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PhD dissertation abstract

Investigations of thermal conductivity of nitride semiconductors thin films

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During the last fifty years from the moment, when the first GaN-based light-emitting diode was presented, interest in fabrication and application of nitride devices systematically grew up. Today, GaN and GaN-based materials, such as AlGaN or InGaN, are used as ultraviolet detectors, laser diodes, high-electron mobility transistors and can potentially be used as thermoelectric materials. Self-heating is a serious problem in the case of high electron mobility transistors – it leads to decrease of their efficiency. If one wants to increase performance of those devices, it is necessary to use material with high thermal conductivity. On the other hand, good thermoelectric material has high electrical conductivity, high Seebeck coefficient and low thermal conductivity. One can see, it is important to define thermal conductivity of the material, used in the device.

Up to this day, thermal conductivity of bulk and film GaN was extensively investigated, while rather small amount of works was dedicated to determination of thermal conductivity of films and superlattices of GaN-based alloys. The objective of this thesis was the investigation of thermal conductivity of AlGaN films and AlGaN/GaN superlattices and explanation of heat transfer mechanisms in those materials.

For implementation of this task experimental setup for thermal conductivity measurement with the use of 3ω method was constructed. On this setup isotropic thermal conductivity of AlGaN films and anisotropic thermal conductivity of AlGaN/GaN superlattices were measured. For description of the obtained experimental results was used Callaway model together with the virtual crystal model.

Isotropic thermal conductivity of 500 nm-thick $Al_xGa_{1-x}N$ films ($x = 0.045$, 0.075, 0.102) was measured in the temperature range from 150 K to 300 K. Thermal conductivity increased with both increasing temperature, and this temperature dependence can be explained with dominance of phonon-boundary and phonon-alloying element scattering mechanisms. Also a decrease of thermal conductivity with increasing amount of Al was observed and increasing role of scattering of phonons on alloying element atoms is responsible for such behavior.

In-plane and cross-plane thermal conductivities of $Al_xGa_{1-x}N/GaN$ (x = 0.225, 0.240, 0.250, 0.280) superlattices with the period thicknesses (which is equal to sum of the thickness of AlGaN and GaN layers) ranging from 44.6 nm to 4.8 nm was measured from 147 K to 325 K. Opposite temperature dependencies of thermal conductivity were observed – in-plane thermal conductivity decreased, while cross-plane – increased with increasing temperature. Superlattice thermal conductivity was calculated with the use of Callaway model; frequency dependence of phonon-boundary relaxation time was taken into account. Results of calculations shown, that long-wavelength phonons are the dominant heat carriers. Decrease of thermal conductivities with decreasing period thickness was observed. Scattering of the phonons on the layer boundaries leads to this thermal conductivity dependence on period thickness, moreover, influence of this scattering increases with reduction of the layer thickness.