# Thermal conductivity of AlGaN layers grown by MOCVD

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The wide-bandgap semiconductors SiC and GaN have gained a significant importance in development of high-power electronic devices, because of their material-based figure-of-merit parameters which greatly surpass those of commonly used Si. Aiming at enhancing the breakdown voltage in power devices, large of efforts have recently been devoted to exploring of new, ultra-wide-bandgap materials. Such a material is AlGaN ternary alloy with a bandgap ranging from 3.4 eV up to 6 eV and a critical electric field up to 16 MV/cm [1]. However, there are several unsolved problems that raise a question about the possibility for practical devices applications, e. g. the alloy-disorder scattering is expected to strongly degrade electron and phonon transport in AlGaN. Our study is aiming at determining and shedding light on the physics behind the thermal conductivity of AlGaN.

The samples we have studied are nominally undoped AlGaN layers with varying Al content (from 0 to 70%) and thickness of 1-2 μm. The layers are grown by Metal Organic Chemical Deposition (MOCVD) either on a SiC substrate with AlN buffer layer or on a 2-μm-thick GaN layer grown on sapphire. The crystal quality and the Al composition of AlGaN layers are examined by XRD theta-2theta scan, high-resolution XRD reciprocal space mapping and electron-dispersive X-ray (EDX). Cross-section scanning electron microscopy (SEM) is used for a precise determination of the thickness of different layers. The heat flow through the samples is elaborately analyzed using a time-domain thermo-reflectance (TDTR) technique that allows solving the quasi-one-dimensional heat transport equation in the multi-stacked layer structure. Reference samples (without AlGaN layer) are also measured. The out-of-plane thermal conductivity, as well as the thermal boundary resistance (TBR) of the AlGaN is extracted from two-parameter fitting of this analyzing technique.

The experimental results show that the thermal conductivity of $Al_xGa_{1-x}N$ layers sharply decreases with increasing Al content and already at $x \approx 0.15$ it is more than one order smaller than that of a GaN layer of the same thickness. At higher Al content nearly constant values of the thermal conductivity is measured up to $x = 0.7$. The obtained data are in a good agreement with the theoretical calculations based on Debye-Callaway formalism. In these calculations, all resistive phonon-scattering processes are taken into account, namely the Umklapp phonon-phonon scattering, the phonon-point-defect scattering, the phonon-dislocation scattering and the phonon-boundary scattering, and the virtual-crystal model is applied. The material parameters extracted from the fitting of the thermal conductivity of the bulk binary compounds (GaN and AlN) are used as input parameters. In the virtual-crystal model, the phonon scattering by alloy disorder is treated as the phonon-point-defect scattering. By separating the contributions of different scattering processes we found that the Al composition dependence of the thermal conductivity of AlGaN follows the shape of the strength of the phonon-alloy-disorder scattering which appears to be the dominant scattering mechanism in this material. For layers thinner than 1 μm, an increasing contribution from the phonon-boundary scattering is also evidenced. The phonon-alloy-disorder scattering is found to not only degrade the thermal

conductivity but also to remarkably increase the TBR. The experimentally extracted data for TBR at the bottom of AlGaN layers cannot be simply explained by the phonon mismatch model which predicts an almost linear Al composition dependence.

The results from our study can be useful for the device structure optimization and the thermal management of the AlGaN-based electronic devices.

[1] R. J. Kaplar et al., ECS J. Solid State Sci. Technol. **6**, Q3061 (2017).