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Electrically Induced Terahertz Emission from GaN/AlGaN High Electron Mobility Transistors

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Abstract— **We report on Terahertz emission from GaN/AlGaN single-gate High Electron Mobility Transistors (HEMT) with electrical excitation. The emission intensity, integrated over a frequency range of 0.2 ~ 2 THz, was found to be over 0.1 uW. Threshold-like behaviour and direct proportionality with the applied bias relates the emission to the Dyakonov-Shur plasma wave instability. Resonant emission peak at 0.1 THz was recorded with a Fourier Transform Infrared (FTIR) Spectrometer.**

Keywords— **THz emission, Plasma-wave Instability, Dyakonov-Shur Theory, FTIR.**

I. Introduction

The last two decades have witnessed a remarkable progress in the field of Terahertz electronics. Extensive research has been done on filters, mixers and modulators, but the area of efficient THz sources still offers vast potential of exploration. Electrical tunability of Terahertz sources is the key to realize their easy integration with other circuit components. Efficient and smart THz sources can revolutionize the THz electronics industry, and many new applications in the THz range of frequencies can emerge.

The idea of electrically excited plasma wave assisted THz generation was first coined by Michael Dyakonov and Michael Shur in 1993 [1]. Following that trail, many authors have reported THz emission from GaAs based grating gated HEMT's [2,3] as well as GaN-based HEMT [4,5]. GaN HEMT with grated Ohmic contacts was also reported to have shown THz emission up to 1.8 uW [6]. Spectroscopic measurements from GaAs-based HEMT's has also been reported recently [7].

In this paper, we report THz emission from a single gate GaN/AlGaN HEMT. Single gate devices are easy to fabricate as compared to grated gate devices usually reported. The recorded emisison intensity from our device was more than 0.1 uW. Emission spectra were obtained with an FTIR spectrometer, and a composite silicon bolometer with a fine resolution of $0.5 cm^{-1}$.

II. Device Description

The device consisted of six transistors grown on 4H-SiC substrate. The Nucleation layer consisted of AlN. The active epitaxy consisted of 1.8um Fe-doped GaN buffer layer, 22 nm $Al_{0.24}Ga_{0.76}N$ barrier layer and 3 nm GaN cap layer. The gate length and width of each transistor were 0.5 um and 365 um respectively. The device had large gate-to-source and gate-to-drain window regions of 2.6um and 6.4um respectively. The threshold voltage measured from the transfer characteristics was found to be -1.3 V. The device showed the maximum transconductance of 300mA/V at a gate bias of -0.5 V whereas unity gain cutoff frequency at the same gate bias, and drain voltage swept up to 10 V, was found to be below 5 GHz. Figure 1 shows the cross-sectional view of the device with some important device dimensions and information about the epitaxy.

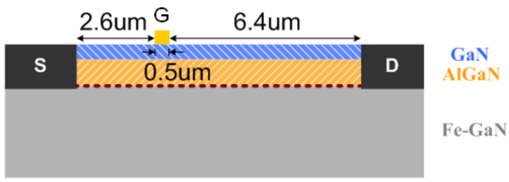

Figure 1: Device Cross-Sectional View

III. Experiment

THz emission from the device was recorded by an indigenously developed FTIR spectrometer. A Silicon bolometer cooled at liquid Helium temperature was used as the radiation detector.

The emission was induced by pulse biasing the drain with a function generator while the gate at a fixed bias. The need of pulsed drain bias arises from the operational mode of the bolometer which only senses the modulated radiation. The pulse frequency and duty cycle were 200 Hz and 50% respectively. The signal was acquired with a lockin amplifier whose input was locked to the reference from function generator sync output.

The reference emission signal was measured with zero drain bias. This signal represented the black-body radiation at room temperature altered by the spectral functions of the Interferometer optics. The reference signal was subtracted from subsequent interferograms to get the actual emission from the device. The interferograms were then Fourier transformed to reveal the spectral information. Figure 2 shows the biasing scheme of the device for THz measurement.

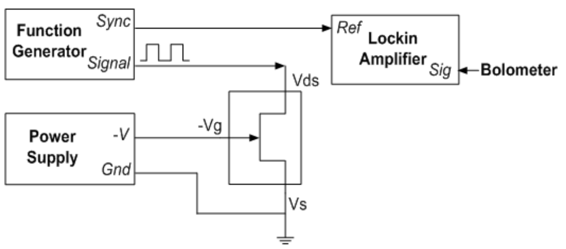

Figure 2: Biasing Scheme for THz Measurement

III. Results and Discussion

Figure 3 shows the output characteristics of the device and emission intensity versus drain voltage. The emission signal was observed once the drain voltage crossed 2.5 V. This threshold-like emission response is characteristic to the plasma wave instability earlier proposed by Dyakonov and Shur.

