Fast device for measuring polarization characteristics of submillimeter and IR laser pulses

A. V. Andrianov, E. V. Beregulin, S. D. Ganichev, K. Yu. Glukh, and I. D. Yaroshetskii

A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, Leningrad

(Submitted April 21, 1988)

Pis'ma Zh. Tekh. Fiz. **14**, 1326–1329 (July 26, 1988)

Rapidly developing laser technology requires the development of instruments for analyzing the polarization of laser pulses with high time resolution. Determining the polarization characteristics of one-time or rarely repeating short laser pulses qualifies as a special problem. Problems of this type have been partially solved for laser light in the visible and near-IR ranges. In the mid-and far-IR regions and, especially, the submillimeter region there are no methods for polarization-dependent measurements of the parameters of pulsed laser radiation.

In this letter we are proposing a method for determining the polarization characteristics of laser pulses in the IR and submillimeter ranges. We have used this method to develop a device which is capable of measuring the characteristics of pulsed lasers, in either periodic or one-time operation, with a high time resolution. The method is based on ballistic photoelectric effects in semiconductors: a photon drag on electrons,[1,2] which results in a transfer of momentum from photons to electrons, and a photogalvanic effect,[3-5] which involves an asymmetry of the generation, recombination, and scattering of charge carriers in crystals lacking a center of inversion.

The current which arises upon the absorption of linearly polarized light in crystals lacking a center of inversion is given by[2,4]

$$j_i = I\Gamma_{ik,lm} l_k l_l \varkappa_m + I\chi_{ik,l} l_k l_l, \qquad (1)$$

where I is the radiation intensity, $\vec{l}$ is the polarization vector, $\vec{\varkappa}$ is the wave vector of the light, $\Gamma_{ik,lm}$ is a fourth-rank tensor which determines the photon drag, and $\chi_{ik,l}$ is a third-rank tensor which determines the photogalvanic effect. Photocurrent (1) arises essentially instantaneously. The time scale of the photoresponse is determined by the momentum relaxation time of the carriers, which is 10^{-12}-10^{-13} s.

In open-circuit operation, an electric field $\vec{E}$ arises in the sample. This field can be found by equating the total current to zero:

$$j - \sigma\vec{E} = 0,$$

$$E_i = I\frac{\Gamma_{ik,lm}}{\sigma}\varkappa_k l_l l_m + I\frac{\chi_{ik,l}}{\sigma} l_k l_l, \qquad (2)$$

where σ is the electrical conductivity of the crystal (generally this is a second-rank tensor, but in cubic crystals and, in particular, III–V semiconductors the conductivity behaves as a scalar). It can be seen from (2) that the photo-emf which arises in the sample carries information about the polarization of the laser radiation incident on the crystal. There are relative orientations of the crystal the wave vector, and the electric contacts, for which the position of the polarization plane of the laser radiation can be determined through measurements of electrical signals.

TABLE I. Values of the Constant A, which Determines the Sensitivity of the Analyzer, at Various Wavelengths

Wavelength, μm	9.2	10.6	90.55	152	385
μ V/W	0.37	0.5	0.21	0.21	0.24

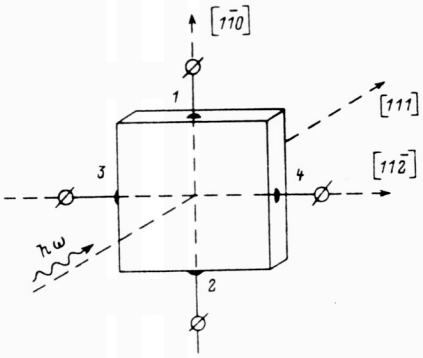

FIG. 1. Device for analyzing the polarization of laser radiation.

A device for analyzing the polarization of laser radiation has been fabricated from a p-GaAs(Zn) single crystal with a hole concentration $p = 2.3\cdot10^{16}$ cm^{-3} and a mobility of 250 $cm^2/V\cdot S$. This crystal is a wafer oriented in the (111) plane with a thickness of 2 mm and 5 × 5 mm square. Two pairs of ohmic point contacts are placed along the [1$\bar{1}$0] and [11$\bar{2}$] directions at the edges of the wafers (Fig. 1).

For light incident normally on the analyzer, a potential difference V_1 arises between points 1 and 2, and a potential difference V_2 arises between points 3 and 4. As can be shown on the basis of (2) and the Td point symmetry group of the GaAs crystal, these potential differences are

$$V_1 = P_L A \sin 2\theta,$$
$$V_2 = P_L A \cos 2\theta, \qquad (3)$$

where P_L is the power of the linearly polarized component of the laser radiation, θ is the angle between the vector $\vec{l}$ and the [11$\bar{2}$] direction, and the constant A is determined by the properties of the crystal and the geometry of the analyzer.

