DEPENDENCE OF TWO-PHOTON ABSORPTION IN GaAs ON THE LIGHT-PULSE DURATION

A. Z. Grasyuk, I. G. Zubarev, V. V. Lobko, Yu. A. Matveets, A. B. Mirnov, and O. B. Shatberashvili
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 17 April 1973
ZhETF Pis. Red. 17, No. 10, 584 - 587 (20 May 1973)

Studies of the interaction of nanosecond pulses from a neodymium laser with GaAs [1, 2] have revealed the presence of two-photon absorption, which was measured in the intensity range 1 - 20 MW/cm^2. On the other hand, we have noted in [3, 4] that when GaAs is exposed to ultrashort pulses (USP) of a neodymium laser of intensity from 50 MW/cm^2 to 200 GW/cm^2 there is practically no two-photon absorption. However, the experiments performed to date with nanosecond and picosecond pulses were made in essentially di f ferent intensity ranges, so that the role of the pulse duration in the aforementioned difference could not be determined.

We report here the results of experiments in which absorption by GaAs of single UPS of 2.5×10^{-11} sec duration and of giant pulses of 4×10^{-8} duration was measured in the same intensity range, so that we were able to establish the connection between two-photon absorption and the duration of the action of the light on the semiconductor GaAs.

The experimental setup is shown in Fig. 1. An n-GaAs sample 2 mm thick, with carrier density 3.3×10^{17} cm^{-3} and mobility 1.4×10^3 cm^2/V-sec was placed in a cryostat and cooled to 77°K. The incident, reflected, and transmitted energy was measured with high-sensitivity calorimeters.

According to measurements made with an electron-optical converter with a resolution time 1 psec [5], the average pulse duration of this laser was τ = 25 psec in that part of the train from which the single pulse was separated. This value was used in the determination of the USP intensity.

We investigated the dependence of the sample transmission $T = W_{tr}/W_{inc}$ on the intensity of the incident pulse I_{inc}. Here W_{tr} and W_{inc} are the energies transmitted through the semiconductor and incident on its surface. We measured simultaneously the reflected energy. The reflection coefficient R = 0.28 differed little from the value calculated for GaAs from the Fresnel formulas. The values of T were compared for USP with the values for the giant pulse (τ = 40 nsec) and also with the transmission by the sample of weakened radiation from the laser in the free running mode ($I_{inc} \approx 10$ W/cm^2), for which the two-photon absorption is negligible.

To increase the accuracy of the determination of the slope of the plot of T against I_{inc}, we measured simultaneously the transmission for two USP with an accurately known intensity ratio, equal to 2.5 (Fig. 2). It is seen from the figure that in the range 1.5 - 7 MW/cm^2

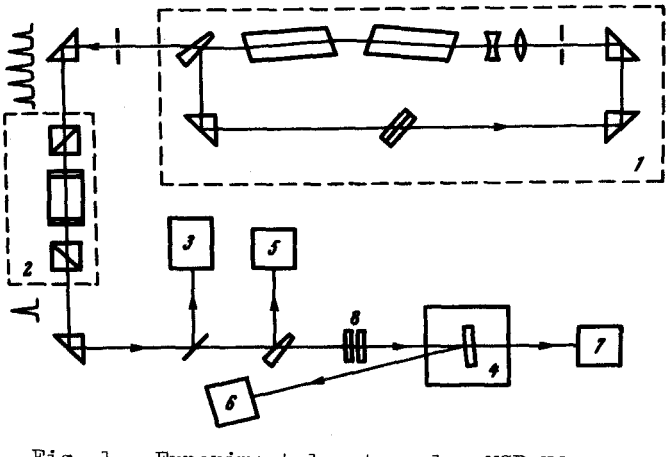


Fig. 1. Experimental setup: 1 - USP Nd-glass ring laser, 2 - electrooptical shutter for separation of a single USP, 3 - coaxial photocell FK-4, 4 - cryostat with GaAs sample, 5, 6, 7 - calorimeters, 8 - light filters.

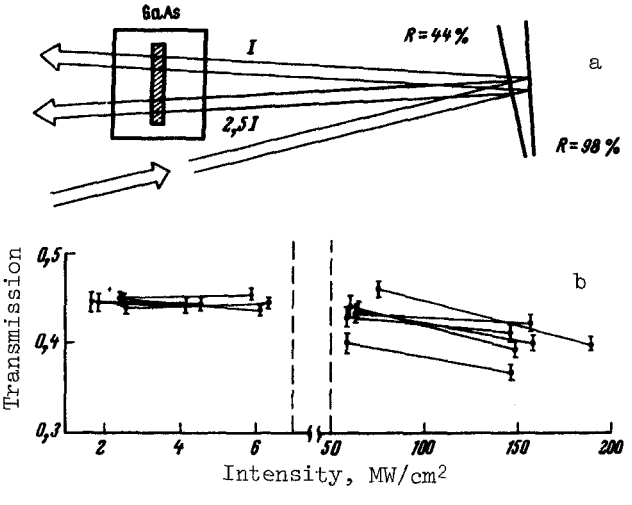


Fig. 2. a) Scheme for obtaining a pair of USP with a mirror wedge, b) transmission ratio for USP pairs (the lines join experimental points obtained with one laser flash.

