Cooperative THz to plasmon coupling in HEMT-array ultrathin membranes

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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 during recent years for THz generation, detection and amplification and 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 (A. V. Muravjov et al., APL, vol. 96, p. 042105, (2010).). 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. Under this approach, every unit cell becomes effectively independent, and the THz to plasmon coupling is enhanced due to a cooperative effect by synchronizing the electron plasma waves in each unit-cell of the array as theoretically discussed by Popov *et al* (V. Popov *et al.*, *APL*, vol. 89, p. 123504, (2006).).

This work discusses on the *experimental demonstration of enhanced THz coupling to electron plasma wave or plasmon in ultra-thin membrane HEMT arrays via plasmon synchronization*. A thin-membrane configuration enables us to remove substrate effects and further enhance the coupling. 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) s. In this structure a 2DEG with charge density ~$5x10^{12}$ 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) and therefore do not exhibit any substrate-related effects. Our experimental observations of plasma wave resonances in the THz spectra point out that under this approach: (*i*) more efficient excitation of high order plasmonic modes, and (*ii*) superior overall coupling -even in configurations having less number of devices per unit area 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.