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

§１. 研究成果の概要

Due to 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 in the real applications. As a result of the large acoustic mismatch (>11%) between GaN and their heat spreader (diamond), a large thermal boundary resistance (TBR) was observed at the interface, leading to the large amount of heat concentration. Due to the poor physical understanding of the thermal transport through the solid-solid interface especially from the nanometer scale, there is NOT an effective thermal management strategy to solve the above problem. In this project, we propose to utilize the piezoelectric effect to enhance the thermal phonon transport from GaN to diamond. The low frequency phonons can be significantly affected by the piezoelectric field, which will help to enhance the thermal transport. The piezoelectric field will be generated by using the strain at the heterojunction of the nitride materials due to the lattice mismatch. The strained AlN/GaN or InGaN/GaN nano-laminated/superlattice structures with the large piezoelectric field are proposed as the transition layer between GaN and diamond to reduce the TBR.

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 achievements include: 1) A photocurrent spectrum measurement was performed to experimentally obtain the intensity of the piezoelectric field in the superlattices, and a high electric field more than MV/cm was obtained; 2) 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 results further confirm the feasibility of the proposed concept; 3) To investigate the phonon transport at the heterojunction of GaN/AlN, the double-clamped MEMS bridge was fabricated. It was found that the strain at the interface can greatly enhance the quality factor and improve the frequency stability. The heterojunction resonator showed a much higher thermal stability compared to the Si-based resonators. Based on this result, a press release was published by JST; 4) the AlN/GaN superlattices and InGaN/GaN superlattices with large piezoelectric field were deposited by using MOCVD and the interface quality was improved. Moreover, the interface thermal property was improved by the superlattice structures. The experimental measurement on the thermal conductivity and the theoretical estimation are in progress.

【代表的な原著論文情報】

1. Liwen Sang, Meiyong Liao, Xuelin Yang, Huanying Sun, Jie Zhang, Masatomo Sumiya, Bo Shen. Strain-enhanced high Q-factor GaN micro-electromechanical resonator. Science and Technology of Advanced Materials. 21 [1] (2020) 515-523 10.1080/14686996.2020.1792257

2. Liwen Sang, Huanying Sun, Xuelin Yang, Tiefu Li, Bo Shen, and Meiyong Liao, Self-

Temperarure-Compensated GaN MEMS Resonators through Strain Engineering up to 600 K, IEDM 2020.
3. Huanying Sun, Liwen Sang, Haihua Wu, Zilong Zhang, Tokuyuki Teraji, Tie-Fu Li, J. Q. You, Masaya Toda, Satoshi Koizumi, Meiyong Liao. Effect of Deep-Defects Excitation on Mechanical Energy Dissipation of Single-Crystal Diamond. Physical Review Letters. 125 [20] (2020) 10.1103/physrevlett.125.206802
4. Bing Ren, Meiyong Liao, Masatomo Sumiya, Jian Li, Lei Wang, Xinke Liu, Yasuo Koide, Liwen Sang. Layered boron nitride enabling high-performance AlGaN/GaN high electron mobility transistor. Journal of Alloys and Compounds. 829 (2020) 154542 10.1016/j.jallcom.2020.154542