Real-Time Measurement Of Nanometer-Order Amplitude Transverse Vibrations Using The Photo-Emf Effect In Photoconductive Materials

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Abstract

We report the use of the photo-emf effect in photoconductive crystals (GaAs and BTO) to measure small lateral vibrations of speckle patterns generated for rough surfaces.Vibration of the rough surface results in a periodic movement of the intensity pattern, this movement leads to generation of an alternating electric current in the crystal proportional to the amplitud of the target vibration. We showing the experimental observed basic dependences of the output signal on the vibration frequency and amplitude as well as on the light intensity.High sensitivity, simplicity of the equipment, shown this method very attractive for practical applications.

Introduction

We report the use of the photo-emf effect in photoconductive crystals to measure nanometer-order amplitude transverse vibrations.The method is based on the illumination of the surface under analysis by a direct laser beam of adequate wavelength (according to the photoconductor that is being used) beam and the collection of the back-scattered speckled pattern of light onto the photoconductor.A pattern of space-charge electric field is built-up in the photoconductive material volume on a time-scale corresponding to the response time of the material that is essentially controlled by charge-transport phenomena.A pattern of free electrons in the conduction band is simultaneously built-up with a much faster time-scale (probably some nanoseconds for the materials in our experiments) that depends on the excitation of electrons from photoactive centers inside the material band gap into the conduction band.If the illuminated target surface is static, the pattern of space-charge field and free electrons are in mutual equilibrium and no electric signal is detected.However,if the target is laterally vibrating,the speckle pattern of light is simultaneously moving and the fast pattern of free electrons follows.The pattern of space-charge field instead is comparatively much slower and is not able to follow.In this way the free charge distribution and the pattern of electric field are mutually displaced proportionally to the amplitude of the target vibration and are not any more in equilibrium.An alternating current is therefore produced that can be detected to find out the size of the target vibration amplitude.We report experiments carried out with GaAs and $Bi_{12}TiO_{20}$ crystals.

Theory

The transverse vibration of a rough surface results in a periodic movement of the intensity (I(x)) of the speckle pattern.This movement leads to a electric current along coordenate x in the fotoconductor crystal add a corresponding density (N(x)) of free electrons in the conduction band :

$$
\begin{aligned}
I(x) &= Io\exp[-(x+\Delta_0 Sin(\Omega t))^2 / D_s^2] \\
N(x) &= No\exp[-(x+\Delta_0 Sin(\Omega t))^2 / D_s^2] \qquad (1) \\
J(x) &= e\mu \mathrm{N}(x)E(x) + eD(\nabla N)_x
\end{aligned}
$$

It is possible to show that the first harmonic component J^{Ω} of the fotocurrent is

$$J^{\Omega} \propto C\Delta_0 \exp(i\Omega t)(i\Omega/\Omega_0)/(1+i\Omega/\Omega_0) \qquad (2)$$

Where Ω_0 is the characteristic response frequency of the material.

The experimental arrangement

The Setup is schematically shown in Fig.1. An vibrating speckle pattern is produced by a diffusely rough surface of a loudspeaker.This surface was illuminated by a collimated laser beam (λ=670 nm, P=5 mw for GaAs and λ=532 nm, P=70 mw for BTO) with a beam diameter 0.5 - 1 mm. The loudspeaker was interferometrically calibrated for velocimetry doppler technic.Two parallel stripe electrodes with an interelectrode separation 1.5mm were deposited on the front surface (4x4mm^2) of a 4mm x 4mm x 1mm crystal of GaAs. And electrodes of silver paint were deposited on the lateral faces (5.3x2mm^2) of a 5mm x 5.3mm x 2mm crystal of BTO. this electrodes were oriented perpendicular to the vibration direction to obtain the maximum output signal. A lens with a focal length F= 24 mm was used to image the illuminated spot on to the front surface of the crystals with a magnification M. Under these conditions, the speckle pattern moved as a whole with the image.The amplitude Δ_0 of the speckle pattern vibration on the crystal was M sin(θ) times the vibration amplitude of the surface (Δ). The average speckle diameter (d) in the crystal plane was calculated with d =1.22 λZ/D where Z is the distance from the lens to the crystal and D is the diameter of the lens aperture.

