熱輸送のスペクトル学的理解と機能的制御
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分極場工学による界面フォノン輸送の最適化

Optimizing the interface phonons transport for thermal dissipation through polarization field engineering

§１. 研究成果の概要

As a result of the tremendous minimization and high-power requirement for the AlGaN/GaN high electron mobility transistors (HEMTs), the efficient thermal dissipation is becoming an important topic. Diamond has the highest thermal conductivity among any known materials, and is utilized as the effective heat spreader for HEMTs. However, diamond and GaN have a large acoustic mismatch (>11%), leading to a large thermal boundary resistance (TBR) at the interface. Due to the poor physical understanding of the thermal transport through the solid-solid interface especially in the nanometer scale, there is **NOT** an effective thermal management strategy to reduce this large TBR. In this project, we propose to introduce an electrical field at the interface to enhance the thermal phonon transport from GaN to diamond. This electrical field will be generated at the nitride superlattice (ex. GaN/AlN, InGaN/GaN) from the piezoelectric field in the structure due to the lattice mismatched induced strain. The phonon transmission probability can be significantly affected by the piezoelectric field, which will help to enhance the thermal transport.

In Y2019, we experimentally demonstrated the piezoelectric field could reduce the TBR at the Al/GaN interface and the high-quality AlN/GaN superlattices were epitaxially grown by MOCVD. In Y2020, the thermal boundary resistance TBR was successfully reduced by using a strained AlN and InGaN interlayer, and the mechanism of TBR reduction was theoretically explained. The intensity of the piezoelectric field was then experimentally measured. In Y2021, the achievements include: 1) the phonon coherence was achieved in nitride superlattice structure. It was found that, at the high-quality GaN/AlN superlattices and InGaN/GaN superlattices, the phonon coherence can be achieved when the period thickness is lower than phonon mean free path. But at the high-density interface, the coherence starts to be disturbed due to larger strain and degraded interface morphology. 2) highly orientated polycrystalline diamond film was deposited on GaN template by micro-plasma chemical vapor deposition.[1] Nanodiamonds was proposed as the seeds. The diamond film has a thermal conductivity approaching 250W/mK when the thickness is ~1 um, belonging to the high level for polycrystalline diamond film. With nanodiamond seeding, the thermal boundary resistance was estimated to be $7m^2K/GW$ between diamond film and GaN, which is much lower than those with SiNx of AlN interlayers. 3) From simulation, the phonon transportation from GaN to diamond was investigated with respect to different scattering and piezoelectric field. It was found that, the interface roughness greatly influences the high-frequency phonon transportation, and the piezoelectric field can enhance the phonon transmission probability especially for high-frequency phonon.

【代表的な原著論文情報】

1) “Diamond as the heat spreader for the thermal dissipation of GaN-based electronic devices”, Functional Diamond, vol. 1, No. 1, pp.174-188, 2021