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Responsivity Analysis in InGaAs/InAlAs HEMT Terahertz Detector Integrated with Patch Antenna

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Abstract

The voltage responsivity of terahertz (THz) detector integrated with InGaAs/InAlAs high-electron-mobility transistor (HEMT) and slot-coupled patch antennas was analyzed. The equivalent circuit model was proposed and established. The admittance of the detector was calculated with 3D electromagnetic simulation (HFSS) and the circuit parameters were obtained from fitting of equivalent-circuit model admittance to HFSS result. A responsivity peak was obtained at 600 GHz, which is well fitted with experimental result.

1. Introduction

The terahertz (THz) frequency is paid an attention because of many attractive applications [1-3]. Compact detectors are key components for those applications. THz detectors using FETs have been investigated [4-7]. We proposed and fabricated HEMT THz detectors, and a high current responsivity R_i of 13 A/W was achieved using a 45-nm gate-length HEMT with maximum transconductance $g_{m.max}$ of 2.35 S/mm [9]. However, a bulky Si lens is necessary to the device to detect THz signal. We proposed and fabricated an InGaAs/InAlAs HEMT THz detector with patch antenna for direct detection without Si lens. We obtained a $g_{m.max}$ of 0.77 S/mm and *S.S.* of 100 mV/dec with 60-nm gate length, and a voltage responsivity of 400 V/W at 600 GHz [10]. However, the calculation method of voltage responsivity for the detector was not established. In this report, we propose and establish the equivalent circuit model of the device. A responsivity peak was obtained at 600 GHz, which is well fitted with experimental result.

2. General Instructions

The schematic device structure of HEMT THz detector integrated with patch antenna is shown in Fig. 1. In the slot antenna, an InAlAs/InGaAs HEMT was integrated. A benzocyclobutene (BCB) layer is coated on the HEMT and slot. A patch antenna is formed on the BCB. The patch antenna is inductively coupled with slot antenna [8]. An irradiated THz signal is received by the patch antenna, and then, the signal is transferred to gates of HEMT. HEMT has diode-like characteristics in the I_d–V_g characteristics, and a detected current flows to drain by rectification.

A T-shaped gate and a Pt-buried gate process was employed. The gate length was 60 nm. The epitaxial layer structure and 2-DEG characteristics of mobility and density were written in [10].

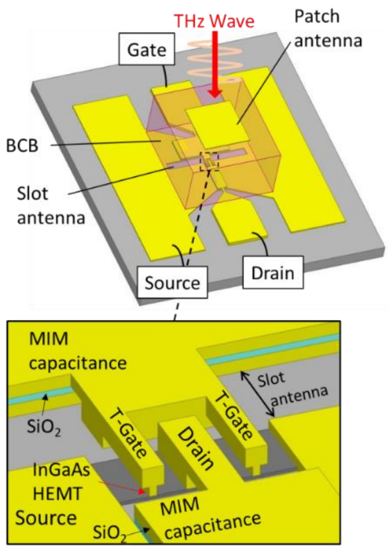

Fig. 1 Schematic of the HEMT THz detector structure integrated with patch antenna.

In the detection process, the patch antenna receives the THz signal, the signal is transferred to slot antenna, and then, a voltage swing is induced at the gate. The size of the patch antenna was designed to be approximately $\lambda/(2n_{BCB})$ long, where λ is the wavelength of target frequency and n_{BCB} is the refractive index of the BCB layer. The size of 140 μm was selected for detection of 0.6 THz signal. The BCB layer thickness is 10.5 μm. We obtained a $g_{m.max}$ of 0.77 S/mm. The measured *S.S.* value was 100 mV/dec. The voltage responsivity, measured as a function of frequency, and a peak responsivity of 400 V/W was obtained at 600 GHz, which is corresponding to patch antenna resonance.

3. Responsivity Analysis

An equivalent circuit model shown in Fig. 2 is proposed to analyze the voltage responsivity. Fig. 2 shows the circuit viewed from gate-source electrode. The admittance viewed from gate-source electrode, which is included of the slot and patch antennas, is expressed as Y_{all}. The slot antenna composed of inductance and capacitance (L_S and C_S), a small radiation to the substrate side (G_s), and the conduction loss (G_{SL}). The patch antenna is composed of series-connected C_P and L_P, and the radiation conductance G_P. G_{PP} and L_{PP} are the coupling part loss and inductance. The BCB dielectric loss is also considered as G_{BCB}. The admittance Y_{all} was simulated by EM simulation (ANSYS HFSS). The circuit parameters can be derived by parameter fitting.

By irradiation of the THz wave with the irradiated power of P_{in}, an induced voltage v_{THz} (= $(8P_{in}/G_p)^{1/2}$) is generated in the antenna having conductance G_p [12]. The induced voltage is connected in parallel with G_p and generates voltage swing between the source and gate, and then, the rectified THz current flows to the drain. We calculated the voltage responsivity using the proposed equivalent circuit. Fig. 4 shows the frequency dependence of normalized voltage responsivity. A responsivity peak was obtained at 600 GHz, which is well matched with experimental result. A frequency selective detection is achieved by this structure. Because, the resonance frequency of patch antenna can be controlled by the antenna size, multi-color imaging device can be achieved by integration of HEMT detectors with different patch antenna size on same substrate.

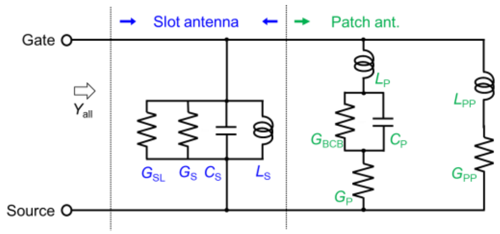

Fig. 2 Equivalent circuit model of slot-coupled patch antenna. Y_{all} can be calculated by HFSS putting an excitation port between gate and source electrodes.

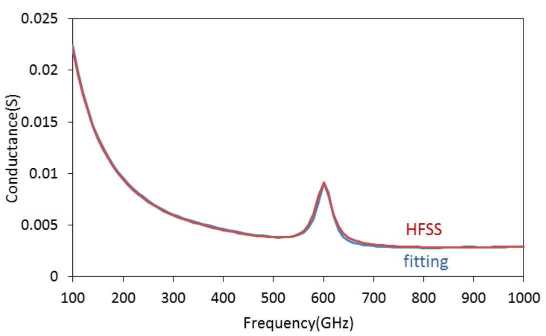

Fig. 3 Real part of Y_{all} (conductance) from HFSS calculation and the equivalent circuit. The equivalent circuit model well fits the curves of the HFSS simulation.

4. Conclusions

The voltage responsivity of HEMT THz detector integrated with slot-coupled patch antennas was analyzed. The equivalent circuit model was proposed and established. The admittance of the detector was calculated with HFSS and the circuit parameters were obtained from fitting of equivalent-circuit model admittance to HFSS result. A responsivity peak was obtained at 600 GHz, which is well fitted with experimental result.

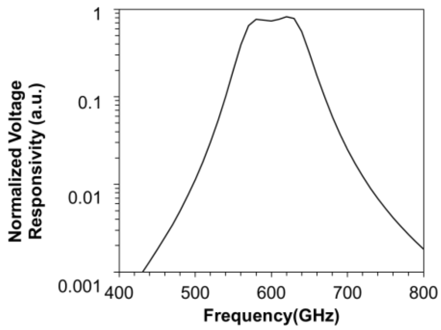

Fig. 4 Theoretical voltage responsivity calculated with detailed equivalent circuit model.

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