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窒化物超格子フォノニック結晶による室温熱輸送制御

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Room-temperature thermal management by GaN-based phononic crystals

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GaN 系電子デバイスでは、出力密度の上昇に伴い、放熱が重要な課題となっている。本研究は、GaN 短周期超格子フォノニック結晶を利用して、コヒーレントフォノン輸送が実現し、熱輸送効率は大幅に向上が成功した。MOCVD 方法に利用して GaN/AlN、InGaN/GaN、および AlInN/GaN 超格子構造でコヒーレントなフォノン輸送を達成した。多結晶ダイヤモンドは、ヒートスプレッダーとして GaN デバイス上に堆積された。コヒーレントフォノントンネリングを制御することで、GaN とダイヤモンド間の界面熱抵抗（TBR）が大幅に低減した。

With the increasing power density in GaN-based electronic devices, thermal dissipation becomes one of the important issues that restrict the full potential of the device output power density. In this project, we propose to use GaN-based short-period superlattices to achieve phonon coherent, thus improve the thermal phonon transportation. We successfully achieved the coherent phonon transport in GaN/AlN, InGaN/GaN, and AlGaN/GaN superlattices. Diamond is utilized as the heat spreader for GaN electronic devices. With the coherent phonon tunneling, the thermal boundary resistance between GaN and diamond heat spreader is greatly reduced.

1. 研究内容

The aim of this research is to achieve the effective thermal management in the AlGaN/GaN high electron mobility transistors (HEMTs) for their application under high-power operations. The wide-bandgap semiconductor GaN is becoming the promising choice for power electronics to enable the roadmap of increasing power density by simultaneous high-power conversion efficiency and low form factor due to its superior characteristics of high breakdown voltages (10 times higher than Si), high switching speed (over GHz), and compact in size (reduced up to 1/1000 than Si power device). With the increased power density, self-heating inside the devices becomes an important issue for the failure and poor reliability in the real application. Unlike the conventional field effect transistor (FETs) which use impurity doping to produce n-type and p-type channels, the conducting n-channel in AlGaN/GaN HEMT is generated by the high-density two-dimensional electron gas (2DEG) at the heterojunctions, leading to the localized hotspots at the gate edge close to the drain site. Different from Si transistors, the thermal boundary resistance (TBR) as high as ～47.6 m^2K/GW between GaN and their heat spreader (typically, diamond) was observed due to interface scattering, vacancy/impurity scattering, ground boundaries or interface disorder/roughness. Therefore, an effective thermal dissipation strategy

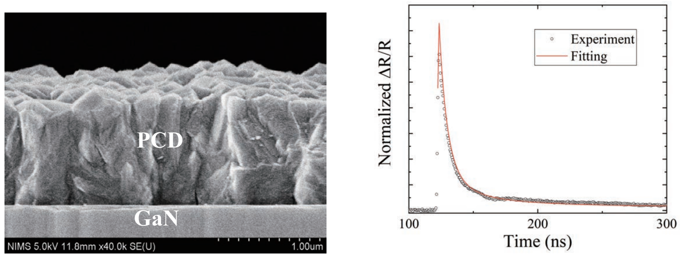

Fig. 1 Cross-sectional SEM showing the polycrystalline diamond grown on GaN template; TDTR signal and fitting result for GaN/diamond.

from GaN to heat spreader is in urgent demand to improve the power dissipation of GaN HETMs.

In this project, we propose to introduce short-period superlattices between GaN and diamond to achieve coherent phonon tunneling, thus reduce the TBR. The polycrystalline diamond was deposited on GaN devices as the heat spreader by using nanodiamond seeding before the deposition of diamond film with microwave plasma chemical vapor deposition (MPCVD).

We successfully grew GaN/AlN, InGaN/GaN superlattices by metal organic chemical vapor deposition (MOCVD). The interface was controlled into namometer scale with the optimized growth condition. It is found that, with the period thickness reducing, the thermal conductivity of the superlattices was firstly improved, showing the incoherent phonon transport behavior. When the period thickness was further reduced, the coherent phonon transport was achieved, and the thermal conductivity was improved. This result indicate the success of the coherent phonon transport in the superlattices.

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 TBR at the interface. Here, we propose to deposit highly orientated polycrystalline diamond (PCD) film on HEMT hotspots for directly cooling. From Raman spectrum, the strong diamond peak was observed, indicating the successful growth. We proposed a nanodiamond seeding method, and greatly improved the quality of the PCD films. A high thermal conductivity approaching 250 W/mK was obtained, which belongs to the high level for polycrystalline diamond film. With the introduction of superlattices, a low TBR of 4 m^2K/GW was obtained between GaN and diamond (Fig. 1). This result will be helpful for the effective thermal dissipation of AlGaN/GaN high power devices.

2. 発表（研究成果の発表）

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