Quasi Self-consistent Monte Carlo Particle Simulations of Local Heating Properties in Single Layer Graphene Nano-channel FETs

S. Oki, T. Misawa, and Y. Awano
Keio University, Yokohama 223-8522, Japan
E-mail: awano@elec.keio.ac.jp

ABSTRACT

In this paper, we report a new algorithm for Monte Carlo quasi self-consistent particle simulations of both electron and phonon transport in nanometer-channel FETs, based on computer time saving considerations. We simulate a local heating properties of a Single layer graphene (SLG) FETs for the first time, comparing with that of a conventional GaAs devices.

INTRODUCTION

Due to high density integration of LSIs and high power applications, thermal management becomes more and more important. Besides, Graphene has received much attention as an emerging research material for future nanoelectronics, because of its excellent electrical, thermal and mechanical properties.

In an advanced electron device scaled below or comparable to the size of electron mean-free-path, Monte Carlo particle simulation method has been used as the most reliable and accurate method to calculate non-stationary electron transport [1]. Similarly, when the mean-free-path of the phonon becomes comparable to the size of device, thermal properties should be analysed for non-stationary state phonon transport. Monte Carlo particle method for both electron and phonon transport [2] must be the most accurate theoretical approach. However, because of a large difference in time-scale between electron and phonon transport phenomena, such a self-consistent simulation with realistic computer time must be very difficult and important for future phonon engineering. In this paper, we propose a new quasi self-consistent algorithm for Monte Carlo method with a reasonable computing time and report electrical and thermal properties of Single layer Graphene (SLG) nano-FETs for the first time.

SIMULATION METHOD

Figure 1 shows the algorithm of our simulation. It consists of two parts; an electron transport part to obtain spatial distributions of phonon emission and absorption and a phonon transport part to estimate local heating in the device. In this process, we developed two simulation procedures. First, we made a program to estimate a local temperature from phonon spatial distribution, where we used a Bose-Einstein distribution function, phonon density of states and phonon generation rate, which were obtained by Monte Carlo simulations (Fig. 2). Secondly, we developed a new algorithm, which made it possible to calculate long time phonon transport by introducing different time steps for electron and phonon transport simulations (Fig. 3). In the new algorithm, first, we only calculate electron transport for a short period of time ΔT and obtain phonon spatial distribution. Then, only phonon transport is calculated for long period of time, where phonon particles are generated at each time step of ΔT based on the simulated spatial distribution of phonons. After that, we calculate a local temperature in the channel and electron-phonon scattering rates. By repeating this process, we can analyse phonon transport for a long period of time in extremely short computation time. By these methods, we succeeded in calculating both electron and phonon transports self-consistently for a reasonable computation time. The phonon velocity is derived from the phonon dispersion curve of SLG [4]. The phonon-phonon scattering rate is assumed to be a constant value for each material.

RESULTS AND DISCUSSION

Using the new method, we succeeded in analyzing local heating phenomena in nano-scale Single layer graphene (SLG) FETs, quantitatively. Figures 4 show the simulated results of SLG and GaAs channel temperature at 500 ns after applying voltage to the device. The gate length Lg is 100 nm. Figure 5 shows the peak channel temperature

978-3-901578-26-7

between both devices. The local heating in the SLG channel is much smaller than that of GaAs channel. It is probably due to high speed optical and acoustic phonon transport in SLG, even though the heat generation rate in SLG is much higher than that of GaAs.

CONCLUSION

Thermal property of SLG-channel nano-FETs is simulated. We developed two kinds of simulation procedures for Monte Carlo method, which lead to quasi self-consistent simulations of electron and phonon transport in nano-sale devices for a reasonable computing time. Our method can be applied other materials for power device applications, in which a local heating is more crucial in determining device performance.

