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Electron Transport Modeling of GaN-based HEMT's by Poisson-Schrodinger Cellular-Automaton Coupled Approach

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Abstract

Self-consistent analysis of Poisson-Schrodinger and cellular automaton is applied to electron transport modeling of GaN-based HEMTs. Like the Monte Carlo method, it treats electron scattering phenomena, but by not using random numbers for stochastic phenomena, extremely stable solutions can be obtained even in low electric fields, and high-accuracy modeling is possible in a short time. The results show that the confinement of a thin GaN film reduces the effective channel thickness and degrades the electron mobility of the channel electron. The proposed method, which can seamlessly analyze electron transport in HEMT channels from low to high electric field, is a powerful tool for HEMT layer design.

1. Introduction

GaN-based HEMTs are required to have higher performance in the field of millimeter wave communication [1]. The design of the channel layer structure is important for HEMT devices, and high-precision prediction of electron transport covering low to high electric fields corresponding to various channel layer structures is required. For 2DEG electron transport, the hybrid of Poisson-Schrodinger and Monte Carlo method has been the standard approach [2]. The Monte Carlo method has been well established, but noises due to random numbers are a problem in low electric field analyses. It is also a problem to get enough statistics of rare electrons in higher subbands and valleys.

We proposed a flux interpolation cellular automaton method for 2DEG modeling [3]. A numerical table of the distribution function is prepared for each subband of 2DEG, and the change of the distribution function is deterministically followed, so that the distribution function can be stably obtained. With this method, it is possible to obtain electron distribution functions over dozens of orders in higher level subbands and upper valleys. Coupling with the Poisson-Schrodinger method, the proposed method is a powerful tool for electron transport modeling of HEMTs. In this report, we study the mobility dependent on the channel GaN film thickness and discuss the effects of interface roughness scattering on the mobility.

2. Simulation methods

Fig. 1 shows a concept of the proposed method. The electrons are represented by a numerical table of their distribution functions prepared for each subband. Fig. 2 is the algorithm of the method. An initial distribution function table is created from the electron concentration distribution obtained by the Poisson-Schrodinger method. The distribution function is updated by the cellular automaton method, and the electron transfer between subbands causes the redistribution of the electron concentration. The redistributed electron profile is returned to the Poisson-Schrodinger solver, to get a consistent solution by self-consistent iterations.

Physical models compatible with the Monte Carlo method [4][5] are used. The conduction band is non-parabolic, and two upper valleys with heavy effective mass can be considered. Acoustic phonon scattering, polar, non-polar and intervalley optical phonon scattering, and interface roughness scattering are considered. The subband calculation considers the influence of the Schottky electrode and of the strain induced interface charge.

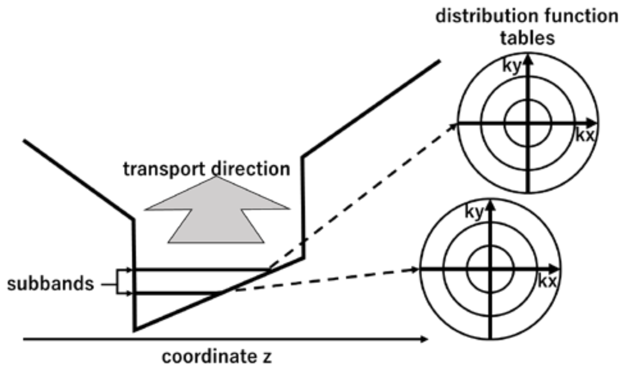

Fig. 1 Concept of the present method. Numerical distribution function tables are prepared for each subbands.

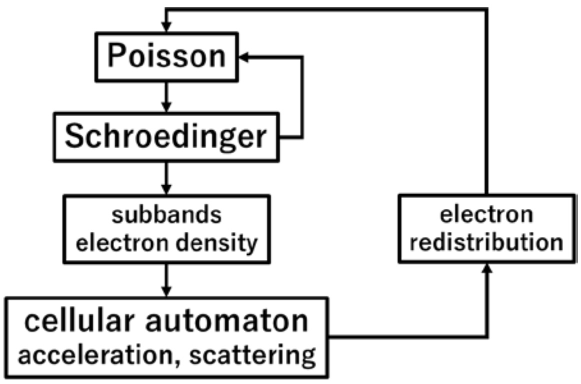

Fig. 2 Algorithm of the proposed method.

