Static-Electric-Field Effects on Harmonic Generation in Gallium Arsenide Bulk Exposed to Intense Sub-THz Radiation

D. Persano Adorno, M. Zarcone and G. Ferrante

Dipartmento di Fisica e Tecnologie Relative, Viale delle Scienze, Ed. 18, Palermo (Italy)
e-mail: dpersano@unipa.it

INTRODUCTION

The process of high order harmonic generation in semiconductors driven by intense radiation fields having sub-terahertz frequencies has been widely investigated in recent years [1-3]. This field of research represents a useful mean for the general understanding of several features of the highly non linear processes of carrier transport in doped semiconductors. Moreover a possible way to achieve high-power and high-frequency radiation sources is given by the efficient frequency conversion of high-power gyrotron radiation in nonlinear materials.

Harmonics generation in the presence of an additional static field has been addressed by several authors [4-5]. Among others, Bao and Starace have experimentally found that in H^- and in Ar the addition of a static field, having an amplitude less than 2% of that of the laser field, produces very intense even harmonics. Furthermore, they have shown that the intensities of odd harmonics near the low-order end of the plateau increase by orders of magnitude. A static field thus appears to have a very sensitive role for controlling the emission rates of both even and odd high harmonics [4].

In this paper we report and discuss the static-electric-field effects on harmonic generation in a GaAs bulk driven by an intense alternating field. To the best of our knowledge this subject in semiconductors has never been addressed before.

PHYSICAL MODEL AND CALCULATIONS

We assume that our GaAs sample is acted by an oscillating electric field and a static field having the components:

$$E_x = E_0 + E_1 \cos\varphi \cos(2\pi\nu_1 t - k_1 z)$$
$$E_y = E_1 \sin\varphi \cos(2\pi\nu_1 t - k_1 z)$$

where φ is the angle between the polarization of the static field E_0 and the oscillating field E_1.

The theory of harmonic generation in semiconductors has been derived in a previous paper [2] and it is based on the Maxwell equation for the propagation of an electromagnetic wave in a medium along a given direction. Our analysis is referred to a thin sample and for this reason we do not consider the complex form of the dielectric function $\varepsilon(\nu)$ in our calculations and neglect the field-dependent absorption. Within these assumptions, the efficiency of the harmonic generation at frequency ν, normalized to the fundamental one (ν_1), is given by:

$$\eta_\nu = \frac{I_\nu}{I_{\nu_1}} = \frac{\nu_1^2}{\nu^2}\frac{u_\nu^2}{u_{\nu_1}^2} \qquad (1)$$

where u_ν is the Fourier transform of the electron drift velocity, obtained via a multiparticles Monte Carlo (MC) simulation of the electron motion in the semiconductor. The spectra of emitted radiation are reconstructed by the analysis of the velocity Fourier components. The algorithm for MC simulation of the electron motion in the alternating electric field used in this work follows the standard procedure. It takes into account the nonparabolicity of the band structure and the intervalley and intravalley scattering of electrons in multiple energy valleys. Since the far-infrared frequencies are below the absorption threshold, in our model we consider the

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electrons in the conduction band as the only source of nonlinearity. We assume field-independent scattering probabilities; accordingly, the influence of the external fields is only indirect through the field-modified electron velocities. All the results are obtained in a stationary regime, just after a transient time of a few ps.

The conduction bands of GaAs are represented by the Γ valley, the four equivalent L-valleys and the three equivalent X-valleys. Our harmonic spectra have been obtained in GaAs by adopting a free electrons concentration of $n=10^{13}cm^{-3}$ and a lattice temperature T=80 K. For a complete set of n-type GaAs parameters used in our calculations, see Ref. [4].

NUMERICAL RESULTS

The process of harmonic generation has been analyzed for different geometries of the linear polarization of the two incident fields. In all cases we have assumed E_0= 3 kV/cm, E_1=30kV/cm and ν_1= 200 GHz.

Also if the intensity of the static field E_0 is only 1/10 of the amplitude of the oscillating one, we have found even harmonics having efficiency comparable with those of the odd ones. In order to study the effect of the static field on the spectrum by varying the angle φ between the two electric fields, we have computed the intensity spectra of the electromagnetic waves polarized along the x axis and the y axis. The spectrum along the x axis when $\varphi=0°$ shows, as expected, odd and even harmonics, while along the y axis we have only noise. The situation is very different when the oscillating electric field has a component also along y, i.e. when $\varphi\neq0°$. In fact in this case we find that the spectrum along the y axis contains also the even harmonics due to the static field E_0 although along the y direction is present only the pump field E_1 at frequency ν_1. When $\varphi=90°$ only the static field E_0 is present along the x axis and the spectrum shows the even harmonics of an oscillating field direct along the y-axis, while along the y direction the spectrum contains only the odd harmonics.

Figure 1 shows the efficiency of the second harmonic as a function of the angle φ between E_0 and E_1, along the x and y directions. The intensity of η_2 is constant along the x-axis, while it is a function of the angle φ along the y-axis.

CONCLUSIONS

The most significant results of our investigation may be summarized as follows:

1) When the only alternating field is applied no even harmonics are present. The presence of a static field, lowering the symmetry of the system, produces the generation of even harmonics, with amplitudes increasing with the intensity of the static field.

2) In GaAs bulk the spectra contain also the even harmonics at angles φ different from zero although the static electric field E_0 has no component along that direction.

3) As compared to the case in which only the oscillating field is present, (for ν=200 GHz and for the studied intensities), two-field calculations show that the addition of the static field does not enhance the efficiency of the odd harmonic.

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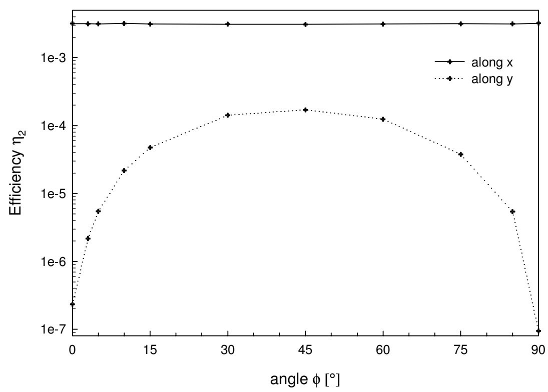

Fig.1 Efficiency of 2nd harmonic generated by the GaAs bulk as a function of the angle ϕ formed by the polarization of the a.c. electric field and the static one.