Electro-optical terahertz modulators based on gallium nitride semiconductors

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Semiconductors based on nitride and arsenide hold new promise for advancing custom-designed photonics and plasmonics, especially in the terahertz (THz) and infrared spectral ranges [1]–[3]. These materials are particularly attractive due to their potential applications in electro-optical modulation, where the control of electromagnetic wave amplitude and phase is essential. Such modulation finds uses in diverse fields such as wireless communications, quantum electronics, and spectroscopic imaging [4], [5].

In this presentation two types of electro-optical THz (EOT) modulators based on gallium nitride (GaN) semiconductors were investigated. The first modulator composed of high-quality n-GaN epilayers were used to operate under the regime of drifting space-charge (SC) domains [6]. The experiment revealed good polarization selectivity at test 0.6 THz frequency demonstrating amplitude modulation depth and maximum modulation speed values being up to 50% and 33 MHz, respectively. The maximum modulation amplitude was limited by an external electric field of about 1.65 kV/cm only. This value corresponded to the threshold at which the sample encountered electrical breakdown while operating within drifting SC domains. Notably, observed breakdown fields were significantly lower than the predicted critical electric field for GaN being of about 3.7 MV/cm [7].

Recent advancements in 2D plasmonics revealed their capability to modulate THz amplitude and phase at the temperature as high as 300 K, if one employs nano-grating-gate couplers with III-nitride group heterostructures providing high conductivity 2DEG layer [8], [9]. Near 2D plasmon resonance a significant modulation of the THz amplitude and phase retardation can be achieved; indeed, our group have demonstrated values of up to 50% and 25 degrees, respectively. The operation of such type of EOT can be efficiently controlled by gate voltage, that modify the resonant frequency of the 2D plasmon resonance, enabling precise control over the resonance characteristics of the device.

Both types of EOTs show potential for diverse applications in modulating THz waves for advanced communication and sensing systems [1]. However, devices employing 2D plasmon resonances offer rapid operation speeds, seamless integration possibilities with other semiconductor devices, and high modulation depth values reaching 100% in theory so far [10].

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