Tunable room temperature THz emission from AlGaN/GaN high electron mobility transistors

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***Abstract*—We present experimental results on the Terahertz radiation from high electron mobility transistors at room temperature, which clearly show the tunability of the emission frequency by the gate voltage.**

I. INTRODUCTION AND BACKGROUND

FIELD effect transistors are of considerable interest as sources of tunable THz (terahertz) radiation based on plasma oscillations in the channel. The plasma waves in two-dimensional channel can be generated thermally [1] or can be due to plasma wave instability [2-4]. Mechanism for tunable terahertz emission in a field effect transistor was proposed by Dyakonov and Shur [2, 3]. They have shown that the electron flow in the channel should be unstable because of plasma wave amplification due to reflection from the device boundaries, the fundamental frequency of plasma waves can given by:

$$f = \frac{1}{4}\frac{s}{L_{eff}} \qquad (1)$$

where $s=(eU_0/m)^{1/2}$ is the plasma wave velocity, e is the electron charge, m is the effective electron mass, L_{eff} is the effective gate length, and U_0 is the gate-to-channel voltage swing.

Experimental studies were carried out on sub-micron gate transistors both at 4,2 K and at room temperature [5,6], however, no frequency tunability by the gate bias was observed.

Here we present experimental results on the terahertz emission from AlGaN/GaN-based high electron mobility transistors at room temperature, which clearly show the tuneability of the emission frequency by the gate voltage.

II. RESULTS

The samples are based on GaN/AlGaN heterostructures grown by MOCVD method. The electron density in the 2DEG was around $1.3\cdot10^{13}$ cm^{-2}, the mobility of electrons is estimated as ≈ 1500 cm^2 /V s. The gate layout of HEMTs had a T-shape with a gate width of 2x100 µm. The gate length (Lg) was 250 nm. The distance between the source and gate, L_{sg}, was 0.5 µm, the gate-drain spacing, L_{gd}, was 3.15 µm. The threshold voltage was Vth = -4.8 V. The gate of sample was covered by the field plate (see insert in Fig. 1) connected to the gate at the gate pad.

The measurements were carried out at room temperature. The emission signal was excited by square source-drain voltage pulses with pulse frequency 30 Hz and duty cycle 0.5, the source-gate voltage being constant. For the spectral analysis of the radiation a Fourier transform spectrometer under vacuum has been used.

The emission was observed in a threshold-like manner, and was accompanied by a drop of the drain current. On increasing the negative gate bias, the current drop and the corresponding onset of emission are shifted toward lower values of V_{ds}. It should be noted that the emission exists in a limited range of Vgs values depends on the drain to source bias.

Emission spectra were measured at the fixed drain bias, the gate bias varied from -3.5 V to 0V. The position of the maxima of emission spectra as a function of the gate voltage is presented by points in Fig. 1. One can see that the theoretical curve (solid curve) describes well the experimental points. Thus, the observed emission can be interpreted as being caused by plasma waves excited in transistor channel.

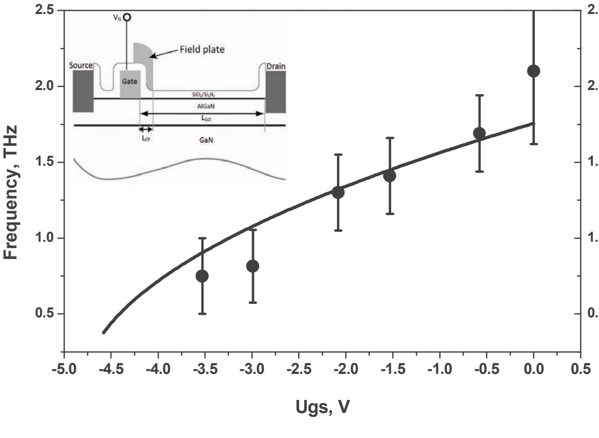

Fig. 1. Position of emission spectrum as a function of gate bias for GaN/AlGaN transistor at drain to source voltage V_{ds}=4V. Solid line is calculation using Eq. 1. Insert: schematics of the sample with gate covered by a field plate.

The dependence of the emission line width on the gate bias gives an additional confirmation of this interpretation. Indeed, since the damping of plasma waves is determined the momentum relaxation time, it should depend on the mobility of the electrons in the transistor channel. It is known that the mobility in the transistor channel depends on the applied gate bias [7,8]. It was shown that that increasing of the carrier density under the gate can degrade the mobility through the enhancement of the interface-or barrier-related carrier scattering. Consequently, the emission spectrum should broaden with the increase in electron density. Indeed, we observe this in our experiments (see Fig. 2). We estimate that the observed spectrum broadening corresponds to the mobility degradation from 1700 to 1100 cm2˜V s which are quite reasonable values for our samples [7,8].

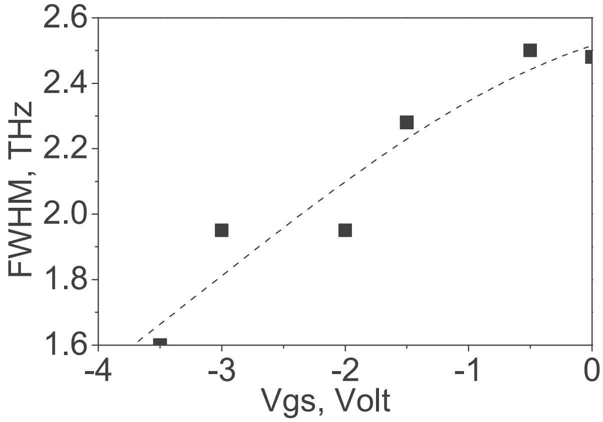

Fig. 1.full width at half maximum of the spectra as a function of Vgs (dotted line is a guide to the eye).

Previously the observed terahertz emission did not show tunability by the gate bias neither at room temperature nor at 4 K [5]. Even though the position of the spectrum changed slightly with the gate voltage, the shift was not significant. We think that the plasma wave excitation is favored by the presence of the field plate covering the gate on the drain side. Generally, the field plate is used to increase the breakdown voltage in high power FETs.[9,10]. This effect is achieved through the expansion of the depletion region toward the drain contact and the weakening of the surface trap effects at the drain side. The boundary conditions needed for the plasma wave excitation could also be affected. For example, the excitation of oblique plasma wave modes and turbulence mode localized near the gate boundaries [4] could be suppressed. Since the experimental and the theoretical results are very similar for the sample under study, we speculate that the presence of the field plate approaches the experimental situation to the theoretical model [2, 3] and favors the plasma wave excitation under the gate.

In summary, we observed the terahertz emission from high electron mobility transistor with the main features: (1) it appears at a certain drain bias in a threshold like manner, (2) the radiation frequency corresponds to the lowest fundamental plasma mode in the gated region of the transistor, and (3) the radiation frequency is tuned by the gate bias. These features are inherent attributes of Dyakonov–Shur plasma wave instability in the two-dimensional gated electron gas, and their presence provides a convincing argument that we observe this phenomenon. We suppose that the plasma wave excitation is favored by the presence of the field plate producing the needed boundary conditions.

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