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TRANSVERSE PHOTON DRAG DETECTION OF FIR RADIATION BY FREE CARRIERS IN ANTIMONY THIN FILMS

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Abstract—Fast and sensitive detection of far-infrared radiation pulses have been observed in large-area Sb thin films by means of transverse photon drag of free carriers. The direct sensitivity was greater than 1 V/MW, about 10–30 times the normal sensitivity of Ge photon drag at 10 μm wavelength. These films are ideal for power detection of fast large-area FIR pulsed emissions.

INTRODUCTION

Fast and sensitive room temperature detectors are very interesting in current laser experiments to obtain quickly the temporal profile of laser pulses. For example, in the middle infrared wavelength region (MIR), Ge doped crystals show fast response by movement of holes on intraband transitions with a mechanism called photon-drag.[1] This detection technique is interesting because it is fast, and is not distorted by other spurious signals as observed in some detectors, e.g. the piezoelectric voltage associated with pyroelectric detection. For the study of Raman far-infrared (FIR) lasers it is important to have such detectors,[2] more sensitive by a factor of 100 and with larger areas because of the larger diffraction of FIR light beams. Normally a Ge crystal shows a photon drag response also in the FIR due to the free carrier absorption,[1,3,4] but only 5 times greater than in the MIR at a very long wavelength ($\lambda > 300\,\mu$m),[1,4] while in the 50–150 μm region its response almost vanishes.[4] On the basis of classical theory of photon pressure on free-carriers,[5] we can assume that higher signals can be generated in the FIR with higher free-carrier densities, shorter relaxation times and smaller effective mass. These conditions are well met by semimetals e.g. for antimony.[6] Furthermore, antimony shows a very promising non-spherical band structure[7] with a possible drag effect related to the intraband transitions.[1] Also in semimetals the absorption coefficient is very high,[6] so that a photon-drag signal should be produced by a transversal through only a thin film. Obviously, in order to obtain a transversal signal the film structure should be either anisotropic, or the angle between the light direction and the film normal should be large.

In order to achieve anisotropic growth of antimony one can evaporate the semimetal over an amorphous substrate with a large angle between the evaporation direction and the substrate normal.[8–10] This is schematically shown in Fig. 1. Oriented crystallization of Sb thin film evaporated on amorphous substrates has been observed previously.[11] In this case a transversal growth of crystal islands[8–10] can be achieved. This can be detected by the transversal thermoelectric response.[8–10] In this case a photon drag signal can be observed. This signal can be related either to the intraband absorptions, as in Ge photon-drag,[1] or to classical free-carrier absorption in plasma.[3,5]

It is important to note that large absorption (10–40%) of IR radiation can be obtained in metallic thin films, when electric resistivity of the film per square area is about equal to the free space impedence of 377 Ω.[12] This result is obtained under the condition:

$$2\pi k\, a \ll \lambda, \tag{1}$$

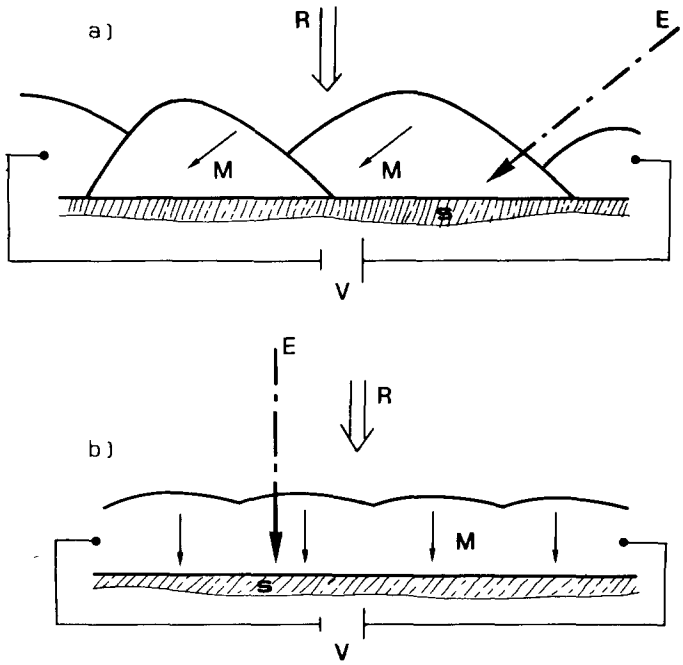

Fig. 1. Sketch of a policrystalline film evaporated at a large angle with the substrate normal direction (a), or at zero angle (b). M = crystalline island, E = evaporation direction, S = substrate, R = radiation, V = transversal voltage, arrow = crystal axis. V can be different from zero only in the transversal growth of case (a).

where k is the complex part of the metal refraction index, a is the film thickness, λ is the wavelength. A similar result can be obtained for semimetals. This large absorption at high wavelengths is surprising but well demonstrated.

