Student Paper

Thermal Model of GaN-HEMT using Thermal Conductivity of Si/SiC on SiC Substrate

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High-power and high-temperature operations of AlGaN/GaN high-electron-mobility transistors (HEMTs) require efficient heat removal. This simulation compares and shows the effect of thermal conductivities of silicon carbide (SiC) and silicon (Si) in AlGaN/GaN HEMT on SiC substrate. In the study of these thermal conductivities over the temperature range of 300 ^{0}K to 415 ^{0}K, the thermal conductivity of SiC on GaN-HEMT is more efficient than of Si. Thus, SiC provides an improved cooling of HEMT devices. In this research, all other structures and parameters are kept constant except the thermal conductivity.

The excellent thermal and chemical stability of SiC and GaN enable them to operate at high temperatures, high-power and harsh environments [1]. A very important property of GaN-HEMT is the ability to dissipate heat to withstand high temperature without external source of cooling. As such, there is an increasing focus on the importance of self-cooling or self-heat transfer. Heat is dissipated faster when thermal conductivity of SiC is used because expansion coefficient of 3C-SiC which is 4.6 x 10^{-6}/K matches with the average expansion coefficient of 4.9 x 10^{-6}/K for GaN from 25^{0}C to 1000^{0}C [2]. In case of Si, the expansion coefficient over the same range of temperature shows the expansion mismatch with GaN. That is, expansion coefficient of silicon changes much more with temperature than that of GaN [2].The material properties of SiC which include exceptionally high breakdown fields, a large band gap, high electron saturation drift velocities and a large thermal conductivity make it suitable for devices requiring low leakage currents, high cut-off frequencies at large voltages, in temperature electronics [3].

Figure 1 and 2 shows the lattice temperatures of AlGaN/GaN with thermal conductivity of SiC and Si respectfully. On the left of both figures, figure 1 shows the gradient of temperature is lower than that of figure 2. With SiC thermal conductivity, the maximum temperature is 313K while it is 405K with Si thermal conductivity. As shown in figure 3, as temperature increases, the current flow in the devices reduces. The current density of AlGaN/GaN with SiC thermal conductivity is higher than with Si. This is due to the reduction in current with Si thermal conductivity because Si dissipates heat less than SiC. When the heat is generated in the GaN-HEMT, the current density reduces which has a major effect on the transistor application. This model shows the current density of using SiC and Si thermal conductivity in GaN-HEMT. Also, the electron velocity is higher with SiC thermal conductivity than with Si thermal conductivity.

The result indicates that with SiC thermal conductivity, heat is dissipated faster than with Si thermal conductivity because the thermal conductivity of SiC is higher than that of Si and as a result SiC thermal conductivity lower chips temperature in device. SiC provides an improved cooling of HEMT devices and efficient heat removal. In term of the current density, more current flows in GaN device that uses SiC thermal conductivity because of the low temperature due to the higher conductivity of SiC while the less current in GaN with Si thermal conductivity because of the high temperature due to low conductivity of Si.

References

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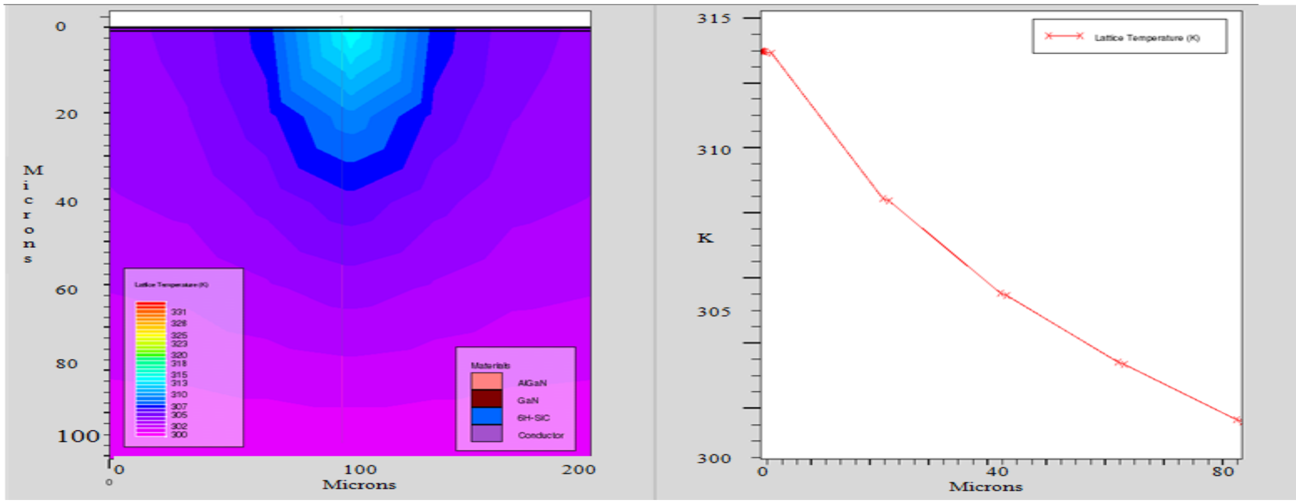

Figure 1: Lattice temperature of AlGaN/GaN with thermal conductivity of SiC at temperature range of 301K to 313K

