Broadband and Efficient Surface Plasmon Generation on Drift-biased Graphene-based Hyperbolic Metasurfaces

L. Wang, N. K. Paul, and J. S. Gomez-Diaz
Department of Electrical and Computer Engineering, University of California Davis.

Cherenkov radiation (CR) is an electromagnetic wave that appears when a charged particle moves in a medium faster than the phase velocity of light in that medium (Ginzburg, V. L., J. Phys. USSR 2, 441-452,1940). Over the years, CR has triggered a wide variety of applications in medical imaging and biomolecule detection, among many others. Hyperbolic Metamaterials (HMTM) (A. Poddubny, et al, Nature Photon 7, 948-957, 2013) have recently been applied to tailor Cherenkov radiation at visible frequencies, allowing to manipulate the electron velocity threshold as well as the strength and frequency range of the emission through the extreme anisotropy and large local density of states of hyperbolic media (F. Liu et al, Nature Photon 11, 289–292, 2017). Similar effects have recently been explored to generate confined surface plasmons polaritons (SPPs) (I. Kaminer et al, Nat Commun 7, 11880, 2016). Specifically, it has theoretically been suggested that a drift-biased graphene sheet can generate surface plasmons through Cherenkov radiation. Unfortunately, this process is somewhat inefficient and narrowband and thus it is challenging to apply it in practical applications, such as in sensing or to construct spasers.

In this context, we propose a novel approach to efficiently generate SPPs in the terahertz and infrared frequency range: exploit Cherenkov radiation in drift-biased graphene-based hyperbolic metasurfaces (D. Correas-Serrano et al, Physical Review B 100, 081410, 2019). In this platform, a simply longitudinal DC bias injects drifting electrons on the graphene nanostructure that couple to the supported SPPs with very high efficiency. The intrinsic yet extreme anisotropy of the surface permits to manipulate the electron-SPP coupling in terms of efficiency and frequency range. To investigate this process, we develop a quantum framework based on energy and momentum conservation: a high energy electron flowing on graphene transitions into a lower energy state and emits a SPP. We calculate the emission rate of this process based on the Fermi's golden rule, considering the interaction Hamiltonian between the electron and the analytical field distribution of the supported hyperbolic plasmons. Our results show that the SPP generation in this platform is broadband (from the terahertz to the mid-infrared band) and very efficient, which is attributed to the large local density of states and indefinite nature of hyperbolic metasurfaces. Besides, the properties of the emission can be further tailored by manipulating the geometry of the nanostructure or modifying graphene's chemical potential with a gate bias. We envision that this technology will open new and feasible venues to construct broadband spasers and THz and mid-infrared sources using hyperbolic media, and will also find applications in sensing, communications, and biology.