By using a suitable anisotropic Sb film and by taking into account the data of Ref. (6), we can assume that large photon drag signals can be produced by free carrier absorption at wavelengths, $>70\,\mu$m.

EXPERIMENT AND RESULTS

A pulsed Raman FIR laser was applied as a radiation source.[2,13] By using NH_3 and CH_3F gases as Raman media, numerous lines can be produced in the 70–500 μm region. By using a 40 ns multimode CO_2 laser as a pump, FIR emission is generated in pulses of 40 ns or less, with strong modulation. This modulation is ideal for the separation of the fast (<1 ns) photon drag response

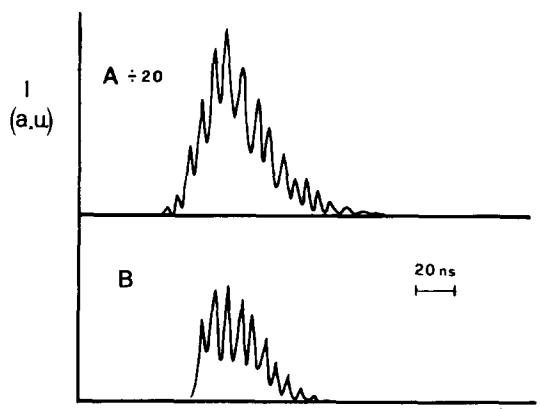

Fig. 2. Fast FIR response at 90 μm: (a) CO_2 pump laser pulse, (b) Sb film FIR response.

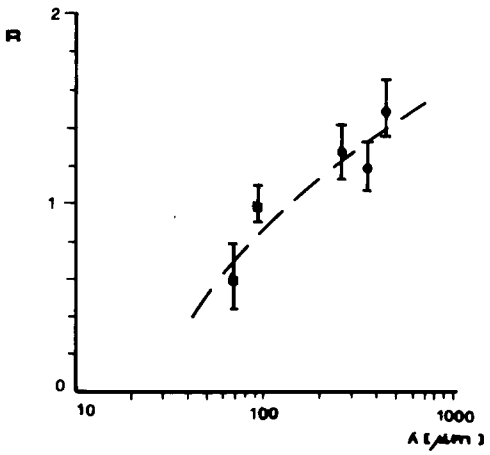

Fig. 3. Crude Sb film responsivity R vs the FIR wavelength λ, by using different Raman laser emissions: squares = NH_3 laser, circles = CH_3F laser.

from the usual transversal thermoelectric signal in the anisotropic films[8–10] since this voltage shows a slower response (> 10 ns). We have produced, by large angle evaporation,[8–10] an anisotropic Sb square film of 1 cm^2 area and about 200 Ω resistivity. It shows a poor thermoelectric response to visible light pulses. In contrast, by using a 400 μJ/40 ns pulse of an ammonia Raman FIR laser of 90 μm wavelength, the fast response is shown in Fig. 2. The responsivity is 1 V/MW, when the detector is matched with a 50 Ω resistance. Without matching resistance the responsivity is about 4 V/MW. The ns response of Fig. 2 is a clear demonstration of a photon drag mechanism. By using a 20 db 150 MHz bandwidth amplifier we have a 10 ns response time, 50 W sensitivity, limited only by the electronics. It should be mentioned that this short-time sensitivity is 10 times or more better than the more efficient Ge photon drag at 10 μm. Besides, the Ge photon-drag detector is not sensitive at 100 μm.[4] By using other FIR pulsed emissions of ammonia and methyl fluoride Raman laser,[13] we obtain the crude spectral responsivity plotted in Fig. 3. A large responsivity is observed in the 60–500 μm range with a wavelength dependence which confirms the assumption of a free carrier absorption of the radiation.

No damage is observed up to 20 mJ/cm^2 pulsed energy density on the film.

CONCLUSION

By using antimony, we have demonstrated the photon drag detection of FIR radiation which is absorbed by the free carriers in a thin semimetallic film. The sensitivity is better than that of Ge photon drag detector, and it is in agreement with the larger free-carrier density and shorter relaxation time of a semimetal. Similar detectors can be widely used in the FIR to obtain sensitive fast response at room-temperature and over large areas.

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