3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

On the Generation of Terahertz and Infrared Waves using Drift-Biased Nanostructures

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Cherenkov radiation (CR) appears when a charged particle moves faster than the phase velocity of light in the surrounding medium [1]. CR has been applied in several niche yet important applications, such as medical imaging, biomolecules detection, super high energy particles experiments, among others. Recently, it has been suggested that tailoring at the nanoscale the electromagnetic properties of the media surrounding moving particles can control the properties of CR, including emission wavelength, radiation strength, and even the electron velocity threshold that enables the emission [2]. An interesting application is the generation of surface plasmons polaritons (SPPs) at terahertz (THz) and infrared (IR) frequencies from hot carriers travelling within a drift-biased graphene layer [3]. Such source holds the promise to effectively contribute to close the so-called "THz gap" using an integrated, portable, and low-cost technology. Unfortunately, the isotropic and moderate density of states offered by graphene limits the electron-photon coupling mechanism and severely hinder the resulting radiation in terms of efficiency and bandwidth.

To overcome this challenge, we propose to construct THz and IR sources based on drift-biased graphene-based hyperbolic metamaterials. A longitudinal DC-bias injects drifting electrons within the graphene sheets [4,5] that transit from the conduction to the valence band in the electronic band structure of graphene. The resulting interband transition of electrons originates photon emission in the form of surface plasmons or bulk modes supported by the surrounding hyperbolic media. To explore this process in detail, a general theoretical formalism based on energy/momentum conservation has been developed. Specifically, the approach applies Fermi's golden rule to the interaction Hamiltonian between the drifting electrons and the field distribution of the hyperbolic modes supported by the nanostructures. Such modes are determined using semi-classical approaches [4]. Our results show that the large density of states provided by hyperbolic metamaterials drastically enhance the coupling mechanism between the drifting electrons and hyperbolic modes over a broad frequency band. The resulting platform exhibits a remarkable efficiency over 20% and is tunable – in terms of efficiency, bandwidth, and radiation direction – by applying a gate voltage. We envision that this platform will pave the wave to the development of new broadband, efficient, and miniaturized THz and IR sources with exciting applications in communication, sensing, spectroscopy, and biomedicine.

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