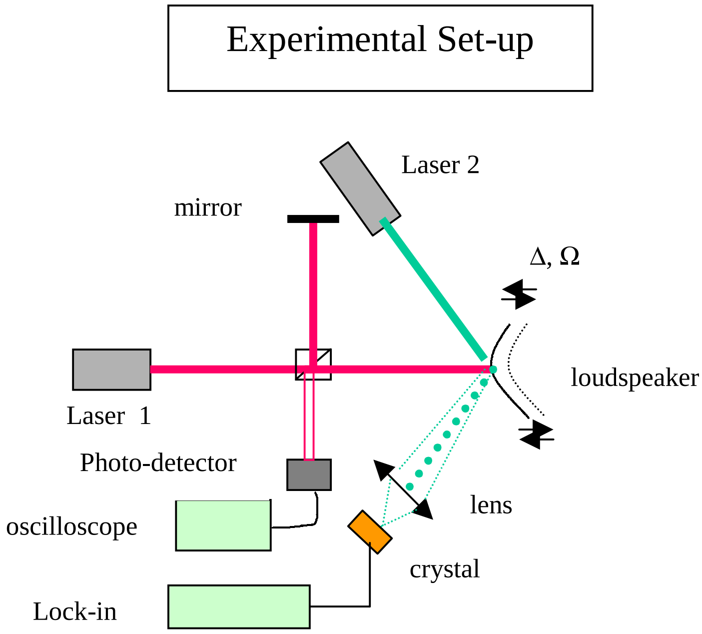

Fig1. The laser1 is used for velocimetry dopller callibration and the laser2 is used for measurement of output ac current i^{Ω}.

Experimental results

The experimental results are showing ,the response of the loudspeaker obtained for velocimetry doppler shown in the fig 2 is used for calibrated of our crystals photodetectors.

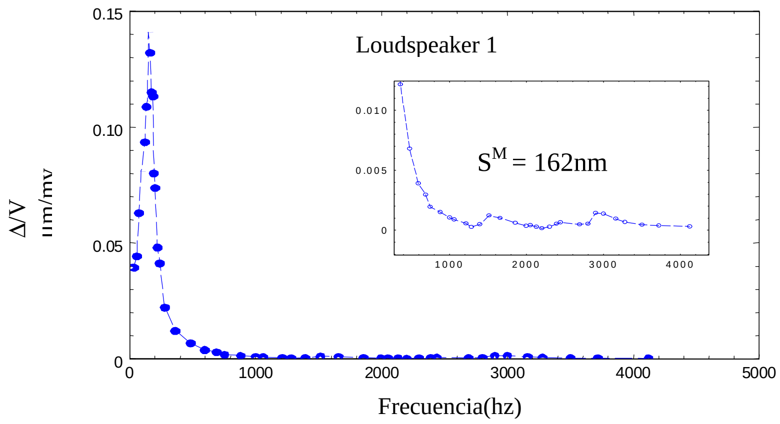

Fig2. Output signal velocimetry doppler showing the respost of loadspeaker 1 on vibration frequency.

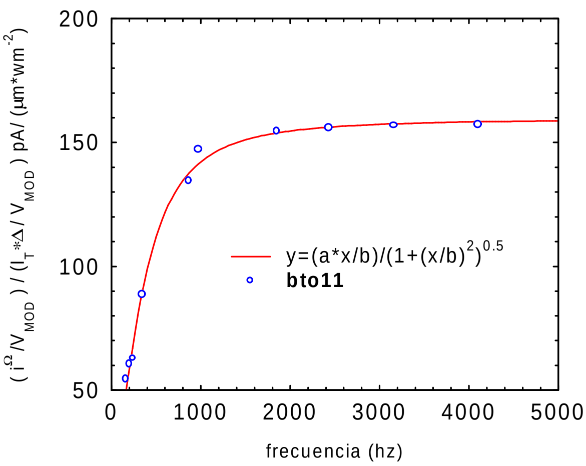

Fig3a.frequency dependence of the output ac current i^Ω .The red curve represent the fit of the theorical equation 3 .W_0=510hz is found .

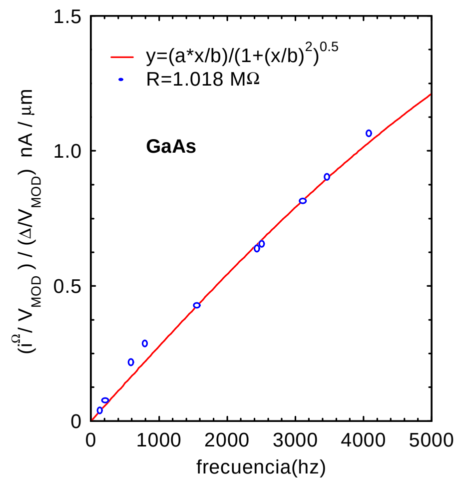

Fig3b.Dependence of output signal on vibration frequency (GaAs).The red curve represent the fit of the theorical equation 3.W_0=8411hz is found.

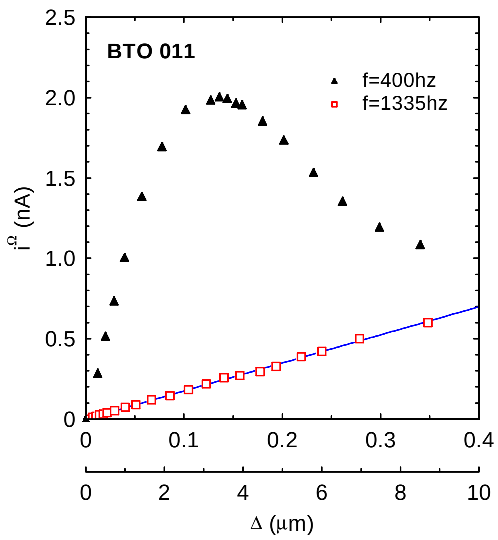

Fig.4a Output signal as a function of vibration amplitude Δ of the loudspeaker 1.Io = 2.5mw/mm^2, λ=532nm.the additional abscissae refer to f=400hz.

