ALT'22 ✳

Anisotropic Photoconductivity and Terahertz Emission from Semiconductors

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One of the methods for generating continuous wave terahertz (THz) radiation is the use of the photomixing effect in semiconductor excited by two optical beams with close frequencies [1, 2]. The photomixing effect arises due to the nonlinear nature of photoconductivity and, in the presence of a constant bias, leads to the generation of a photocurrent at the beat frequency. In this report we consider the anisotropic photoconductivity in a semiconductor excited by two-frequency optical radiation, as well as its contribution to the photocurrent at the beat frequency corresponding to the THz region. The interband anisotropic photoconductivity arises due to the anisotropy of the momentum distribution of electrons excited by polarized light and the energy dependence of the momentum relaxation [2] time and effective mass of the electrons. The response time of the anisotropic photoconductivity is very short, since it is determined by the electron momentum relaxation time, which for typical semiconductors is about 200 – 300 fs.

Let us consider a cubic semiconductor under interband excitation by the two-frequency linearly polarized optical radiation $\mathbf{E}(t) = \mathbf{E}_1 \cos\omega_+ t + \mathbf{E}_2 \cos\omega_- t$ with nearby frequencies $\omega_\pm = \omega \pm \Omega/2$. The constant electric field $\mathbf{F}$ is directed along the z-axis. The vectors $\mathbf{E}_1$ and $\mathbf{E}_2$ are assumed to be parallel to each other, lying in the xz plane and making an angle γ with the z-axis. Solving the kinetic equation for the component of the electron distribution function at the beat frequency Ω, we obtain expressions for the current density components:

$$j_z = \frac{e^2 F}{3\pi^2} \frac{\alpha I}{\hbar\omega g(\varepsilon_0)} \left\{ \frac{\tau_0}{1+i\Omega\tau_0} \frac{d}{d\varepsilon_\mathbf{p}} \left(p^2 v_\mathbf{p} \frac{\tau_1}{1+i\Omega\tau_1} \right) - \frac{2}{5} P_2(\cos\gamma) \frac{\tau_2}{1+i\Omega\tau_2} V(\varepsilon_\mathbf{p}) \right\}\Bigg|_{\varepsilon_\mathbf{p}=\varepsilon_0},$$

$$j_x = -\frac{e^2 F}{10\pi^2} \frac{\alpha I \sin 2\gamma}{\hbar\omega g(\varepsilon_0)} \frac{\tau_2}{1+i\Omega\tau_2} V(\varepsilon_\mathbf{p})\Bigg|_{\varepsilon_\mathbf{p}=\varepsilon_0}, \quad V(\varepsilon_\mathbf{p}) = p^3 \frac{d}{d\varepsilon_\mathbf{p}} \left(\frac{v_\mathbf{p}}{p} \frac{\tau_1}{1+i\Omega\tau_1} \right).$$

Here α is the optical absorption coefficient, I is the optical excitation intensity, $\varepsilon_\mathbf{p}$ is the energy of an electron with momentum $\mathbf{p}$, ε_0 is the excess energy of photoelectrons in the conduction band, $\mathbf{v}_\mathbf{p} = \partial\varepsilon_\mathbf{p}/\partial\mathbf{p}$ is the electron velocity, $g(\varepsilon)$ is the density of electron states in the conduction band, τ_0 is the recombination time of nonequilibrium electrons, $\tau_1(\varepsilon)$ and $\tau_2(\varepsilon)$ are the momentum relaxation times corresponding to the first and second spherical harmonics of the distribution function, $P_2(\cos\gamma)$ is the second-order Legendre polynomial.

In typical semiconductors the recombination time is usually much longer than the times τ_1 and τ_2. In the low frequency range ($\Omega\tau_0 \ll 1$) the anisotropic part of the photoconductivity is very small, since its relation to the normal (isotropic) photoconductivity is characterized by the parameter $\tau_2/\tau_0 \ll 1$. However, in the THz frequency range, when $\Omega\tau_0 \gg 1$, the anisotropic and isotropic parts of the photoconductivity can be comparable since their ratio is characterized by the parameter $\Omega\tau_2 \sim 1$. In THz photoconductive antennas used for photomixing, semiconductor layers with a subpicosecond lifetime are usually used [3]. Given that the carrier lifetime in such semiconductors $\tau_0 \sim \Omega^{-1}$, we obtain that even in this case the anisotropic component of the photoconductivity is comparable to the value of the isotropic photoconductivity.

[1] S. Preu G. H. Döhler, S. Malzer, L. J. Wang, and A. C. Gossard, Tunable, continuos-wave Terahertz photomixer sources and applications, J. Appl. Phys., 109, pp. 061301-1-061301-56, (2011).
[2] V. Belinicher and V. Novikov, Nonequilibrium photoconductivity and influence of external fields on the surface photogalvanic effect, Sov. Phys. Semicond., 15, pp. 1138-1142, (1981).
[3] N. Burford and M. El-Shenawee, Review of terahertz photoconductive antenna technology, Opt. Eng., 56(1), pp. 010901-1-010901-20, (2017).