The Hybridization of Plasmons in GaN-based Two-Dimensional Channels

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Abstract

This paper displays the plasmon resonance phenomenon in single channel and double channel (DC) devices with varying dimensions in grating-gate period, slit and spacing between two channels in DC structures at terahertz domain. The results indicate that higher order plasmon can be excited in devices with longer period and narrow slit grating due to the enhanced coupling between plasmon and terahertz radiation. Splitting of plasmon resonance takes places in double channel device due to the hybridization between plasmons, which will improve the tunability of terahertz plasmonic device.

I. INTRODUCTION

Since the last decades, terahertz (THz) technology such as sensing of drugs and explosive materials has attracted great interest due to its inherent advantage in biomedical imaging and security imaging [1] [2]. To sense the THz radiation, detectors available now include bolometers, Schottky diodes [3], and photoconductive detectors. However, these detectors are not frequency-agile and require mechanical motion of external optics to generate spectral information [4, 5]. Recently, a new detection mechanism utilizing hydrodynamic nonlinearity of plasma wave (plasmon) in the channel of field effect transistors (FETs) has been proposed [6]. Plasma waves in FETs have a linear dispersion [7], $\omega=sk$, where s is the wave velocity. The plasma wave velocity $s=(e^2n/m^*C)^{0.5}$ depends on the carrier density as controlled by the gate voltage and the gate-to-channel capacitance per unit area $C=\varepsilon/4\pi d$. For the device with gate length L, the channel can serves as resonant "cavity", and the frequencies of plasma waves are discretized as $\omega_N= sk$ ($k=(2n-1)\pi/L$, and $n= 1, 2, 3,\ldots$). The plasmon is the spatio-temporal collective vibration of carrier densities under the excitation of external radiation, which will lead to the rectification of ac component gate voltage as induced. In the III-V compound semiconductor heterostructures with $L\sim1\mu$m, the typical frequencies of plasma waves are located at THz band. Further, the plasmon is result of classical excitation and does not saturation with temperature, which will eliminate expensive cooling system [8]. Thus, a low-cost and frequency-tunable THz spectrometer/detection system will compact will be realized based on the state-of-art FETs.

Most of previous work focus on the the GaAs or InP material system with deep-submicron meter gate-length operating in the THz/sub-THz regime [9][10]. While Murovjov et al. illustrate that wider frequency tunability of plasmon resonance in grating-gate GaN HEMTs can be reached with finger-length around 1 μm [11], which is benefit for the designing of coupling elements with area-matched to the collimated incident wave. This paper aims to present the resonance properties of plasma wave in single channel and their interaction in double-channel GaN HEMTs, the appearence of new mode may be utilized for the resonant detection.

II. DEVICE DESCRIPTION AND DISCUSSION

Figs. 1 (a) and (b) show the structure of grating-gated single-channel (SC) and double–channel (DC) heterojunction FETs (HFET). The grating-gate can be used both as the electrodes controlling the sheet electron density and polarizer for the incident waves. Both of these devices consist of 2μm $Al_yGa_{1-y}N$ buffer layer (note that the mole fraction y should not exceed 0.15, which will cause the depletion of electron density in the channel) and 30nm channel layer or upper and lower channel layers. The fabrication of these devices can be completed after the deposition and patterning of gate electrodes with period L and slit S. Room temperature Hall measurement indicate that the sheet electron densities in these devices can reached at about $2\times10^{13}cm^{-2}$ or even higher and mobility is around $1200cm^2/Vs$~relaxation time is around 0.18ps. It has been known that in a single channel device contains two elementary plasmons with symmetrical (Ω_+) and asymmetrical charge (Ω_-) distribution across the channel can be excited by the THz radiation (and plasmon energy $\Omega_+>\Omega_-$). While in double channel device the case is even more complicated due to the

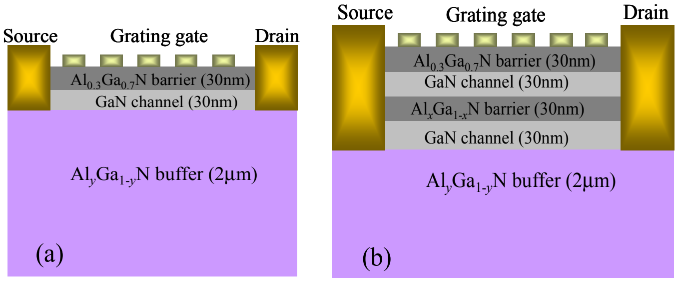

Fig.1. Schematic of device structures: (a) grating-coupled single-channel HEMT; (b) double-channel HEMT with $Al_xGa_{1-x}N$ inter-layer separating the upper and lower channels.

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interaction between these two kinds of plasmons in upper and lower channels, which will lead to the splitting of plasmon resonance further. The interactions between these plasmons can be separated into three categories according to the permutations and combinations: (a) symmetrical plasmon vs. symmetrical plasmon; (b) symmetrical plasmon vs. asymmetrical plasmon; (c) asymmetrical plasmon vs. asymmetrical plasmon. However, the splitting phenomenon does not always happen, which depends on the dipole distribution and resonant frequencies of these plasmons. As examples, the splitting of plasmons takes places when the frequencies of asymmetrical/symmetrical plasmons in the upper and lower channels approach with each other leading to the formation of (Ω_{+-} and Ω_{++})/(Ω_{-+} and Ω_{--}) new dispersion branches, however it does not happen when the symmetrical plasmon and asymmetrical plasmon are near resonant with each other. Further, in a single channel device, the change in strength and frequencies (the regime Ω_- and Ω_+) of plasmon resonance can be obtained through the change of grating period. Higher order plasmons (Ω_-) can be excited in the channel with longer period and narrow slit gratings. This is because the coupling strength between THz wave and plasmon is enhanced due to larger net dipole moment and stronger near-field in long period and narrow slit samples, respectively.

III. CONCLUSIONS

A finite-difference method is employed to describe the local response of plasmonic oscillation in single and double channel devices. Our results indicate that in long period/narrow slit samples, higher order plasmon resonances are being activated due to the improvement of field coupling. In addition, the interaction between plasmons in different channels leads to the splitting and enhancement of plasmon resonance, which is benefit for the wider tunability of THz device.

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