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Numerical Simulations of Propagation of SCWs in Strained Si/SiGe Heterostructure at 4.2 and 77 K

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Abstract

The propagation and amplification of space charge waves (SCWs) in a strained Si/SiGe heterostructure at 4.2 and 77 K has been studied by means numerical simulations, using the negative differential conductance phenomenon. The results indicate the possibility of a major amplification of SCWs on the surface of this heterostructure at 4.2 K, until frequencies $f < 44$ GHz at 4.2 K and $f < 40$ GHz at 77 K.

Introduction

High-speed heterostructure device is a new topic to high speed semiconductor devices, but how almost all modern technology is Si-based, the high-speed heterostructure also need to be compatible with Si. In this paper, we present 2D simulations of propagation and amplification of space charge waves in a strained Si/SiGe heterostructure at 4.2 and 77 K, using the negative differential conductance phenomenon described in [1]. The two-dimensional electron gas is in a strained Si (100) layer on relaxed SiGe substrate. We have used the quasi-hydrodynamic model added by the Poisson's equation to describe non-stationary carrier transport, which incorporates the population transfer between two different valleys, the lower and upper valleys. The model used is two-valley model, which is described in [2]. It uses two-dimensional electron gas model and with numerical simulations based on solving a set of nonlinear partial differential equations for non-local carrier transport and the Poisson's equation for electric field can be simulated the propagation of space charge waves. These results are very import because they explain the physical and mathematical models of space charge wave excitation, propagation, interaction and reception in such heterostructure.

Electron Transport

Fig. 1 shows the strained Si/SiGe herostructure. The excitation of space charge waves takes place in the input coupling element (input antenna, 1) at a frequency of the microwave range and the amplified space charge waves are received in the output coupling element (output antenna, 2) on the plane of strained Si/SiGe layer.

The following parameters have been chosen: 2D concentration of electrons in the film is $n_0 \approx 10^{12}$ cm^{-2}, the initial uniform drift velocity of electrons is $V_0 \approx 1.7 \times 10^7$ cm/s (E_0 = 10 to 11.7 kV/cm), the length of the film is L = 10 µm, the thickness of the film is $2h$ = 0.5 µm.

Fig. 2 shows the calculated steady-state drift velocity as a function of electric field at 4.2 and 77 K, where negative differential conductivity appears beyond 10 kV/ cm. This is due to the transition of electrons from twofold valley to the fourfold valley where the effective mass is heavier.

Discussion and Results

In [3] we showed the possibility of amplification of space charge waves in a strained Si/SiGe heterostrusture at 77 K with all details, but now we make analysis at 4.2 K too. Fig. 3 and fig. 4 show the typical output spectrum of the electromagnetic signal at 77 and at 4.2 K, respectively. It happens when a small microwave electric signal $E_{ext} = E_m \bullet sin(\omega t) \bullet exp(-((t-t_1)/t_0)^2) \bullet exp(-((z-z_1)/z_0)^2)$ is applied in the input antenna and the excitation of space charge waves in 2D electron gas takes place. The input carrier frequency is $\omega = 8 \times 10^{10}$ rad/s. The amplitude of the input electric microwave signal is E_m = 0.025 kV/cm. Here z_1 is a position of the input antenna, z_0 is its half-width, therefore, the parameter $2t_0$ determines the duration of the input electric pulse. In our simulations the duration of the input

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pulse is $2t_0$ = 2.5 ns. The maximum of the input pulse occurs at t_1 = 2.5 ns. One can see both the amplified signal at the first harmonic of the input signal and the second harmonic of the input signal, which is generated due to nonlinearity of space charge waves.

Fig. 5 shows the alternative part of the electron concentration $\tilde{n}/n_0$, where n_0 is the concentration in equilibrium $n_0 \approx 10^{12}$ cm^{-2}. The maximum variation is in the output coupling element.

CONCLUSION

We show the propagation and amplification of space charge waves in a strained Si/SiGe heterostructure at 4.2 and 77 K by numerical simulations. We have a major amplification at 4.2 K, it is due to the dynamic range in the negative differential conductance. Furthermore, the scope of space charge waves applications is not limited to the device here described, but can be useful to monolithic phase shifters, delay lines, as well as analog blocks for microwave signals.

ACKNOWLEDGEMENT

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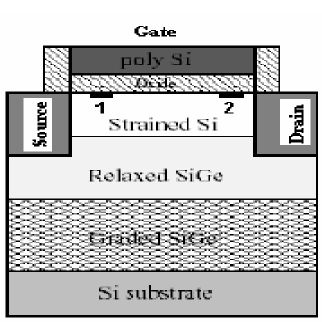

Fig. 1. Cross-section of the strained Si/SiGe heterostructure, 1 and 2 are input and output antenna respectively.

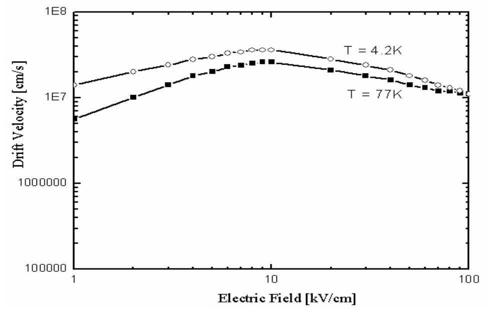

Fig. 2. Steady-state drift velocity as a function of electric field in strained Si/SiGe heterostructure at 4.2 and 77 K.

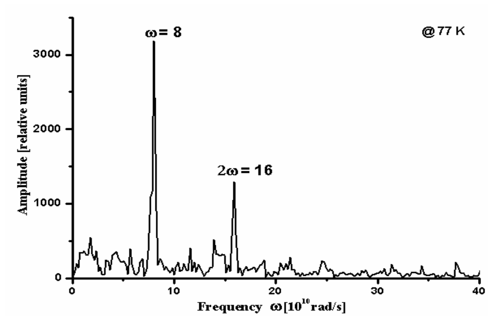

Fig. 3. Spectral components of the electric field of space charge wave at the output antenna with an excitation input signal (ω = 8 x 10^{10} rad /s) at 77 K.

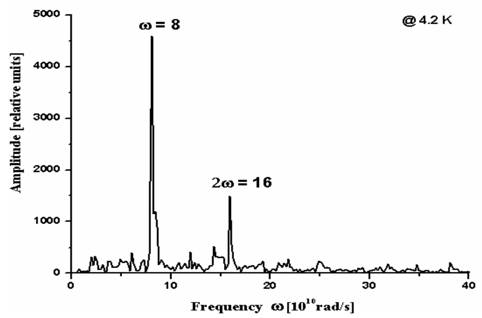

Fig. 4. Spectral components of the electric field of space charge wave at the output antenna with an excitation input signal (ω = 8 x 10^{10} rad /s) at 4.2 K.

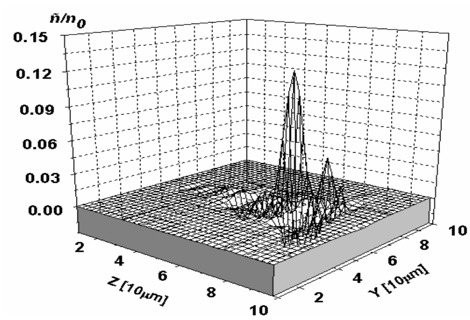

Fig. 5. The spatial distribution of the alternative part of the electron concentration $\tilde{n}$.