Quantum Metaphotonics: Hyperbolic Metacavity Devices

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Hyperbolic metamaterial (HMM) with multiple metal–dielectric interfaces using nanorod arrays or multiple layers were presented for which the principal components of the uniaxial permittivity tensor have opposite sign. This results in an anomalous dispersion with an indefinite hyperbolic isofrequency contour (IFC). This hyperbolic dispersion leads to a high photonic density of state which enhances the spontaneous emission rate of light emitters through the Purcell effect [1]. It supports the propagation of a broad range of wavevectors, confirming that the plasmonic resonant modes are confined at a deep-subwavelength scale in all three dimensions [2]. Additionally, the hyperbolic curve is also used to predict the behavior of energy propagated inside HMM. The tailoring light effect of HMM was demonstrated on a specific polarized gain medium [3].

In this talk, I will present nanoscale HMM structures, named hyperbolic metacavity, on a specific polarized-light UV AlGaN sample (emission wavelength: 289 and 318 nm) to demonstrate giant enhancement in quantum emission efficiency and the light directivity. Through the integration of AlGaN and hyperbolic metacavity, the radiative emission rate of AlGaN emitter is significantly increased, which suppresses emission being consumed by nonradiative processes. Also, the emitter’s emission direction is efficiently directed to increase light extraction and avoid energy wasting in emitter structure. Furthermore, as the wave vector and metacavity size satisfy the round-trip phase condition for x, y, z directions. (i.e., the possible resonant modes of metacavity marked on the k-space along with the IFC curve), a clear sign of lasing operation of the AlGaN emitter with metacavity is therefore observed [4]. The results show that the specifically designed metacavity can merge all plasmon resonant modes within the cavity and provide a unique resonant radiation feedback to AlGaN emitter. This unique plasmon field allows the dipoles of AlGaN with various orientations into radiative emission, achieving enhancement of spontaneous emission rate and quantum efficiency, which is beneficial for coherent laser action. The use of the metacavity shows a promising candidate for the desired metaphotonic applications and the metacavity effect can be extended to many other material systems.