Channel temperature determination of a multifinger AlGaN/GaN high electron mobility transistor using a micro-Raman technique*

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Self-heating in a multifinger AlGaN/GaN high electron mobility transistor (HEMT) is investigated by micro-Raman spectroscopy. The device temperature is probed on the die as a function of applied bias. The operating temperature of the AlGaN/GaN HEMT is estimated from the calibration curve of a passively heated AlGaN/GaN structure. A linear increase of junction temperature is observed when direct current dissipated power is increased. When the power dissipation is 12.75 W at a drain voltage of 15 V, a peak temperature of 69.1 °C is observed at the gate edge on the drain side of the central finger. The position of the highest temperature corresponds to the high-field region at the gate edge.

Keywords: AlGaN/GaN high electron mobility transistors, Raman spectroscopy, temperature

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1. Introduction

The AlGaN/GaN high-electron-mobility transistor (HEMT) receives much attention for high-frequency and high-power applications because of its advantages, such as a high breakdown field, high drift velocity and high electron density.[1,2] Despite its exceptional performance and great potential, thermal management is still an important issue preventing a higher output power level. In order to improve the high power performance, information about the thermal management of a AlGaN/GaN HEMT is critical.[3,4] Therefore, the accurate measuring of temperature is required to optimize the design of the device and achieve higher reliability.

An infrared technique, commonly used for temperature measurements,[5,6] has a spatial resolution of ∼ 5–10 μm, which is insufficient to profile micrometer-sized source/drain openings in AlGaN/GaN HEMT. On the other hand, micro-Raman spectroscopy has been demonstrated to be a powerful tool to obtain the temperature of semiconductor materials and devices with a spatial resolution better than 1 μm.[7,8]

In the present paper, the temperature profiles in multifinger AlGaN/GaN HEMTs, across the fingers and inside the gate-drain gap of an individual finger, are investigated using micro-Raman spectroscopy. The power dependence of the channel temperature of the device is also discussed.

2. Devices and experiments

The AlGaN/GaN hetero-junction structure used in this paper is grown by metal-organic chemical vapour deposition (MOCVD) on SiC substrates. Both the GaN buffer layer (2 μm) and the AlGaN layer (25 nm) are unintentionally doped, and the AlGaN layer has an Al content of around 30%. After growth, the wafer is processed into a multiple gate finger HEMT device. After mesa isolation, Ti/Al/Ni/Au ohmic contacts are deposited by lift-off and consecutively annealed at 850 °C for 30 s under ambient nitrogen. This is followed by the deposition of a Ni/Au/Ni

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gate, a Ti/Au contact metal, and a 200 nm Si_3N_4 passivation layer obtained by plasma enhanced chemical vapour deposition (PECVD). The gate length L_g is 0.5 μm, and the width of a single gate finger W_g is 150 μm. The distance between two neighbouring gate fingers is 40 μm. Finally, a 1.6 μm thick Au air-bridge is electroplated to interconnect all the source regions of the multiple-gate-finger HEMT. The device structure of the AlGaN/GaN HEMT and image of the chip are shown in Figs. 1(a) and 1(b), respectively.

