Resonant Detection and Modulation of Terahertz Radiation by 2DEG Plasmons in GaN Grating-Gate Structures

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Abstract:
We observed, for the first time, resonant absorption and modulation of terahertz (THz) radiation by two-dimensional electron gas (2DEG) plasmons in gallium nitride (GaN)-based large area grating-gate structures. Transmission spectra of the fabricated grating-gate devices were measured by a commercial Fourier transform infrared spectroscopy (FTIR) system using a blackbody emitter as broadband radiation source and a CW FIR gas laser. Obtained spectra clearly showed the absorption peaks, which were attributed to the resonance plasmon excitation in the 2DEG at the AlGaN/GaN heterointerface. The results demonstrate the potential of using GaN-based plasmonic devices for THz applications.

Summary:
THz radiation has found many applications for sensing and characterization of chemical and biological systems and for detection of concealed weapons and explosives. Such applications require detectors possessing high responsivity, sensitivity, fast response and operation at room temperature. THz detectors based on plasma waves in FETs have demonstrated fast response time and comparable sensitivity with conventional detection methods. Such FETs support two different types of plasma oscillations. The first is the plasma oscillations in the gated region of the 2DEG channel, which have frequency independent phase velocity $s = \omega/k$. The second type of plasma oscillations exist in ungated regions. For negligible electron scattering in 2D electron gas, the dispersion relation for ungated plasma oscillations in an infinite homogeneous 2D electron sheet is in the form of $\omega \sim k^{1/2}$. Response of a single FET plasma detector is limited by its small area compared to the beam cross section. Also, gated plasmons in a single-gate FET are weakly coupled to terahertz radiation because of the strong screening of the gate plasmons by the metal gate electrode and their vanishingly small net dipole moment due to their acoustic nature. One way to resolve this problem is to use multiple gate structures. Periodic metal gates covering a large active area are expected to increase the coupling efficiency and allow to excite higher order (up to 6th order) plasmon modes for detection and modulation purposes [1].

In this study, we fabricated multigated AlGaN/GaN heterostructures to investigate their THz plasmonic response. Details of the epilayer structure and fabrication process can be found in [2]. The active region was approximately 1.5 mm × 1.5 mm and covered by the periodic gate fingers. The gate lengths of different devices were 1, 2, and 3 µm while the spacing between the fingers was 0.5 µm and 1 µm (see Figure 1). Transmission spectra of the devices were measured by Bruker IFS 66v/S Fourier Transform Infrared (FTIR) spectrometer with broadband blackbody radiation for detection and modulation purposes [1].

Figure 1: SEM image of a fabricated multigated AlGaN/GaN heterostructure device.
source. Measured spectra were normalized with respect to the transmission spectrum of the sapphire substrate which was measured as background reference. Figure 2 shows the transmission spectra of samples with $L_g = 3 \mu$m and $L_g = 1 \mu$m gate length and $0.5 \mu$m gate-to-gate spacing and bare sample without gates. The shaded area represents the calculated free-carrier (Drude) absorption. The inset shows the expected transmission spectra of the same devices calculated using the method described in Ref [1]. We also observed strong dependence of the transmission on polarization, associated with longitudinal metallization of the gate structure. We attributed the absorption peaks to the resonance plasmon excitation in the 2DEG at the AlGaN/GaN heterointerface.

Next, we measured the transmittance of the fabricated sample under different biasing conditions using the THz gas laser SIFIR-50 at different frequencies. We first measured the amplitude of the THz beam transmitted through the grating gate device without biasing using a pyroelectric detector. The device was placed right in front of the detector and the THz beam was focused by parabolic mirror. The beam was modulated by a mechanical chopper at the frequency of 100 Hz, and the signal from the detector was recorded by Tektronix TDS 3052 oscilloscope. Then the mechanical chopper was removed and pulsed bias was applied to the gate electrodes of the device. Pulse amplitude was varied from -8V to 0V. The intensity of the transmitted THz radiation was measured by the same pyroelectric detector. Figure 3 shows the measured intensity of the transmitted THz radiation. It is clear that the transmitted signal follows the gate pulse signal indicating a good modulation. Due to its very low speed, the pyroelectric detector can not keep up with the chopper modulation and hence the transmitted signal has distorted shape rather than perfect rectangular pulse.

We define the effective modulation rate as $M = \frac{V_{chopped}}{V_{pulsed}}$ where $V_{chopped}$ and $V_{pulsed}$ are the measured signal from the pyroelectric detector under the conditions of modulation by mechanical chopper and modulation by the device without chopper. The modulation rate remains almost constant for the pulses beyond the threshold voltage of the devices $V_{th} \sim -4.5V$. The maximum estimated effective modulation rate was over 7% for 1.89 THz radiation. We believe that the estimated value is limited by the slow detector speed and the actual modulation rate is much higher. Transmittance characteristic of the devices with pulsed gate electrodes provided effective modulation of the THz radiation at different frequencies. The results demonstrate the potential of using GaN-based plasmonic devices for THz applications, especially those requiring high speed modulation and detection.

References:
