Electronic Noise in Semiconductor Systems: A Monte Carlo Simulation under Mixed Fields

M.C. Capizzo, D. Persano Adorno and M. Zarcone

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

INTRODUCTION

Progress in telecommunications systems has been made possible by computer simulation techniques and physical modelling of semiconductor structures. The level of noise in semiconductor components limits the successful design of any low noise electronic system. Therefore, characterization of the semiconductor behaviour under dynamic operation condition could help to predict the sensitivity of semiconductor based devices. The generation of electronic noise in bulk semiconductor is due to the strong nonlinear behaviour at microscopic level.

For these reasons, the Monte Carlo (MC) method has been used for the simulation since it includes at a microscopic level, the sources of the nonlinearities (hot carriers, velocity overshoot, intervalley transfer, etc) taking place in electronic devices operating under large-signal conditions. In particular, the electronic transport in the bulk semiconductor driven by two a.c. mixed electric fields has been performed and the noise response has been analysed.

Recently, an analysis of electronic noise under large-signal conditions has been developed for the case of bulk semiconductor and simple devices [1,2,3,4]. However, to the best of our knowledge, these effects have not been investigated in the presence of a mixing of coherent electromagnetic radiations of commensurate frequencies.

In the last years we have investigated high-order harmonic generation and frequency mixing effects in low-doped bulk semiconductors subject to far-infrared intense electric field [5,6]. It has been shown that the wave mixing can produce an enhancement of the harmonic generation. However, the extraction of these harmonics is limited by the intrinsic high-frequency noise of the nonlinear medium, which can mask the generated high-order harmonics. Therefore, under cyclostationary conditions, these dynamical effects have to be considered and nonlinear analysis of noise must be performed.

However, a physical understanding of noise sources and a full theory for nonlinear noise modelling is still under development.

PHYSICAL MODEL AND NOISE CALCULATION

In this study we investigate electronic noise in bulk GaAs operating under two mixed large-amplitude periodic electric fields. The microscopic modelling of system is the same of Ref. [5].

To analyze the noise present in the carrier velocity, the autocorrelation function approach has been used [4]. The two times autocorrelation function is defined as:

$$C_{\delta v\delta v}(t,\tau)=\left\langle v\left(t-\frac{\tau}{2}\right)v\left(t+\frac{\tau}{2}\right)\right\rangle-\left\langle v\left(t-\frac{\tau}{2}\right)\right\rangle\left\langle v\left(t+\frac{\tau}{2}\right)\right\rangle \qquad (1)$$

By averaging over the whole set of values of t during the period T_f, the longer period of excitation mixed fields, one obtain the autocorrelation function as:

$$C_{\delta v\delta v}(\tau)=\frac{1}{T_f}\int_0^{T_f}C_{\delta v\delta v}(t,\tau)dt \qquad (2)$$

Finally, the mean spectral density is defined as:

$$S_{\delta v\delta v}(t,\nu)=\int_{-\infty}^{\infty}C_{\delta v\delta v}(t,\tau)e^{i2\pi\nu\tau}d\tau \qquad (3)$$

RESULTS

Figure 1 and 2 illustrate the autocorrelation function of velocity fluctuations and the mean spectral density for a GaAs bulk with doping level of n=10^{13} cm^{-3}, temperature T=80 K, amplitude of excitation signal E_1= 7 kV/cm, E_2= 15 kV/cm and different frequencies. The autocorrelation curves show oscillations becoming more pronounced at higher mixed fields frequencies. The whole relaxation process becomes the longer the higher is the mixed fields frequencies.

For mixed fields frequencies $\nu_1 <$ 400 GHz and $\nu_2 <$ 800 GHz, the spectral density have the shape typical for the hot carrier conditions under the steady-state operation and the peak maximum slightly shift to higher frequencies. The frequency of the peak value of the spectral density has no direct relations with mixed fields frequencies. In contrast, at higher mixed frequencies the "steady-state" peak is replaced by two resonant peaks appearing at the mixed fields frequencies. For fixed frequencies, the amplitude of the resonant peaks are related to the amplitude of the excitation signal.

CONCLUSION

This study reports some interesting results for bulk semiconductor under two large amplitude mixed electric fields. Our results indicated that, the intensities and the frequencies of the mixed fields can play an important role in the noise enhancement or suppression. Future work could be oriented to the investigation of the influence of different polarization of mixed fields in the noise behaviour in both bulk materials and submicron structures.

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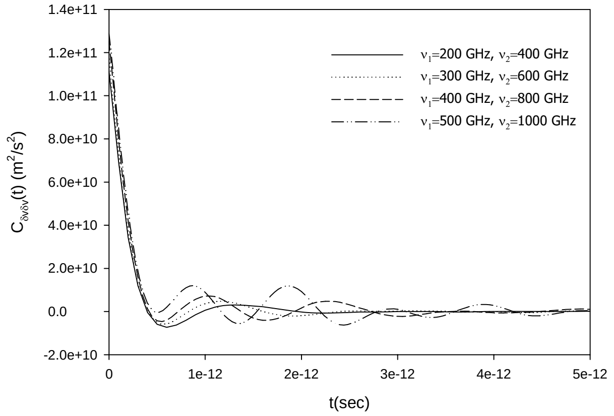

Fig. 1. Autocorrelation function of velocity fluctuations for a GaAs bulk with doping level of $n=10^{13}$ cm^{-3}, temperature T=80 K, amplitude of excitation signal E_1= 7 kV/cm, E_2= 15 kV/cm and different frequencies

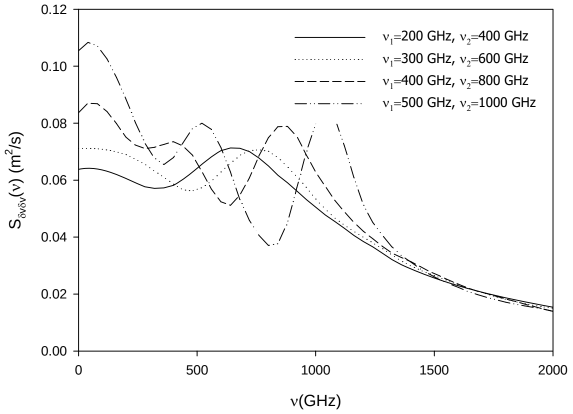

Fig. 2. Spectral density for the same case as in fig. 1