It is easy to see from (3) that by simultaneously measuring the absolute values of the signals V_1 and V_2 and also their signs one can unambiguously determine the instantaneous orientation of the polarization plane of the laser radiation (i.e., the angle θ) and also the power of the linearly polarized component of the laser radiation. A solution of system (3) is

$$\theta = \frac{\pi}{4}(1 - \operatorname{sign} V_2)\operatorname{sign} V_1 + \operatorname{sign} V_2 \cdot \frac{1}{2}\arcsin\frac{V_1}{\sqrt{V_1^2 + V_2^2}},$$

 0360-120X/88/07 0580-02 $02.60

$$\rho_L = \frac{\sqrt{V_1^2 + V_2^2}}{A}. \quad (4)$$

Using the photosensitive element described above, we have made a photodetector which has two wide-band differential amplifiers with a bandwidth of 70 MHz and a gain of 100. This detector is capable of operation over a wide spectral range (from 9 to 400 μm). Table I shows values of the quantity A, which essentially determines the sensitivity of the analyzer. The response time of this photodetector is 5 ns, determined by the bandwidth of the amplifiers used. The photosignals are measured simultaneously by an S9-6 digital oscilloscope. Data on the magnitudes and signs of V_1 and V_2 are entered into a computer, where algroithm (4) is implemented. The computer determines the time evolution of (a) the position of the polarization plane and (b) the power of the linearly polarized component of the laser radiation during the pulse. The time resolution is determined by the speed of the signal-processing channel which is used.

[1] S. M. Ryvkin and I. D. Yaroshetskii, Problems of Modern Physics [in Russian], Leningrad (1980), pp. 173-185.
[2] A. M. Danishevskii, A. A. Kastal'skii, S. M. Ryvkin, and I. D. Yaroshetskii, Zh. Eksp. Teor. Fiz. 58, 544 (1970) [Sov. Phys. JETP 31, 292 (1970)].
[3] V. I. Belinicher and B. I. Sturman, Usp. Fiz. Nauk 130, 415 (1980) [Sov. Phys. Usp. 23, 199 (1980)].
[4] A. V. Andrianov, E. L. Ivchenko, G. E. Pikus, R. Ya. Rasulov, and I. D. Yaroshetskii, Zh. Eksp. Teor. Fiz. 81, 2080 (1981) [Sov. Phys. JETP 54, 1105 (1981)].
[5] E. V. Beregulin, S. D. Ganichev, K. Yu. Glukh, Yu. B. Lyanda-Geller, and I. D. Yaroshetskii, Fiz. Tverd.Tela (Leningrad) 30, 730 (1988) [Sov. Phys. Solid State 30, 418 (1988)].

Translated by Dave Parsons

Dynamics of electric field screening in photorefractive $Bi_{12}SiO_{20}$ crystals

V. N. Astratov, A. V. Il'inskii, and A. S. Furman

A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, Leningrad

(Submitted April 15, 1988)

Pis'ma Zh. Tekh. Fiz. **14**, 1330–1335 (July 26, 1988)

1. The dynamics of the space charge determines the nonlinear optical properties of photorefractive crystals which are of practical importance. Of considerable interest in this group of crystals are the electrooptic sillenite crystals ($Bi_{12}SiO_{20}$, $Bi_{12}GeO_{20}$), which are widely used in dynamic holography and in devices for optical data processing.[1]

In this letter we report an experimental and theoretical study of the dynamics of the space charge in the screening of an electric field applied to a $Bi_{12}SiO_{20}$ crystal after preliminary illumination. The results show that the nature of the screening depends strongly on the crystal temperature T. At T ~ 300 K, the screening is accompanied by a stratification effect[2-4]: Space-charge layers of alternating sign form in the crystal. As time elapses, the charge density in the layers increases, and the thickness of the layers decreases. In contrast, for 130 < T < 200 K the screening occurs as a result of the expansion of a single space-charge layer, of constant density, which forms near the negative blocking electrode. All these features of the screening dynamics can be described in a simple model which incorporates ionization of impurity centers, the drift of electrons, and the trapping of electrons. We reach the conclusion that the charge transport is controlled over a wide temperature range by the trapping of electrons by trapping centers with an ionization energy of 0.4 eV.

2. In the experiments, a $Bi_{12}SiO_{20}$ crystal with a thickness d = 8 mm was illuminated uniformly at the wavelength λ = 488 nm. A voltage v = 9 kV then applied to the crystal in darkness while the flux of charge carriers through the negative electrode was blocked by a thin (30-μm) insulating interlayer (see the inset in Fig. 1). The electric field distribution E(z) at subsequent times was detected, as in Refs. 2 and 3, on the basis of the transverse electrooptic effect. Measurements were carried out at various crystal temperatures T. At T ~ 300 K, we observed a stratification effect as in Refs. 2-4. In contrast, at T = 161 K an expanding layer of space charge with a constant density $\rho_0 = e \cdot 3.75 \cdot 10^{13}$ cm^{-3}, where e is the magnitude of the electron charge, forms near the negative electrode (Fig. 1).

3. Let us consider theoretically the screening processes. According to Refs. 1-3, the band gap of sillenite crystals contains a large number of levels of deep recombination centers and trapping centers. Our experiments, however, can be interpreted completely on the basis of a scheme with one deep level (A) and two trapping levels L_1 and L_2 (see the inset in Fig. 2). In the course of the preliminary illumination, the electrons move out of the a centers through the conduction band to the trapping centers. After the illumination is stopped, the electrons are thermally excited from the trapping centers into the band, and then they are retrapped. At temperatures near room temperature, excitation from level L_2 plays an important role in the charge transport. Under these conditions, the screening is accompanied by a stratification effect, in accordance with the theory of Refs. 2-4.

At lower temperatures, the excitation from the deeper level, L_2, is suppressed, and the dynamics of the space charge is determined exclusively by

0360-120X/88/07 0581-03 $02.60