FIR multiphoton absorption and photon drag effects in degenerate valence band semiconductors

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ABSTRACT

Intraband linear-circular multiphoton dichroism of far infrared absorption in p-Ge has been observed for the first time. Previously this nonlinear optical phenomenon was observed only under the valence-conduction interband electronic transitions induced by IR or visible-range radiation. Experimentally, the dependencies of the optical transmission and the photon drag effect on the FIR radiation (λ = 90 μm) intensity and polarisation have been investigated in p-type Ge crystals. A polarisation dependent sign inversion of the photon drag effect with increasing radiation intensity has been also observed.

2. INTRODUCTION

Experimental investigations of n-photon absorption in crystals are usually made under the conditions that optical transitions with fewer photons are forbidden. Then, many photon transitions of higher order can be ignored in the visible to middle infrared range, as the value of n-photon absorption coefficient $K^{(n)}$ is much higher than the coefficient of (n+1)-photon absorption, $K^{(n+1)}$. This holds up to the light intensities corresponding to the damage threshold of the investigated materials. For the same reason, the main contribution in the case of intraband absorption of light comes from one-photon processes, and many-photon transitions with intermediate virtual states make a negligible contribution.

The appearance of lasers capable of generating high power FIR radiation has revealed new aspects of the interaction of the electromagnetic radiation with solids. In fact, if the calculation of the n-photon absorption coefficient $K^{(n)}$ is limited to the lowest order of perturbation theory for each of these processes, it is found that the ratio $\eta_n=K^{(n)}/K^{(n+1)}$ is proportional to $I\omega^{-3}$ in the case of intraband absorption of light, where I is the intensity of light in a crystal. Thus in the case of FIR radiation of wavelength $\lambda \approx 100$ μ and relatively small intensity I, of the order of 1 MW/cm^2, the parameter η_n is comparable with unity for the first few values of n. A new type of nonlinear absorption of light due to a set of simultaneous n-photon transitions with comparable contributions to the total absorption coefficient has been observed recently for p-type Ge crystals excited by high-power pulses from an optically pumped NH_3 laser (λ = 90.55 μm, $\hbar\omega$ = 13.7 meV)[1].

In the present work the influence of FIR radiation polarisation state on the intraband (heavy to light holes subbands) multiphoton absorption in p-Ge has been observed and investigated by photon drag effect behaviour.

3. SAMPLES, EXPERIMENTAL TECHNIQUES AND RESULTS

Investigations were carried out on n- and p-type Ge samples with densities 10^{12}-10^{16} cm^{-3} at T = 300 K. The radiation source used was FIR NH_3 laser optically pumped by a TEA CO_2 laser operated at the wavelength λ = 90.5 μm with pulse durations ~ 40 ns. The longitudinal photon drag e.m.f. was investigated. The experimental set up and the typical oscilograms are shown on Fig.1 (a: the excitation pulse , b: p-Ge photoresponse).

It has been shown that the photon-drag current J in p-Ge at T = 300 K changes its polarity with increasing intensity of the incident light I (Fig.1b, 2) due to the opposite directions of the one- and two- photon contributions to the photocurrent and the superlinear dependence of two photon current. It has been shown that, at T = 300 K the characteristic intensity I^*, when the inversion takes place, does not depend on the carriers density. The investigation of polarisation dependences has shown that the inversion of the photocurrent induced by circularly polarised radiation (Fig.2, •) occurs at a lower intensity level as compared to the linearly-polarised excitation (Fig.2, x). In n-type Ge, where the absorption is due to the one photon Drude intraband transitions, the inversion of the photon drag effect is absent and the photocurrent depends linearly on the light intensity.

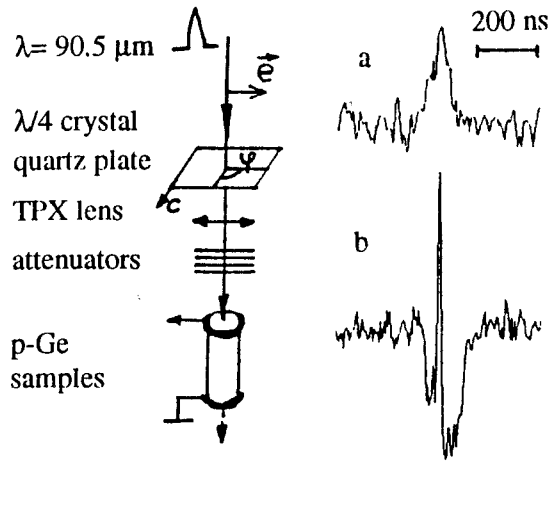

Fig. 1

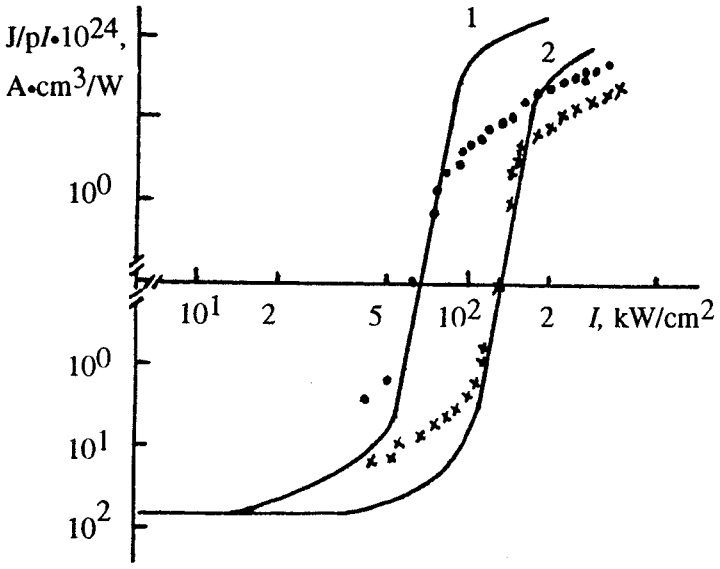

Fig. 2

A theory is developed describing the nonlinear absorption of the intense FIR radiation by direct multiphoton transitions of free carriers between two subbands of a degenerate valence band. The role of the polarisation has been analysed and it has been established that the polarisation dependence of the nonlinear photon drag effect is caused by the two-photons absorption and the resonant saturation of the one-photon absorption. The dependence of the photon drag current $J=J^{(1)}+J^{(2)}$ ($J^{(1)}$, $J^{(2)}$ are one- and -two photons currents) on the light intensity has been calculated for two polarisation. The result is plotted in Fig.2 (curve: 1-circular, 2- linear polarisation). It is seen that experimental results are in the good agreement with the theory, which predicts the stronger two-photon absorption and resonance saturation for the circular polarisation. The role of the light polarisation has been analysed also for the developed nonlinearity regime, when the nonlinearity parameter η_n is about unity and the absorption involves a set of simultaneous n-photon transitions with comparable contributions to the total absorption coefficient.

4. ACKNOWLEDGEMENTS

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

5. REFERENCES.

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6–10 September 1993
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Sponsored and Published by
SPIE—The International Society for Optical Engineering

Volume 2104