New semiconductor structures for electro-optical THz wave modulation

Justinas Jorudas, Daniil Pashnev, Liudvikas Subačius, Surya Revanth Ayyagari,
Vytautas Janonis, Maxim Moscotin, and Irmantas Kašalynas

THz Photonics Laboratory, Department of Optoelectronics,
Center for Physical Sciences and Technology (FTMC)

irmantas.kasalynas@ftmc.lt

Nitride- and arsenide-based semiconductors are very attractive for the developments of custom-designed photonics and plasmonics, particularly in the terahertz (THz) and infrared spectrum regions [1]–[5]. Electro-optical modulation of electromagnetic wave amplitude and phase is required for various applications, including wireless communications, quantum electronics, and spectroscopic THz imaging [6].

In this work we discuss two types of electro-optical THz (EOT) modulators based on GaN semiconductor structures. The first modulator relies on n-GaN epilayers operating under the regime of drifting space-charge (SC) domains [7]. We demonstrated good polarization selectivity achieving the amplitude modulation depth values of up to 50% and maximum modulation spped limit of approximately 33 MHz, which was not optimized in the research. The peak modulation amplitude was constrained by an external electric field of roughly 1.65 kV/cm, reaching the threshold value allowable before the sample experienced 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 [8].

Recent advancements in 2D plasmonics revealed their capability to modulate THz amplitude and phase even at even room temperatures, if one employs nano-grating-gate couplers with nitride-based heterostructures [9], [10]. Our group achieved significant amplitude modulation of up to 50% and phase shifts of up to 25 degrees at the vicinity of 2D plasmon resonance, particularly at liquid nitrogen temperatures. The operation of such type of EOT is solely determined by the behavior of the gated electron plasma. Consequently, the applied gate voltage serves as a means to control both the frequency and magnitude of the 2D plasmon resonance. By adjusting the gate voltage, the properties of the electron plasma can be manipulated, enabling precise control over the resonance characteristics of the device.

Both type of the EOTs hold promise for various applications in modulating THz waves for advanced communication and sensing systems [1]. However, devices utilizing 2D plasmon resonances offer fast operation speed and integration compatibility with other semiconductor devices, achieving modulation depth values of up to 100% in theory [11].

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