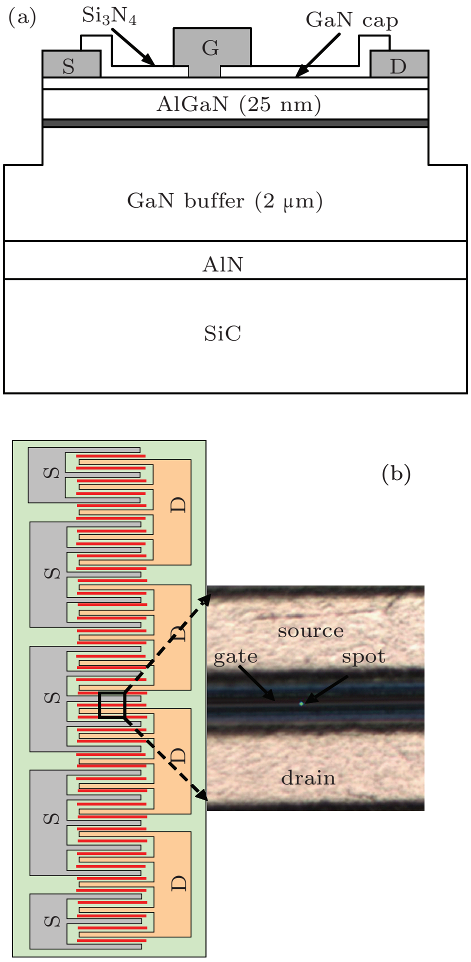

Fig. 1. (colour online) A schematic diagram (a) and micrographs (b) of the 40×150 μm finger device. The insert shows a detailed view of the gap where measurements are taken.

3. Results and discussion

The micro-Raman spectrum is measured on the AlGaN/GaN HEMT using a JY LabRam HR800 micro-Raman system. The 514 nm line of an Ar^+ ion laser is used as an excitation source, and the laser beam is focused on the sample surface, into a spot less than 1 μm in diameter. Since the 514 nm line is below the band-gap of GaN, neither absorption nor laser-induced heating occurs in micro-Raman measurements. Because of its higher relative intensity and its sensitivity to temperature, E_2^H phonon is selected as a probe to monitor the temperature. The temperature shifts of the GaN E_2^H phonon mode are measured up to 190 °C on the unpowered device for calibration purposes by passively heating the baseplate and allowing the temperature to be stabilized. Figure 2 shows the plot of the peak position of the E_2^H phonon as a function of temperature for the HEMT device structure. The temperature dependence of the E_2^H frequency is obtained and the temperature coefficient α is $-0.01125\ \mathrm{cm^{-1}/°C}$ extracted by linear fitting.

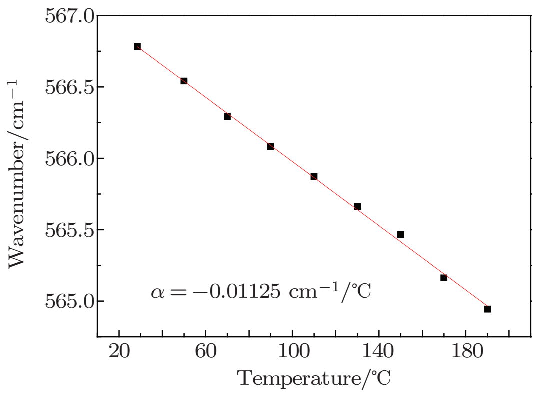

Fig. 2. (colour online) GaN E_2^H phonon frequency as a function of temperature for AlGaN/GaN HEMT.

The operating temperature of the HEMT is acquired by recording micro-Raman spectrum data from an actively heated HEMT. The results of the Raman temperature measurement in a 40×150 μm finger device, with a finger spacing of 40 μm, are displayed in Fig.3 as a function of dissipation power. Temperature is recorded from a single spot in the gate-drain gap of the device by varying gate bias. Source and drain bias are fixed at 0 V and 15 V, respectively. A linear increase of junction temperature is observed when direct current dissipated power increases. The maximum temperature of about 69.1 °C is observed in the gate-drain gap of the central gate finger of the device when the power dissipation is 12.75 W.

Additionally, the temperature is measured in the gap area between neighbouring gate fingers at a dissipation power of 12 W as shown in Fig. 4. This measurement enables the estimation of thermal crosstalk between individual gate fingers. The device central finger shows a higher temperature of about 64 °C, whereas the temperature drops to around 42 °C near the edges of the device. Thermal crosstalk is responsible for the higher temperature in the central area of the multifinger device.

