# A Numerical Study of Amplification of Space Charge Waves in n-GaN Films

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## INTRODUCTION

Amplification of traveling space charge waves (SCW) of the microwave range in n-GaAs films due to negative differential conductivity (NDC) has been under investigations for many years [1]. But the frequency range of amplification of SCW in GaAs films is $f < 44$ GHz. It is better to use new materials possessing NDC at higher frequencies $f$ = 100…500 GHz, like gallium nitride GaN. This compound semiconductor has become interested for use in many semiconductor device structures. It has potential to develop optical devices and high power electronics, because of its large direct band gap, and high frequency devices due to its expected high peak velocity. All these characteristics become GaN into an important candidate for high power, temperature, and frequency electronic applications. A comparison of GaAs and GaN shows that NDC occurs in GaAs when the occupancy of higher valleys ($L$, $X$ ones) is 30% and more [2]. In GaN the occupancy of higher valleys is essentially lower, of about 10%. Therefore, in GaAs it is impossible to describe the amplification of SCW by means of the simplest nonlocal hydrodynamic model, where the unified electron concentration, average electron velocity, and energy are considered [3]. For GaN, it is possible to apply the simplest nonlocal model; there are evidences that in the zinc blende n-GaN the mechanism of NDC is different from the intervalley transfer, but is due to the inflection of the electron dispersion.

In our simulations, an approximation of two-dimensional electron gas is used in device of fig. 1. The set of balance equations for concentration, drift velocity, and the averaged energy to describe the dynamics of space charge waves in a thin GaN film takes following form:

$$\frac{\partial n}{\partial t} + div(n\vec{v}) = 0$$

$$\frac{d\vec{v}}{dt} = \frac{\partial \vec{v}}{\partial t} + (\vec{v}\nabla)\vec{v} = \frac{e\vec{E}}{m^*(w)} - \frac{1}{nm^*(w)}\nabla(nT) - \vec{v}\gamma_p(w);$$

$$\frac{dw}{dt} = e\vec{E}\vec{v} - \frac{1}{n}\nabla((n\vec{v} - k\nabla)T) - (w - w_{00})\gamma_w(w)$$

$$T = \frac{2}{3}\left(w - \frac{m^*(w)v^2}{2}\right); k = \frac{5nT}{2m^*\gamma_p(w)}$$

Here $n$, $v$, and $w$ are electron concentration, average velocity, and average electron energy; $\gamma_p$, $\gamma_w$ are momentum and energy relaxation frequencies; $m^*$ is the effective mass, $T$ is the electron temperature in energetic units, $\kappa$ is the thermoconductivity coefficient; $w_{00}$ = 0.039 eV is the electron energy at 300 K; $\gamma_p$, $\gamma_w$, $m^*$ are functions of the average electron energy $w$. Thermoconductivity is not essential up till the frequencies 2..3 THz. From stationary dependencies $v = v(E)$ and $w = w(E)$, it is possible to get the relations $E = E(w)$, $v=v(w)$, $\mu = v(w)/E(w) = \mu(w)$, then the relaxation frequencies can be calculated as:

$$\gamma_p(w) = \frac{e}{m^*(w)\mu(w)}; \; \gamma_w(w) = \frac{e\mu(w)E^2(w)}{(w - w00)} \quad (2)$$

The results of direct simulations of $k(f)$ ($f$ is frequency and $k = k' + ik''$ is complex) of set linearized equations (1) is showed in Fig. 2, with different film thickness. The typical output spectrum of electromagnetic signal is given in Fig. 3. The input frequencies are $f_1$ and $f_2$ and amplitudes of the input electric microwave signal are $E_{m1}$ and $E_{m2}$, respectively. One sees both the amplified signal at the first harmonic of the input signal and the second and third harmonic of the input signal, which is generated due to nonlinearity of SCWs. The spatial distributions of the alternative part of the electric field, $E_z$, of space charge wave in 1D is shown in Fig. 4a, and for 2D are shown in Fig. 4b.

## CONCLUSION

A numerical study about the nonlinear interaction of space charge waves in n-GaN films possessing negative differential mobility has been presented. A microwave frequency conversion using the negative differential conductivity phenomenon is carried out when the harmonics of the input signal are generated. The nonlinear effects can be technologically profiteers for the design and fabrication of new kind of semiconductor devices that operate in the microwaves and millimeter waves range.

