Crossover from Resistive to Ballistic Phonon Transport and Giant-Phonon Drag in Homoepitaxial ß-Ga_2O_3 Films

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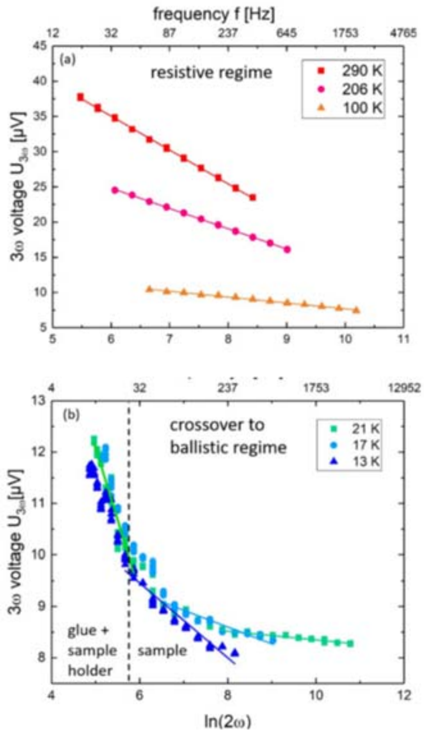
ß-Ga_2O_3 is a transparent ultra-wide bandgap (4,7-4,9 eV) semiconductor of topical research interest for deep UV-devices, gas sensors and high power electronic applications [1] with a predicted breakthrough electric field of E_b = 8MV/cm. A major challenge in electronic device design is heat dissipation due to the low room temperature thermal conductivity [2] which is approximately a factor of 8 and 30 lower than those of bulk GaN and SiC, respectively.

Here, we observe the cross-over from resistive to ballistic phonon transport [3]: The anisotropic thermal conductivity and the phonon mean free path (mfp) of monoclinic ß-Ga_2O_3 single crystals and homoepitaxial films are determined by the 3ω-method in the temperature range from 300 K down to 10 K. The measured effective thermal conductivity of *both*, single crystal and homoepitaxial films are in the order of 20 W/(mK) at room temperature, proving high quality *phonon-transparent homoepixial interfaces*. Below 30 K a maximum of 1000 to 2000 W/(mK) is achieved, decreasing with T^3 below 25 K. Analysis of the phonon mfp shows a dominance of phonon-phonon-Umklapp scattering above 80 K, below which the influence of point-defect scattering is observed. Below 30 K the phonon mfp is limited by the total ß-Ga_2O_3 sample size. Ballistic phonon transport is observed below 20 K and boundary effects of the total sample size become dominant. The resistive and ballistic phonon transport regimes in ß-Ga_2O_3 are discussed.

These findings open a route to harness the phonon-drag to enhance the thermoelectric functionality by a control of the electron and phonon interaction. Here, we demonstrate giant phonon-drag in homoepitaxially grown β-Ga_2O_3 films. We show that a decoupling of the cross sections of electron-phonon and phonon phonon interaction can be achieved by nanometer-thin homoepitaxial films with phonon-transparent epitaxial interfaces. For decreasing film thickness a crossover from three-dimensional to two-dimensional electron-phonon interaction takes place if Umklapp scattering dominates.



Examplary data: 3ω-voltage as a function of the logarithmic frequency for a 3μm homoepitaxial ß-Ga_2O_3 film on a single crystalline substrate in the [100]/[010] configuration. Crossover to the ballistic thermal transport regime at low temperatures (21 K – 13 K). The linear dependence $U_{3\omega} \propto \ln(2\omega)$ can clearly be seen.

References

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