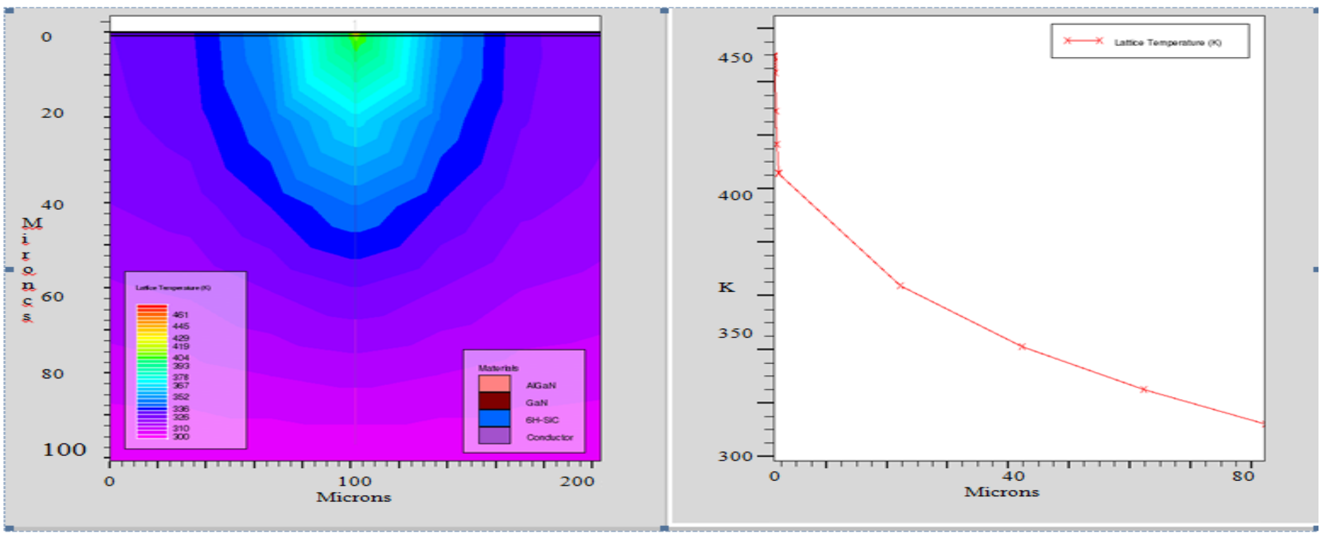

Figure 2: Lattice temperature of AlGaN/GaN with thermal conductivity of Silicon (Si) at temperature range of 315K to 405K

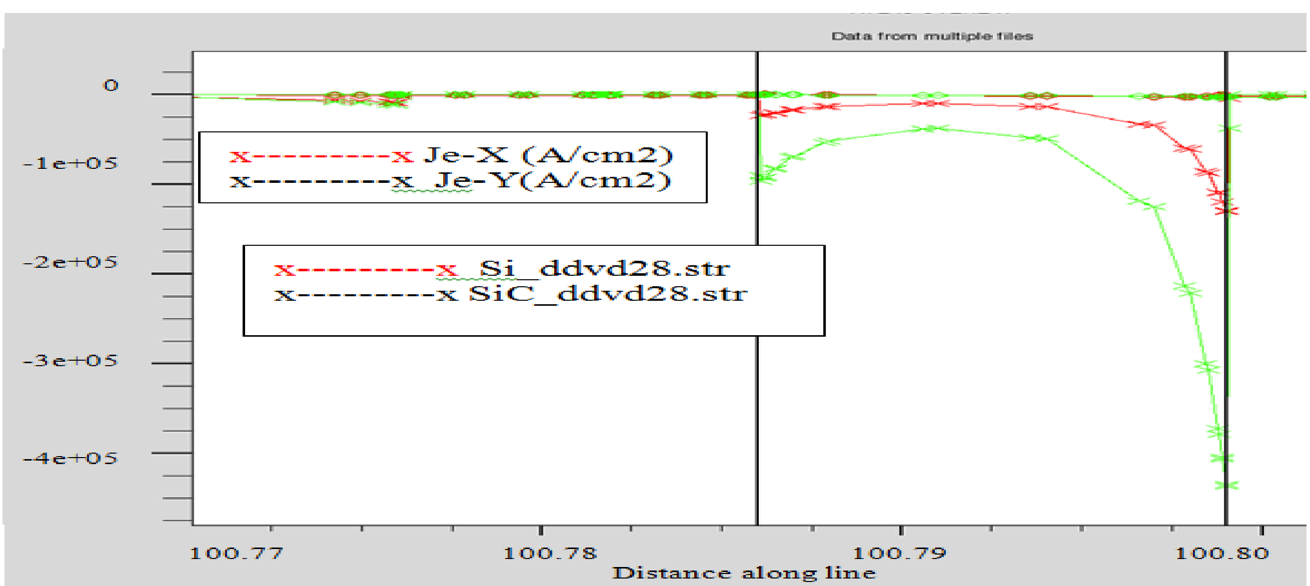

Figure 3: Comparison of the changes in current with temperature using current density curve. The red is the current density with Si thermal conductivity and the green is with SiC thermal conductivity