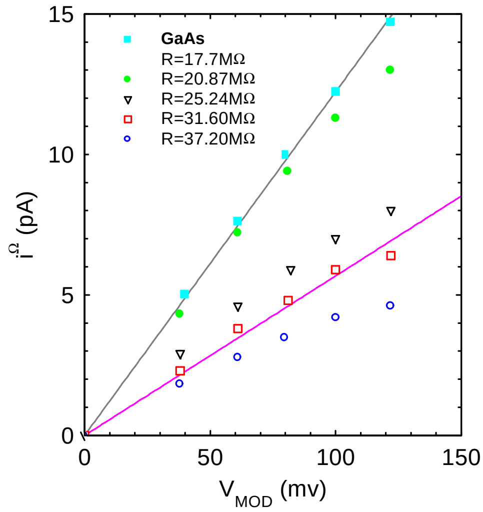

Fig.4b Output signal as a function of vibration amplitude Δ of the loudspeaker 2. λ=670nm, f=950hz.

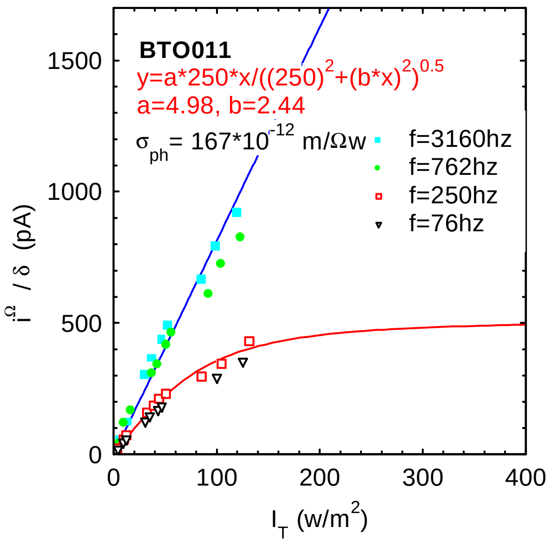

Fig5a Output signal i^{Ω}/δ dependence on light intensity. (λ=532nm)

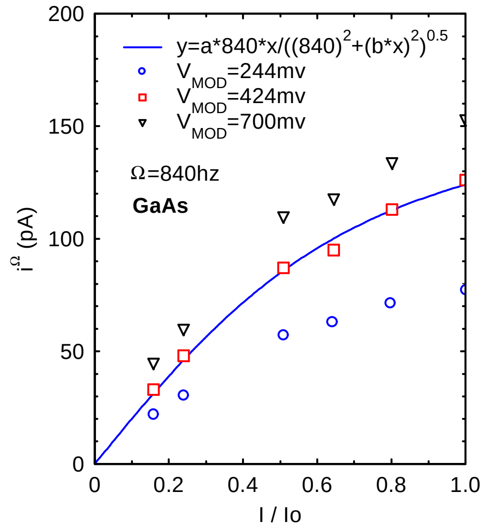

Fig5b Output signal i^{Ω} dependence on light intensity.Io=1 correspond to R=28.1MΩ (λ=670nm).

Data analysis and Conclusions

The figure 2 shows the characteristic frequency response of a commercial loadspeaker (10 watts, 8Ω) carried out using Doppler velocimetry. The validity of relation (2) was verfied from the experimental results in figs 3, 4 and 5 for BTO and GaAs crystals. The figures 3a and 3b shown the output signal of current i^{Ω} as a function of vibration frequency obtained for vibration amplitudes much smaller than a speckle diameter.The best fit to equation (2) was obtained for $\Omega_o=2\pi*$ 510 s^{-1} for BTO (this value of Ω_o is nearly equal to that measured in [2] for a BTO crystal using oscillating sinusoidal patterns under similar conditions of illumination. Ωo= 2π *8411 s^{-1} was obtaines for GaAs. The dependence of the output signals on vibration amplitude are shown in figures 4 and 4b. Data in fig 4a show linear response for small amplitudes at 1335 hz and nonlinear response (for large amplitudes) at 400hz. For 1335 hz the smallest possible amplitude to be measured was 0.3nm. The signal dependence on light intensity are shown in the figures 5 and 5b. That is proportional to I for vibration frequencies higher than the cut-off frequency Ωo as predicted by equation (2). A specific conductivity $\sigma_{ph}=167*10^{-12}$ $m\Omega^{-1}w^{-1}$ is found for BTO in good agreement with results report in ref [2].

In conclusion,we have shown that the interaction of a vibrating speckle pattern with fotoconductors crystals (BTO and GaAs) results in the generation of non-steady-state photo-emf signal that should be used to measure small vibrations, as low as 10^{-5} of the speckle diameter.

References

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