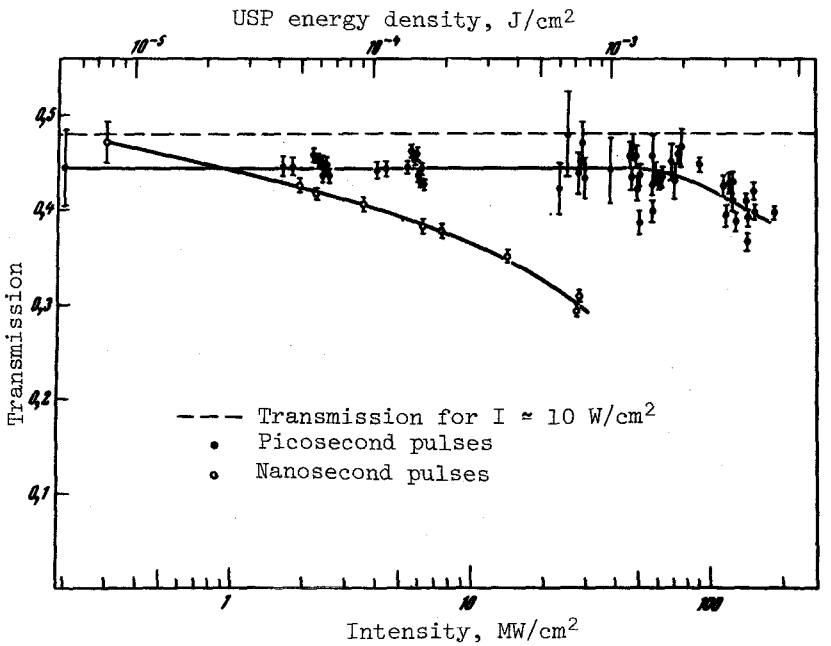


Fig. 3. Transmission of GaAs sample vs intensity of light pulses of various durations.

the transmission remains unchanged, and in the range 50 - 200 MW/cm^2 it decreases with increasing USP intensity.

As follows from the experimental curves shown in Fig. 3, the value of T for the USP does not change in the region from 0.2 to 50 MW/cm^2 and is equal to 0.45, and in tnis entire region it is lower than the transmission for weak radiation. When the intensity increases from 50 to 200 MW/cm^2, the value of T decreases from 0.45 to 0.40.

The transmission for the nanosecond pulse was measured at emission spectrum widths 30 and 0.03 cm^{-1}, both yielding the same dependence on I_{inc}, as shown in Fig. 3. In the intensity region 0.5 - 5 MW/cm^2, this dependence corresponds to the usual law of two-photon absorption [2] with a coefficient $\beta = 0.30 \pm 0.05$ cm/MW. When I_{inc} is further increased from 5 to 30 MW/cm^2, the transmission decreases more slowly than called for by the two-photon absorption law.

Thus, in the investigated region, the dependence of the absorption on the intensity is significantly different for picosecond and nanosecond pulses. Consequently the mechanism whereby the light pulses interact with GaAs depends essentially on their duration.

If the pulse duration is shorter than the coherence relaxation time, i.e., $\tau < T_2$, the decrease of the absorption for the USP can be accounted for qualitatively by coherent saturation of the two-photon transition in the semiconductor. No oscillations of the transmission should then be observed at low or at high intensities. At intermediate intensities, on the other hand, such oscillations are possible, although they are not as clearly pronounced as in the case of ordinary self-transparency. However, the presently available data on the value of T_2 for GaAs and on the effective mass of the electron far from the edge of the conduction band are still insufficient for a quantitative comparison of the theory [6] with the experimental results.

We note in conclusion that the observed dependence makes it possible to select light pulses of required duration.

The authors thank P. G. Kryukov for the opportunity of using the laser setup, I. A. Poluektov for a discussion of the reuslts, A. V. Dudenkova for measuring the sample parameters, and S. I. Mikhailov for help with the experiments.

[1] N. G. Basov, A. Z. Grasyuk, I. G. Zubarev, V. A. Katulin, and O. N. Krokhin, Zh. Eksp. Teor. Fiz. 50, 551 (1966) [Sov. Phys.-JETP 23, 366 (1966)].
[2] V. V. Arsen'ev, V. S. Dneprovskii, D. N. Klyshko, and A. N. Penin, ibid. 56, 760 (1969) [29, 413 (1969)].