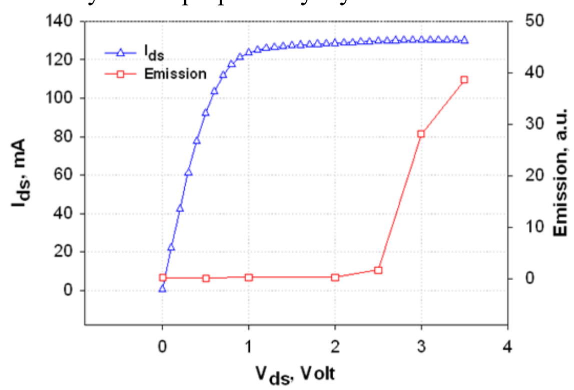

Figure 3: Output Characteristics at V_{gs}=-0.5 V; and Emission Threshold

The threshold-like response stems from the damping of plasma waves due to electron-electron collisions. At low drain bias, the plasma wave growth is not sufficient to surpass the deteriorating effect of inter-electron collisions, a condition which is met after the emission threshold is crossed.

Figure 4 shows the measured spectra at two drain bias values while gate at -0.5 V. Near the emission threshold of 2.5 V, broad emission profile can be seen which corresponds to the non-resonant plasmons thermally excited by hot electrons [8,9]. This kind of response is dominant at low drain bias. With the drain at 3V, the emission profile features a resonant peak at 0.1 THz which is representative of resonant plasmons under the gated region.

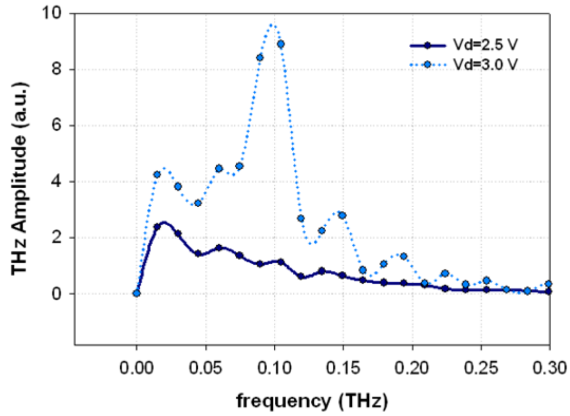

Figure 4: Resonant and Non-resonant emission from the device

Our experiments were based on the Dyakonov and Shur plasma wave instability theory which states that plasma waves can be generated in the channel of a ballistic FET when the collision time of electrons is much smaller than the transit time, a condition which is easily achievable in a HEMT device since the electrons are well-confined in a quantum well resulting in very high electron-electron collision rates. For sub-micron gate length devices, the transit time may well be reduced, and consequently the frequency of plasma waves can reach the THz region.

The required boundary conditions for THz emission from the channel cavity are (i) short circuit boundary at the source side which is obtained by the gate-to-channel capacitance, which can create a very effective short circuit at very high plasma wave frequencies, and (ii) open circuit boundary at the drain side which is achieved by depleting the 2DEG channel by driving the transistor into saturation. Due to asymmetric boundary conditions at either side of the channel cavity under the gate, only odd harmonics of the plasma frequency are supported.

The frequency of the plasma waves excited in the gated region of the device can be expressed as:

$$f_p = K\frac{\left(s^2 - v_d^2\right)}{4sL_{eff}} \qquad s = \sqrt{\left(V_{gs} - V_{th}\right)/m^*} \qquad (1)$$

where, s is the plasma wave velocity, v_d is the electron drift velocity, and $K = \sqrt{2L_{eff}/\pi^2 L_w}$ is the decrement factor due to window regions, L_w [10]. Equation (1) shows that the plasma frequency depends on the overdrive voltage V_{gs}-V_{th} and is inversely proportional to the effective gate length, L_{eff}, which is region of the channel controlled by the gate. The window regions have significant effect on the plasma frequency. For instance, the gate-to-drain window region of 6.4um in our device reduced the emission frequency to 0.1 THz from the expected value of 0.37 THz.

V. CONCLUSION

THz emission from a single gate GaN/AlGaN HEMT has been reported. The emission intensity from our device was more than 0.1uW. Threshold-like emission indicated the origin of emission to be plasma wave instability. Non-resonant as well as resonant emission was observed from the device at low and high drain bias respectively.

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