Thermal Conductivity of Ultra-Wide Bandgap Thin Layers: High-Al Content AlGaN and β-Ga_2O_3

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Ultra-high bandgap semiconductors have been increasingly important for high-power and high-frequency device applications. SiC and GaN have emerged as interesting materials offering very high breakdown voltage, almost one order larger than the commonly used semiconductors like Si or GaAs. A lot of efforts have also been spent on exploring new materials aiming at enhancing breakdown voltage of the power devices. Adding aluminum (Al) into GaN to make high-Al AlGaN alloy or switch to completely new materials such as β-Ga_2O_3 is already proved to increase the device breakdown voltage [1, 2]. However, there are several unsolved problems that raise a question about the possibility for practical devices applications. Alloy scattering in AlGaN due to the incorporation of Al element strongly degrades thermal conductivity of AlGaN. Very low thermal conductivity was found for β-Ga_2O_3 even it possesses relatively high phonon velocity which is comparable to GaN. Our study is aiming at determining and shedding the light on the physics behind the thermal conductivity of high-Al AlGaN and β-Ga_2O_3.

Our study on AlGaN [0001] and β-Ga_2O_3 [-201] thin films using time-domain thermoreflectance (TDTR) technique with the assistance of modeling based on Callaway-Debye formalism [3] found that AlGaN becomes more heat-resistive and its thermal conductivity is minimized at high-Al content ([Al] = 0.5-0.8) (Fig. 1a). The thermal conductivity value is reduced more than 10 times for sub-micrometer high-Al AlGaN film compared with GaN film of the same thickness. β-Ga_2O_3 layers show comparable value to high-Al AlGaN (Fig. 1b). Our analysis points out high thermal boundary resistance at heterojunctions of AlGaN and β-Ga_2O_3 with other materials (Au transducer in our sample structure). Phonon mismatch model cannot explain for the thermal boundary resistance of these two materials. Because of strong alloy scattering in high-Al AlGaN and strong normal scattering in β-Ga_2O_3, their phonon mean-free paths get closed to 10 nm comparable to surface roughness that might be the reason of remarkably increasing thermal boundary resistance.

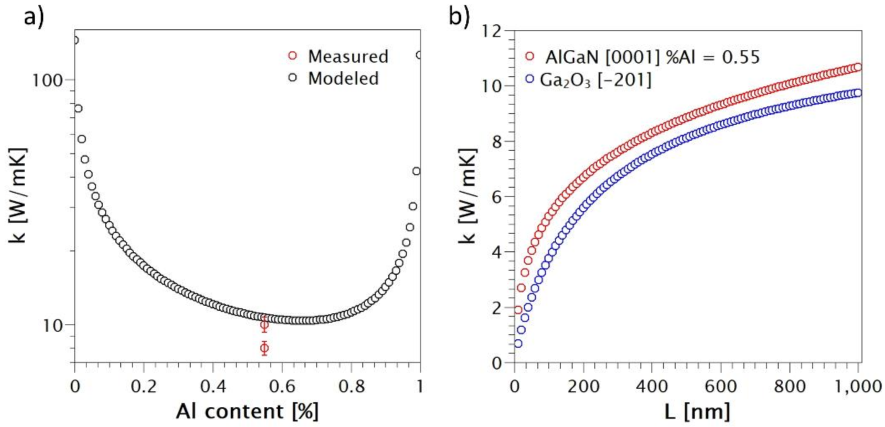

Figure 1. a) The measured and modeled data for Al composition dependent thermal conductivity of AlGaN, the thickness of 1 µm is used. b) A comparison of modeled thickness-dependent thermal conductivities between $Al_{0.55}Ga_{0.45}N$ [0001] and β-Ga_2O_3 [-201].

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