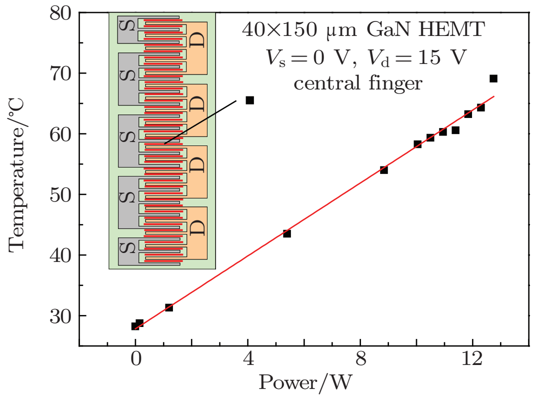

Fig. 3. (colour online) Junction temperature as a function of applied power at the central finger of the 40×150 μm finger device.

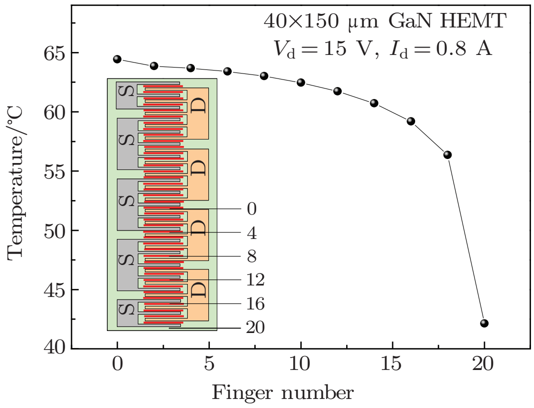

Fig. 4. (colour online) Temperature distribution in the gap between fingers measured at a dissipation power of 12 W.

High spatial resolution of Raman spectroscopy allows the measurement of not only spot temperature in the channel but also a temperature distribution within the source-drain region of the channel, and the results are shown in Fig. 5. The drain bias voltage V_d varies from 0 V to 20 V, while the gate bias voltage V_g is maintained at −2 V.

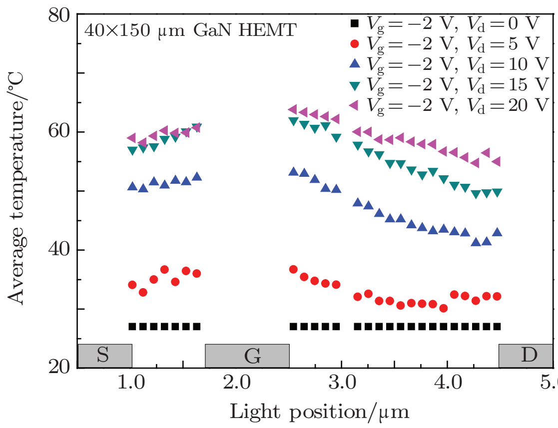

Fig. 5. (colour online) Micro-Raman temperature scanning in the source-drain gap of the central finger of the same device.

As shown in Fig. 5, the temperature scanning across the source-drain gap shows that the device temperatures at the drain side of the gate are higher than that of the source under various bias conditions. Indeed, since the peak electrical field appears near the drain side of the gate edge, heat generation occurs predominantly within this small sub-micrometer region near the gate.[9] Similar temperature profiles were also recorded in Raman measurements on AlGaN/GaN HEMTs.[9,10]

4. Conclusion

Micro-Raman spectroscopy is successfully employed to measure the temperatures of multifinger AlGaN/GaN HEMTs under both active heating and passive heating. Temperature measurements on AlGaN/GaN HEMT devices show that Raman spectroscopy can be applied to obtain information about self-heating in these devices. Raman measurements allow the accurate measurement of the GaN device channel temperature with a high spatial resolution. Significant variations of temperature not only across the multifinger device but also inside the source-drain gap of individual fingers were observed.

Temperature measurement can be employed as a powerful tool not only to predict the device lifetime from the device peak temperature but also to optimize the device layout by examining the thermal crosstalk between individual fingers.

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