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Transient Device Simulation Using Deterministic Boltzmann Equations Solvers

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Abstract

The transient simulation of semiconductor devices using a deterministic Boltzmann equations solver is presented. In order to avoid the numerical difficulties originated from the conventional H-transformation, the kinetic-energy-based scheme is adopted. Within the kinetic-energy-based scheme, the transport parameters become time-independent, therefore, implementing the transient simulation capability can be done easily. Preliminary results for a device are shown.

Introduction

The terahertz (THz) technology has gained much research interest worldwide. However, realization of a THz emitter with a small form factor is still a difficult task. The plasma instability in the two-dimensional (2D) electron gas has been proposed as a possible mechanism to enable an extremely fast semiconductor device operating in the THz frequency range [1].

Recently, we have reported the numerical simulation results of plasma oscillation in two-dimensional electron gas [2]. A periodic steady-state solver has been used to obtain the oscillating solution efficiently. The set of governing equations contains the 2D Poisson equation, the electron continuity equation, and the electron current density equation. The time derivative of the current density and the convective derivative are considered in the electron current density equation. It has been numerically verified that inclusion of those terms are mandatory to support sufficiently strong plasma instability in the 2D electron gas.

However, it is noted that the set of governing equations adopted in [2] is based on the moments of the Boltzmann equation. It is not sufficiently accurate to describe the behaviour of plasma waves quantitatively [3]. A more advanced modelling approach is required. In order to solve this issue ultimately, the Boltzmann equation solver with the transient simulation capability is mandatory.

Although the stochastic Boltzmann equation solvers (the Monte Carlo simulators) have been used to simulate a device operating in the THz frequency range (for example, [4]), the stochastic nature of the Monte Carlo simulators introduces some numerical difficulties. Therefore, the deterministic Boltzmann equation solver is desirable. In this work, our motivation is to present some transient simulation results using a deterministic Boltzmann equation solver.

Projected Boltzmann Equation

The Boltzmann equation is a microscopic transport equation. It governs the spatiotemporal motion of the electron gas in a semiconductor device. Since it is defined on the phase space, evaluating its solution is a highly non-trivial task.

As discussed above, the stochastic Monte Carlo method can be applied to solve the Boltzmann equation efficiently. However, nowadays, the deterministic Boltzmann equation solvers [5] have gained popularity. In these solvers, the angle-dependent part of the electron distribution function is expanded

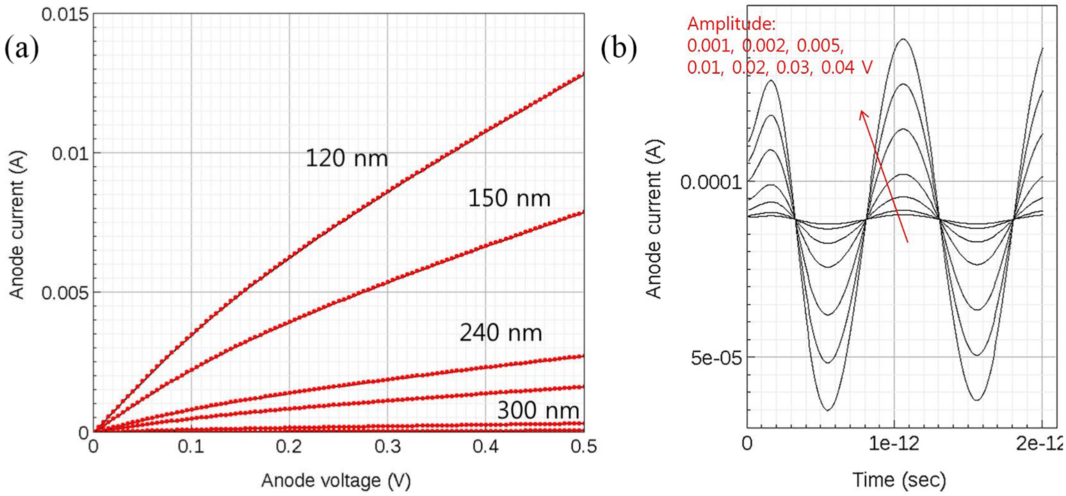

Figure1 (a) DC IV characteristics of various N^+NN^+ devices, which are obtained from the deterministic Boltzmann equation solver. (b) Transient results of an N^+NN^+ device whose total length is 1200 nm. The DC bias voltage is 0.8 V. AC voltages of 1 THz with various amplitudes are applied to the anode terminal. The first two periods are simulated.

with basis functions. Depending on the dimensionality of the momentum space, there can be a few variants of deterministic Boltzmann equation solvers. In this work, the three-dimensional momentum space is understood. Therefore, the spherical harmonic expansion [6] is the appropriate technique. A numerical stabilization scheme called the H-transformation [6] has played an important role in the development of this simulation technique. In the H-transformation, the total energy (which is a sum of the kinetic energy and the potential energy) instead of the kinetic energy is used as the energy variable.

Unfortunately, when the transient simulation is concerned, the H-transformation introduces a serious difficulty [7]. The time-varying potential energy yields the time-varying transport parameters. Unavoidable interpolation procedure prevents the transient simulation capability eventually. Of course, the fundamental solution to the above problem is to invent yet another numerical stabilization scheme, which does not suffer from the time-varying transport parameters. Since it is currently a formidable task, in this work, we simply apply the kinetic-energy-based scheme [8] to get the preliminary solutions.

Numerical Results

A spherical harmonics expansion solver has been newly implemented into our in-house device simulation framework [2]. All parameters for Si are taken from [6]. The lowest expansion order is used. Various N^+NN^+ devices are simulated. Figure 1(a) shows the DC IV characteristics of those devices. The transient simulation results of the 1200-nm-long device are shown in Figure 1(b). The DC bias voltage is 0.8 V. The frequency of the AC voltage is 1 THz. It is clearly demonstrated that our deterministic Boltzmann equation solver can perform the transient simulation at such a high frequency without any numerical problem.

Conclusion

In this work, the transient device simulation results using a deterministic Boltzmann equation solver based on the spherical harmonics expansion has been presented. In order to avoid the numerical difficulties originated from the H-transformation, the kinetic-energy-based scheme is adopted. The numerical results demonstrate that both of DC and AC analyses can be performed without any numerical problem. It is expected that this simulator can be applied to the THz devices based on the plasma instability.

Acknowledgements

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