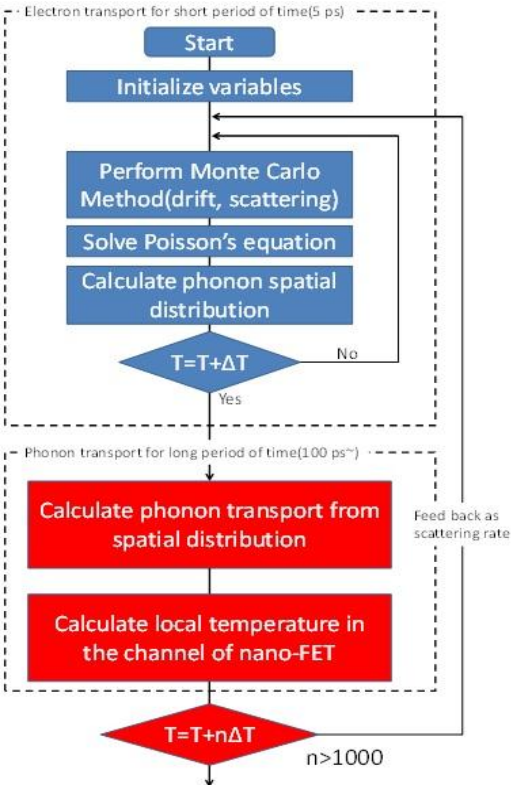
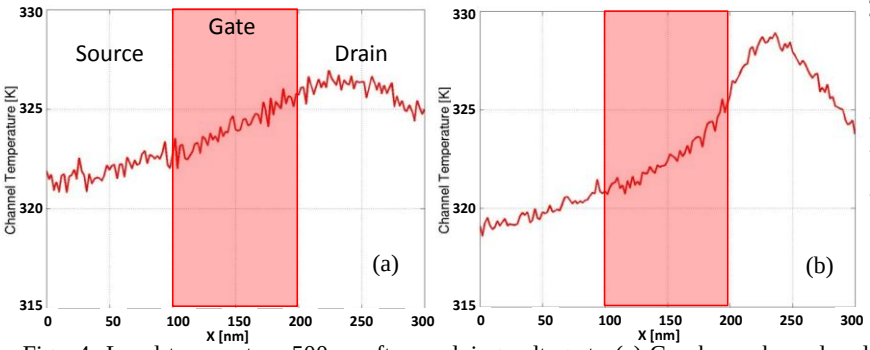


Fig. 1 Algorithm of Quasi Self-consistent Monte Carlo method for electron and phonon transport



Figs. 4 Local temperature 500 ns after applying voltage to (a) Graphene channel and (b) GaAs channel FETs (Lg=0.1 μm)

ACKNOWLEDGEMENT

The authors would like to thank Professor K. Tomizawa of Meiji University and Professor S. Murakami of Tokyo Institute of Technology for their helpful suggestions and discussions. This research is supported by JSPS through its FIRST Program.

REFERENCES

[1] N. Harada et al., APEX, 1, (2008) 024002
[2] Y. Kamakura, et al., SISPAD 2010, (2010) pp. 89 - 92
[3] D. L. Mafra, et al., Phys. Rev. B 76 (2007) 23340

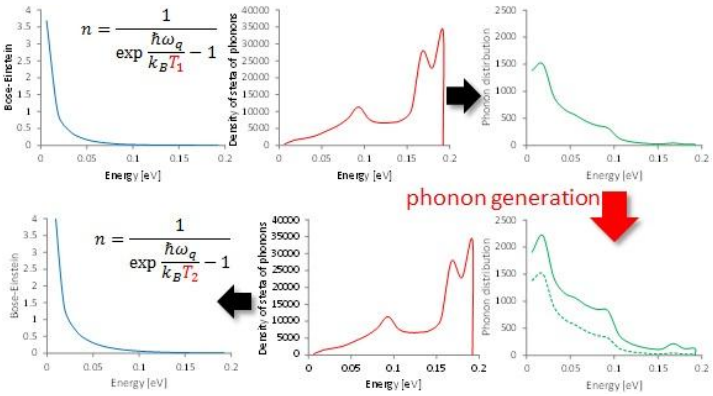


Fig. 2 Schematic of estimation method of a local temperature from phonon population

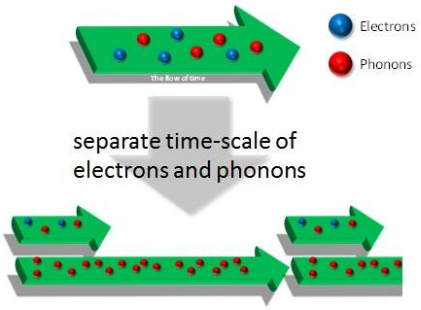


Fig. 3 Schematic of quasi self-consistent simulation procedure for both electron and phonon transport

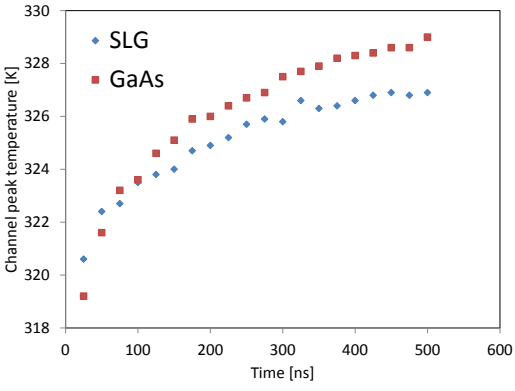


Fig. 5 Local heating in SLG and GaAs channel FETs (Lg=0.1 μm)