3. Results and discussions

Fig. 3 shows the test channel structure of an AlGaN/GaN/AlGaN HEMT. Strain-induced charges were assumed at each interface. Fig. 4 shows the results of the Poisson Schrodinger analysis when the channel GaN layer thickness is 10 nm. The e subband energies from the bottom are shown along with the conduction band profile. The electron concentration profile is obtained from these energy levels. In this case, the induced areal density of electrons is the order of 10^{12}/cm2. The conduction band has a steeper slope toward the interface because electrons are concentrated near the interface.

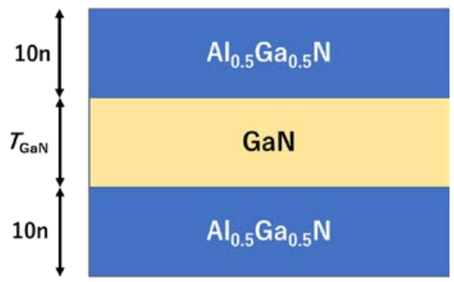

Fig. 3 The HEMT device structure to be discussed.

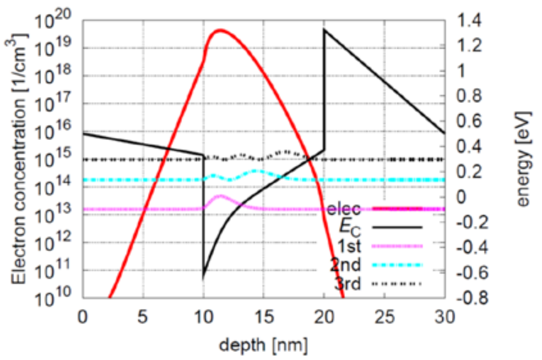

Fig. 4 Poisson Schrodinger results for channel GaN thickness of 10 nm.

Fig. 5 shows the electron velocity over time when an electric field of 1 kV/cm is applied in the direction of channel electron acceleration. Unlike the Monte Carlo method, the proposed method obtains the smooth velocity overshoot curves even for low electric field conditions. Since the cellular automaton method always holds the distribution function, it is possible to seamlessly handle the difference in electron concentration between subbands when the energy difference between subbands is large or small. This means that the method is also robust for changing the gate voltage.

Fig. 6 shows the dependence of electron velocity on the GaN channel film thickness at an accelerating electric field of 1 kV/cm. Three curves are for the cases with two sets of interface roughness parameters, and for the case ignoring the interface roughness. A Gaussian correlation model with an average displacement Δ and its spatial spread Λ was used for the interface roughness. Assuming the interface roughness parameter, the speed decreases regardless of the film thickness. It is worth mentioning that the electron velocity slightly degrades for thinner cases even without surface roughness considerations.

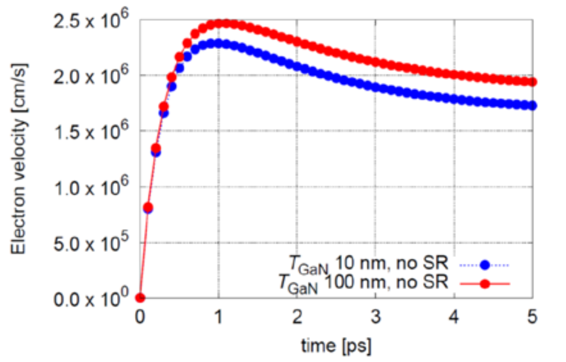

Fig. 5 Drift velocity overshoot of the channel electrons.

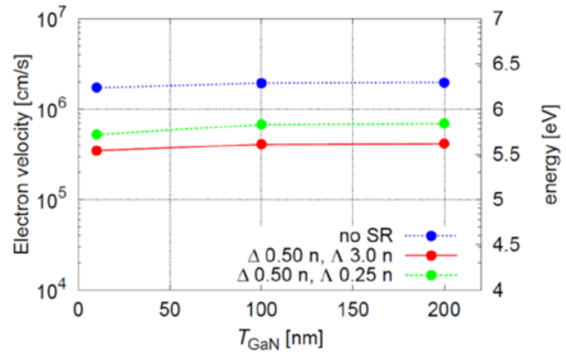

Fig. 6 GaN channel thickness dependence of electron low field drift velocity for various interface roughness cases.

4. Conclusions

The self-consistent solutions of Poisson-Schrodinger method and cellular automata method were applied to the electron transport modeling of 2DEG of GaN-based HEMT. Low field mobility tends to decrease with thin channel GaN film thickness, and especially interface roughness scattering causes large mobility degradation. Thus the proposed method reveals the detailed electron transport phenomena both qualitatively and quantitively.

Acknowledgements

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