# Terahertz Plasmons in Grating-Gate AlGaN/GaN HEMTs

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Plasma excitations in high-electron mobility transistors (HEMTs) with two-dimensional (2D) electron channels can be used for detection, mixing, and generation of terahertz (THz) radiation [1]. Plasmon modes excited in the HEMT channel under the gate contact (gated plasmons) were considered to be more attractive for electronic applications because their frequencies can be effectively tuned by varying the gate voltage. However, the gated plasmons are difficult to couple to THz radiation due to acoustical nature and, hence, a small net dipole moment of this plasmon mode [2]. Hence, special antenna elements are needed to couple the gated plasmons to THz radiation. As an alternative, a grating gate in a large area (comparable with a typical cross-section area of THz beam) HEMT structure can act as an aerial matched antenna strongly coupling the plasmons to THz radiation [3]. It was shown recently that a large-area grating-gate GaAs/AlGaAs structure can operate as an electrically tunable detector in sub-THz frequency range [4]. A double-grating-gate HEMT structure with lateral dimensions smaller than THz wavelength was used as an effective THz photomixer and emitter [5,6].

We have designed and fabricated a large-area (3×3 $mm^2$) grating-gate GaN/AlGaN HEMT structure exhibiting plasmon resonances in frequency range from 1 to 4 THz. The AlGaN/GaN structures were grown on a sapphire substrate. The metal grating was deposited on top of the structure, and the gap between 2D electron channel and the grating was 20 nm yielding the threshold pinch-off voltage – 5 V. The grating gate served as the HEMT gate electrode and also for coupling plasmons with incident THz radiation. A high 2D electron density in GaN/AlGaN heterostructure (exceeding $10^{13}$ $cm^{-2}$) and narrow grating-gate slits ensured a high operating plasmon frequency for this device. With the grating gate of 3.5-μm period and 0.5-μm-wide slits, the structure supported very pronounced higher-order plasmon resonances up to the 7th plasmon mode at frequencies up to 4 THz. The large-area grating-gate coupler excites evanescent spatial Fourier harmonics of the incident THz field with wavevectors $q=2n\pi/L$, where $L$ is the period of the grating gate with $n$ being an integer corresponding to the plasmon mode number [3]. Narrower grating-gate slits excite stronger spatial Fourier harmonics of the incident THz wave, which, in turn, effectively excite higher-order plasmon resonances in the channel, when the frequency of incoming THz wave coincides with the plasmon mode frequency related to the plasmon wavevector by the plasmon dispersion law.

We observed decrease of transmission at the plasmon resonances by almost 90%, which demonstrated efficient absorption of the THz radiation by the resonant plasmons, far exceeding free carrier absorption. The resonances were widely tunable by changing the applied gate voltage, which controlled the equilibrium 2D electron gas concentration in the channel of the device. Plasmon resonances were well pronounced at elevated temperature up to 180 K and died of at greater temperatures due to increasing the electron relaxation. Operating temperature possibly can be increased up to room temperature by fabricating the grating gate with even narrower slits stronger coupling plasmons to THz radiation. This device might be very attractive for its potential applications as a tunable THz filter, modulator, and detector for “on-chip” THz spectroscopy.

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