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Optically induced space-charge and conductivity gratings in wide-bandgap semiconductors

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Abstract

We report optical excitation of space-charge and conductivity gratings in wide-bandgap semiconductors. The approach is based on the illumination of semiconductor material with an oscillating interference pattern formed of two light waves, one of which is phase modulated with frequency ω. The non-steady-state photocurrent flowing through the short-circuited semiconductor is the measurable quantity in this technique. The alternating current results from the periodic relative shifts of the photoconductivity and space charge electric field gratings which arise in the volume of the crystal under illumination. The experiments are carried out in β-Ga_2O_3 crystal and the main parameters of the photoinduced carriers are determined.

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Keywords: non-steady-state photoemf; wide-bandgap semiconductor; dynamic gratings

1. Introduction

Investigation of electronic kinetic processes in solid state material and, in particular, in wid-bandgap semiconductors and nanostructured materials has great has great importance because it provides information about the main fundamental characteristics of the material, such as energy level structure, relaxation processes, Fermi surface shape, volume charge distribution, specific properties of charge carriers, etc. These parameters can be

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measured using both electrical and optical methods. The latter are preferable because they allow nondestructive testing of materials to be carried out. There are two modern techniques for such measurements. The first one is based on the recording of the dynamic holographic gratings in photorefractive crystals (Petrov M.P. et al. (1991), Kamshilin A.A. et al. (2009)). The second one uses the effect of non-steady-state photoelectromotive force (photo-EMF) (Petrov M.P. et al. (1990), Bryushinin M.A. et al. (2014)). The non-steady-state photocurrent appears in a semiconductor material illuminated by an oscillating light pattern. Such illumination is usually created by two coherent light beams one of which is phase modulated with frequency ω. In contrast to the holographic methods this technique allows the direct transformation of phase modulated optical signals into the electrical current and can be applied for characterization of centrosymmetrical and even amorphous materials. Since the current is induced due to periodic spatial shift of photoconductivity gratings and the space charge field, the technique based on this effect makes it possible to determine a number of photoelectric parameters (conductivity type and value, lifetime, diffusion length, and carrier mobility). In this paper we present the experimental results on optical excitation of space-charge and conductivity gratings in β-Ga_2O_3 crystal.

2. Samples and experimental set-up

The experiments with the excitation of the non-steady-state photo-EMF in β-Ga_2O_3 are carried out with the arrangement (Fig. 1) used earlier for investigations of other wide-bandgap semiconductors and nanostructured materials (Bryushinin M.A. et al. (2014)). The second harmonic of Nd:YAG laser with the wavelength of λ=532 nm is split into two beams, which then create the interference pattern with spatial frequency K, contrast m=0.98 and average intensity I_0 on the crystal surface. The electro-optic modulator introduces phase modulation with amplitude δ = 0.61 and frequency ω into the signal beam. The photocurrent arising in the sample produces a voltage across the load resistor, which was amplified and then measured by the lock-in voltmeter. The polarization plane containing electric field vector is perpendicular to the incidence plane (TE-polarization) in the most of the experiments. The placement of the half-wave plate in front of the sample allows the rotation of the polarization plane, when it is necessary.

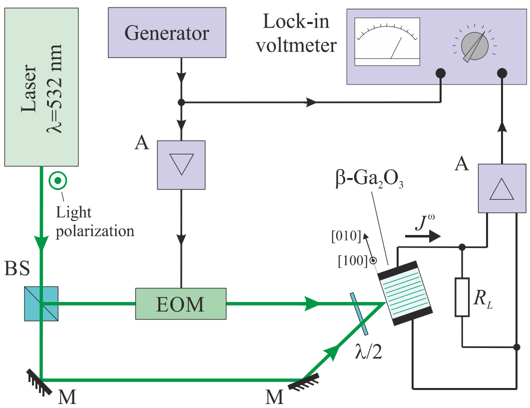

Fig. 1. Experimental setup for the investigation of the non-steady-state photo-EMF. EOM is the electrooptic modulator, BS is the beamsplitter, M is the mirror, A is the amplifier.

β-Ga_2O_3 is a monoclinic crystal with the cell dimensions a=2.23 A , b=3.04 A , c=5.80 A and β=103.70. The band gap is indirect with Eg=4.84 eV. The static dielectric constant of the material is a tensor with eigenvalues ε_{11}=10.84, ε_{22}=11.49 and ε_{33}=13.89. The crystal of gallium oxide was grown by the floating zone method at URN-2-ZM machine produced in Moscow Power Engineering Institute. The single crystal was grown from the ceramic bar obtained by the conventional technology. The seed was oriented so that the crystal grew along the [010] direction.