.3, Ch.4, pp. 182-220

5. I.N.Kotel`nikov, N.A.Mordovets, and A.Ya.Shul`man. Conf. Digest IX Int. Conf. on IR & MM Waves, Takarazuka, Japan, 1984, p.137.

6. S.D.Ganichev, I.N.Kotel'nikov, N.A.Mordovets, A.Ya.Shul'man, and I.D.Yaroshetskii. "Photoresestive effect in n-GaAs/Au tunnel junctions during plasma reflection of laser light" JETP Lett, 1986, 44, 5, p.301-304

7. S.D.Ganichev, K.Yu.Glookh, I.N.Kotel'nikov. N.A.Mordovets, A.Ya.Shu'lman, and I.D.Yaroshetskii. "Tunneling, accompaning plasma reflection of radiation, in metall-semiconductor junctions with a self-consistent Schottky barrier." Sov. Phys. JETP, 1992, 75, 3, 495-504.

8. A.Ya.Shui'man and V.V.Zaitsev. Solid State Commun. 1976, 18, p.1623

9. I.N.Kotel'nikov, I.L.Beinikhes, and A.Ya.Shul'man. Fiz. Tverd. Tela, Leningrad, 1985, 27, p.401.

PROCEEDINGS
EUROPTO
SERIES

International Symposium

Physical Concepts and Materials for Novel Optoelectronic Device Applications II

Fabio Beltram
Erich Gornik
Chairs/Editors

24–27 May 1993
Trieste, Italy

Sponsored by
European Optical Society (EOS)
International Centre for Science and High Technology (UNIDO)
SPIE—The International Society for Optical Engineering

SPIE
P
PROCEEDINGS SERIES

Volume 1985