Studies on Heat Generation Processes in Heavily Doped Semiconductor Devices

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Abstract:

Semiconductor devices are attractive for their power capability and linearity in microwave and millimeter wave applications. Energy conversion processes in the operation of semiconductor devices are associated with the generation of heat. The effects of heat generation on the performance of semiconductor devices have been widely studied. Due to size reduction to sub-micron range or increase in packing density, heat generation seriously affects the reliability and lifetime of sub-micron devices. With increasing complexity of semiconductor devices, the need for accurate simulation also increases. Moreover, if the sample be irradiated by chopped light, it will be periodically heated leading to thermal expansion. As a result, elastic waves will be developed in the sample. Under illumination, heat is generated due to photo-acoustic effect through energy relaxation of photo-generated carriers within the bands, non-radiative recombination and absorption processes within the heavily doped opto-electronic devices along with other processes. Photo-acoustic measurements of the energy conversion efficiency of photovoltaic devices and internal efficiency of Schottky diodes have been reported. To reduce the thermal impact, a detailed study on heat generation mechanisms must be carried out.

Here, a model has been developed to investigate different heat generation processes in semiconductor devices under heavily doped condition. The model may be used for semiconductors with position-dependent band as well as multi-valley, and multi-band structures. Fermi-Dirac statistics is taken into account along with an accurate treatment of electron-hole scattering. The photo-acoustic effect has been included taking into account the generation of free carriers, their diffusion and recombination. When the sample is irradiated by chopped light, electron-hole pair is generated, which transfers a part of the energy to the lattice. A relatively slow energy transfer follows this process to the lattice as a result of recombination. Investigations on the contributions of different processes to the heat generation have been made by various methods mostly through the solution of Poisson and Boltzmann transport equation. Crystal lattice is heated owing to recombination processes. In Auger recombination, two electrons and a hole or two holes and an electron by empty traps produce lattice heating. In SRH recombination, capture and emission of electrons produce lattice heating. In relaxation process, lattice heating occurs as a result of energy flow from hot carriers to the thermal phonons of the lattice. Phonon-phonon interaction causes lattice heating in phonon recombination process. The effects of Peltier heating and electron-hole scattering have also been taken into account.

From the various mechanisms as stated, contributions towards the heat generation are estimated. The model developed here deals with the establishment of the equilibrium in the various processes of heat generation and heat dissipation in heavily doped optoelectronic devices. The energy balance expressions are consistent with thermodynamic principles. The variation of heat generation with the change of carrier concentration is obtained through numerical analysis. Heat dissipation along the distance from the junction to the bulk has been estimated and compared graphically with some previous results.