## ACKNOWLEDGEMENT

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## REFERENCES

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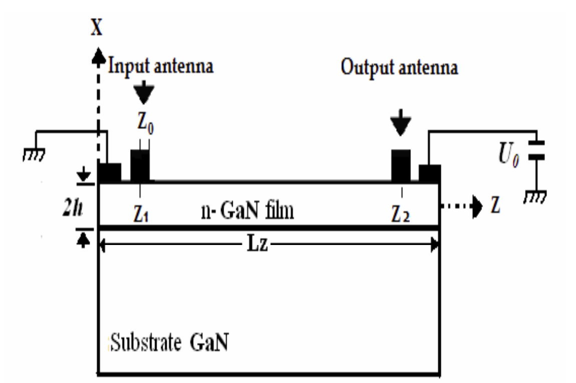


Fig. 1. The structure of the n-GaN traveling-wave amplifier fabricated with an epitaxial layer.

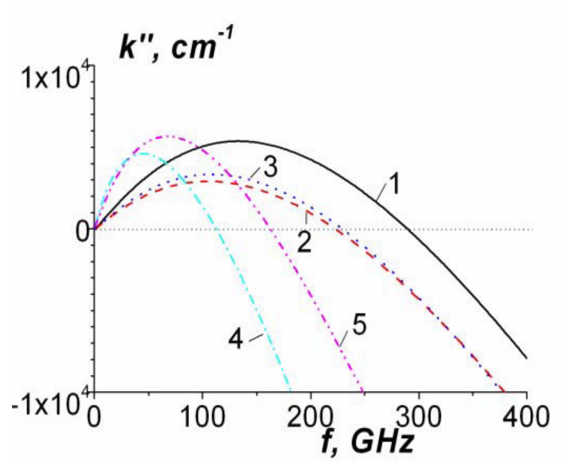


Fig.2. The spatial increments k´´(f). Curve 1 is for $E_0$ = 150 kV/cm, Nd = 1.5 x1017 cm$^{-3}$; 2 is for $E_0$ = 150 kV/cm, Nd = 1 x 1017 cm-3; 3 is for E0 = 160 kV/cm, Nd = 1.5x10$^{17}$ cm-3; 4 is for $E_0$ = 150 kV/cm, Nd = 1.5x 10$^{17}$ cm-3, $x_0$ = 0.05 µm (reduced mobility at the boundaries); 5 is the same as 4, but with nonuniform doping, $x_d$ = 0.02 µm.

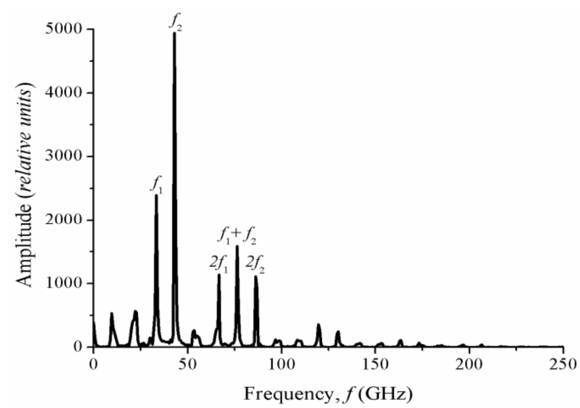


Fig. 3. Spectral components of the electric field of space charge waves at the output antenna using signals with the following parameters: Amplitudes $E_{m1}$ = 0.0015 kV/cm and $E_{m2}$ = 0.04 kV/cm and frequencies $f_1$ = 33 GHz and $f_2$ = 43 GHz, respectively.

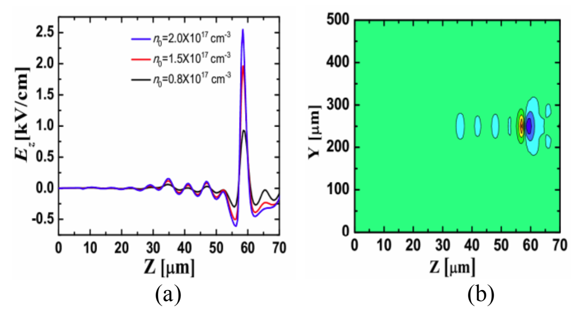


Fig. 4. Spatial distributions of the alternative part of the electric field, $E_z$, of space charge wave in 1D (a) and 2D (b) along the n-GaN film in Z direction.