AlGaN/GaN Plasmon-Resonant Terahertz Detectors with On-Chip Patch Antennas

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Abstract: We demonstrate room temperature terahertz detection by AlGaN/GaN heterojunction field effect transistors (HFETs) integrated with an on-chip microstrip patch antenna. Polarization dependent photoresponse is observed in accordance with the design of the antenna.

OCIS codes: (040.2235) Far infrared or terahertz; (040.1880) Detection; (110.6795) Terahertz imaging

1. Introduction

Plasma resonant terahertz detection using semiconductor field effect transistors (FETs) is an effective way to realize compact and efficient terahertz detectors [1-4]. One of the interesting reports concerning the FET-based terahertz detector is that a metallic bonding wire fabricated on the gate electrode can act as an antenna which receives terahertz electromagnetic waves [5]. Once terahertz detection via antennas is implemented, one can easily perform real-time imaging by use of an array of such antennas. Terahertz antenna array will also enable frequency-selective detection at individual elements. This kind of device is applicable to terahertz spectroscopy. Thus, antenna-coupled FET terahertz detectors are strongly required for the advance of terahertz applications.

In this work, terahertz detection by GaN HFETs integrated with planar patch antennas is demonstrated. We provide experimental evidence of terahertz detection at the patch antenna.

2. Design and fabrication of on-chip patch antenna coupled AlGaN/GaN HFETs

Figure 1 shows the schematic cross-section of the AlGaN/GaN schottky-gate HFET on a sapphire substrate with a microstrip patch antenna. The gate length of HFET is 300nm and the gate width is 100μm. The on-chip patch antenna consists of a metal patch, a metal ground plane, and an interlayer insulator between them. The device shares the source electrode of HFET with the ground plane of the patch antenna. Keeping this simplified device structure, we can tune detection property of the antenna by the thickness of the interlayer insulator.

We performed antenna design by using three-dimensional finite element method (3D-FEM). The radiation patterns of the on-chip patch antenna are calculated at 0.7THz. We confirmed that a well-confined radiation pattern was obtainable together with a high directional gain. This ensures that the on-chip patch antenna can effectively receive incoming terahertz electromagnetic waves. Fig 2 shows the angular dependence of the electric field intensity. Polarization-dependent detection is possible by using the integrated antenna.

3. Device characteristics

We use a ZnTe emitter irradiated by a femtosecond pulsed laser as a pulsed terahertz source. Nonlinear nature of plasmons can rectify the terahertz irradiation, reflecting the photoresponse on the DC drain-to-source voltage as an offset, ΔU_{DS}. ΔU_{DS} was measured by a lock-in amplifier. The I_{DS}-V_{DS} characteristics of the fabricated AlGaN/GaN HFETs with the patch antenna are shown in Fig. 3. As seen from Fig. 3, the threshold voltage is about -3.5V. Figure 4 shows the detector responses of the fabricated device under terahertz irradiation of different polarization directions. This measurement was performed without applying drain voltage, which decreases the THz-sensitivity of the HFET itself and can make the antenna function clear. As can be seen in Fig. 4, the HFET with the antenna shows intense photoresponse signal peaks at around the threshold voltage, which is a signature of terahertz detection, while no detection signal is observed for the HFET without the antenna. We estimate the enhancement of the detector sensitivity by the antenna to be at least two orders of magnitude. The peak intensity is much higher when the polarization direction of the incoming terahertz pulse is parallel to the designed polarization direction of the patch

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antenna. We also confirmed that this polarization dependence was independent of the directions of metallic bonding wires or the gate electrodes. These results clearly indicate the fabricated FET detects terahertz radiation at the patch antenna.

4. Conclusions

We fabricated an AlGaN/GaN HFETs integrated with a patch antenna and experimentally demonstrated antenna detection of terahertz radiation at room temperature for the first time. This terahertz detector is applicable to future terahertz imaging or terahertz spectroscopy systems.

Acknowledgements

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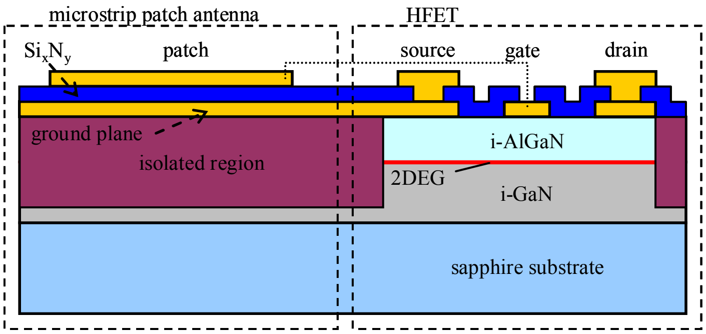

Fig.1 Schematic cross-section of the fabricated AlGaN/GaN HFETs with integrated on-chip microstrip patch antenna

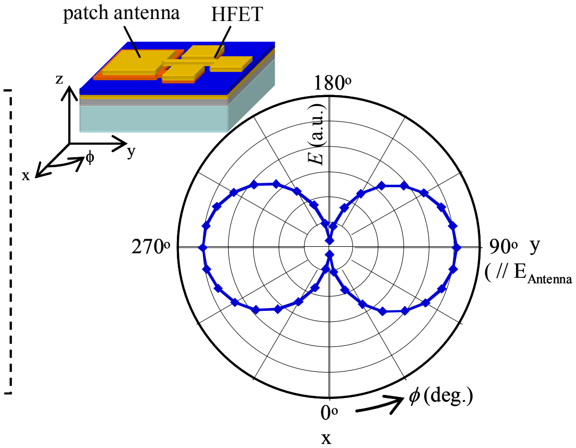

Fig.2 Simulated angular dependence of the electric field intensity

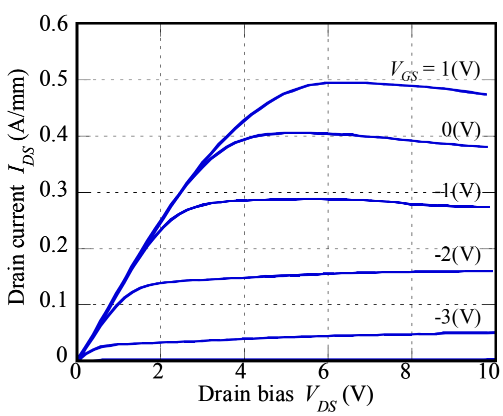

Fig.3 I_{DS}-V_{DS} characteristics of the fabricated AlGaN/GaN HFETs

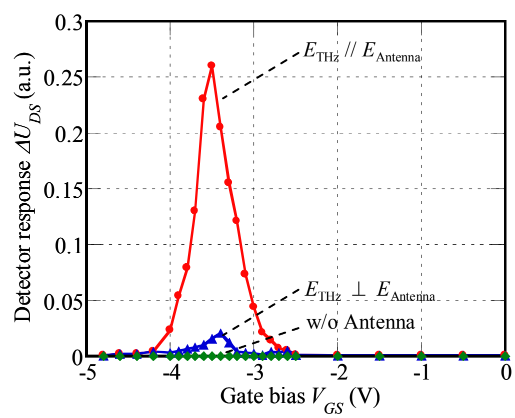

Fig.4 Detector photoresponse ΔU_{DS} under THz radiation as a function of gate voltage V_{GS}