Synchronized plasma wave resonances in ultrathin-membrane GaN heterostructures

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***Abstract*—In this work we report on synchronized plasma wave resonances in ultrathin-membrane GaN heterostructures. In contrast to commonly employed grating-gate configurations, the analyzed structure contains periodically-patterned ohmic contacts to the two-dimensional electron gas (2DEG), which are laid-out parallel to the gate fingers. Our work demonstrates that the proposed approach allows: more efficient excitation of high order plasmon modes, and superior overall coupling, even in configurations having less number of devices per unit area.**

I. INTRODUCTION

OVER the past decades, the THz frequency regime has become the subject of much attention due to its wide range of applications in diverse areas such as astronomy, imaging, spectroscopy, communications, and so on. Devices based on electron plasma waves have attracted significant attention for THz generation, detection and amplification. In this regard, efficient coupling of external THz radiation into and out of plasma waves in semiconductor heterostructures is essential for the operation of these devices. A conventional approach to excite plasma waves in a 2DEG is via a grating gate coupler as discussed in [1]. Under this approach, adjacent unit-cells interact with each other making this a coupled resonant system. A further improvement in the coupling can be attained by periodically adding source (S) and drain (D) electrodes in a HEMT-array configuration (see Fig. 1a). As depicted in Fig. 1b, in this configuration every unit cell becomes effectively independent, and the THz to plasmon coupling is enhanced due to a cooperative effect by synchronizing electron plasma waves in each unit-cell of the array as theoretically discussed by Popov *et al* [2-3]. This work discusses on the experimental demonstration of enhanced THz coupling to electron plasma wave in ultra-thin membrane HEMT arrays via plasmon synchronization. A thin-membrane configuration enables us to remove substrate effects and further enhance the coupling.

II. RESULTS AND DISCUSSION

Devices were fabricated in MOCVD-grown epitaxial structures consisting of a 4.5 μm thick AlGaN-based buffer layer, followed by a 200 nm GaN layer and a 20 nm AlGaN barrier, which were grown on Si (111). In this structure a 2DEG with charge density ~5×10^{12} cm^{-2} and μ ~1,700 cm^2/V.s is formed at the top AlGaN/GaN interface. *S/D* ohmic contacts (Ti/Al/Ti/Ni/Au) and Schottky gate contacts (Ni/Au) were defined in successive lithography and lift-off steps in a periodic-pattern through direct writing using a Heidelberg PG 101 pattern generator. TLM measurements indicate a contact resistance of 1.3 Ω.mm and a sheet conductivity of 1.5 mS; this agrees well with our results from THz spectroscopy. The center area of the Si substrate was etched from the backside by DRIE (Oxford ICP 100). The resulting samples are ultra-thin HEMT membranes (thickness ~5 μm as shown in Fig. 1c) and therefore do not exhibit any substrate-related effects. Our experimental observations of plasma wave resonances in the THz spectra, shown in Fig. 2, point out that indeed in this approach: (*i*) very efficient excitation of high order plasmonic modes, and (*ii*) excellent overall coupling -even in configurations having much less number of devices per unit area than in grating-gate devices- can be attained. Our results reveal a straightforward way to enhance the THz to plasmon coupling and thus improve the performance of electron plasma wave-based devices; this effect can be exploited, for example, to improve the response of HEMT THz detectors.

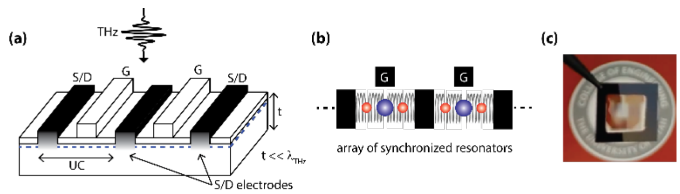

Fig. 1. (a) Schematic cross section for the unit cell of a HEMT-array (b) Modeling of mobile carrier interactions in the 2DEG via a coupled harmonic resonator. This model allows to visualize the interaction of charges in each unit cell; the continuum of charges located below the gate is represented by blue-circles, the continuum of charges located in the ungated 2DEG is represented by red-circles, and the interaction between charges is represented through springs. (c) Optical image of a fabricated sample, the structure is transparent at visible wavelengths owing to its ultra-thin thickness (~5 μm).

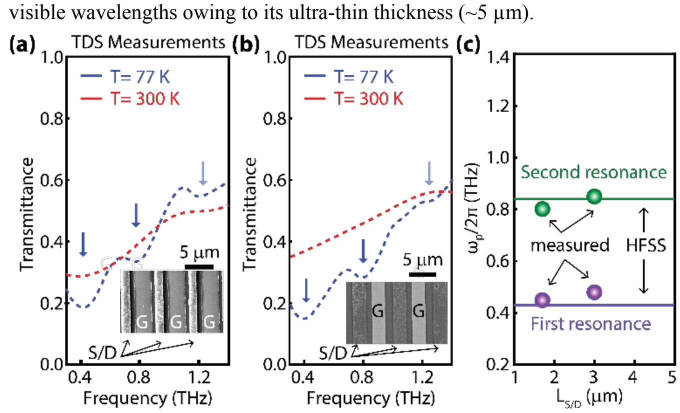

Fig. 2. (a-b) Experimental THz transmission spectra for two representative HEMT-array samples with different unit cells. (UC=6μm and UC=7.5 μm for a) and b), respectively). The insets depict a SEM detail of the array. Both samples, have similar gate-length (2.7 μm) and ungated length (1.8 μm). However, the unit-cell period (UC) is varied via changing the length of the S/D electrodes ($L_{S/D}$). Measurements were taken at 300 K and 77K, well defined resonances are present at 77K (up-to third order). (c) Position of the resonance frequency (first and second resonances) vs. $L_{S/D}$, no dependence is observed.

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