[3] T. L. Gvardzhaladze, A. Z. Grasyuk, I. G. Zubarev, P. G. Kryukov, and O. B. Shatberashvili, ZhETF Pis. Red. 13, 159 (1971) [JETP Lett. 13, 111 (1971)].
[4] T. L. Gvardzhaladze, A. Z. Grasyuk, and V. A. Kovalenko, FIAN Preprint No. 86, 1972.
[5] N. G. Basov, M. M. Butslov, P. G. Kryukov, Yu. A. Matveets, E. A. Smirnova, S. L. Fanchenko, S. V. Chekalin, and R. V. Chikin, FIAN Preprint No. 82, 1972.
[6] I. A. Poluektov, Yu. M. Popov, and V. S. Roitberg, Kvantovaya elektronika No. 4, 111 (1972) [Sov. J. Quant. Electr. 2, 385 (1973)].

ABSORPTION OF INFRARED LIGHT ON THE SURFACE OF A SILICON CARBIDE SINGLE CRYSTAL

Yu. A. Pasechnik, O. V. Snitko, O. M. Getsko, and V. F. Romanenko
Institute of SEmiconductors, Ukrainian Academy of Sciences
Submitted 26 February 1973; resubmitted 12 April 1973.
ZhETF Pis. Red. 17, No. 10, 587 - 590 (20 May 1973)

It is known that ionic crystals of finite dimensions have surface mode of optical oscillations [1 - 3].

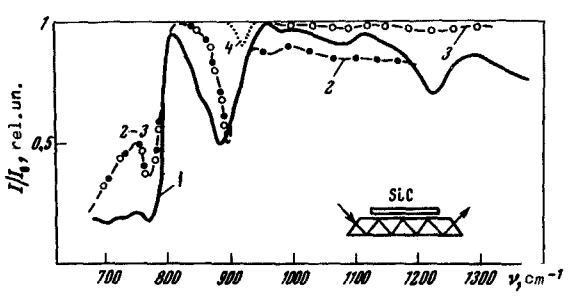
If the crystal dimensions exceed the IR wavelength of that region of the spectrum, then radiative modes of the phonon frequencies of the microcrystals appear in the absorption. These phonons were observed in [4] on β-SiC whisker microcrystals. Thin plates and semi-infinite crystals are characterized by surface nonradiative modes, which do not appear in ordinary absorption and reflection spectra.

Nonradiative surface polaritons in optical spectra were first investigated in NaCl [5] and GaP [6] using a total-internal-reflection method.

In the present study we investigated the absorption of IR light on SiC surfaces by the method of multiple internal reflection (MIR) method. Silicon carbide crystals have a covalent bond between atoms, the fraction of the ionic bond in them is 12%, but the optical volume phonons appear sufficiently clearly in the reflection spectra [7].

The MIR spectra were measured in p-polarized light with an IKS-12 spectrometer with IMEIK-1 attachment in the wave-number range 700 - 1300 cm^{-1}. The presence of a trapezoidal MIR element of gallium arsenide on the surface of the silicon-carbide sample (see the figure) makes the nonradiative surface modes optically active. The influence of interference effects was eliminated in the experiment.

In the investigated frequency region, the IR light causes optical oscillations of the SiC lattice, and also oscillations of the Si-O bonds in the silicon carbide itself and in the oxide film on its surface. We investigated the natural growth surfaces of the crystals β-SiC and α-SiC(6H), and also the surfaces obtained after etching the crystals in HF acid, which removed the oxide from the silicon carbide surface. The figure shows the multiple-reflection spectra for the cubic (curve 1) and hexagonal (curve 2) modifications of silicon carbide.



Spectra of multiple internal reflection of natural silicon-carbide surface: curves 1 and 2 - β-SiC and α-SiC(6H) before etching in HF, 3 - α-SiC(6H) after etching, 4 - β-SiC after etching and d_3 = 2 - 4 μ. T = 300°K, I/I_0 is the ratio of the intensities of the IR light passing through the MIR element with the sample (I) and without it (I_0).

IR absorption appears at frequencies close to 795, 900, 1060 - 1080, and 1150 - 1300 cm^{-1}. The spectrum region near 795 cm^{-1} has been well investigated for its absorption and reflection spectra [7] and characterizes the frequency of the transverse optical phonon. The absorption spectra at 1060 - 1080 and 1150 - 1300 cm^{-1} are typical of fused quartz and are apparently due to light absorption by the amorphous SiO_2 film, the thickness of which is estimated at 60 - 80 Å. Indeed, treatment of the SiC samples with HF decreases the absorption in these bands (curve 3). The removal of the amorphous oxide film ($d_f \leq 5$ Å) is evidenced by electron-diffraction data obtained with glancing incidence of the electron beam.

Particularly intense in the MIR spectrum is the 840 - 950 cm^{-1} absorption band, observed only