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Hyperbolic Metamaterial Nano-Resonators Make Poor Single Photon Sources

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We study field and radiation attributes of photonic nano-resonators composed of alternating metal and dielectric layers, known as hyperbolic metamaterials (HMMs). HMMs offer the ability to confine light in ultra-small volumes and enhance its interaction with matter, thereby increasing the spontaneous emission rates of nearby photon emitters through the Purcell effect. It has been suggested that one of the first applications of HMM nanophotonics is in the domain of single photon sources for use in quantum cryptography and quantum plasmonics. Here we describe the physics of HMM nano-resonators in terms of open cavity resonant modes known as quasinormal modes (QNMs). Using an analytical expansion of the photon Green function in terms of QNMs, we introduce a modelling technique that is orders of magnitude faster that direct dipole solutions of Maxwell's equations and offers considerable insight into the HMM coupling effects. We show how coupling to HMM nano-resonators can substantially increase spontaneous emission rates of quantum emitters by an order of magnitude more than pure metal resonators. However, in contrast to recent claims, we also show that most of this emission increase is lost to Ohmic heating. We demonstrate that, counter-intuitively, less metal present in the HMM resonator results in larger non-radiative losses. Using our semi-analytical QNM theory, we describe how this increase in photon quenching originates from an increased overlap between the metal and dielectric, which allows fields to leak or tunnel into the lossy metallic regions. We thus conclude that HMM nano-resonators likely make poor single photon sources, and that pure metallic resonators are preferred for single photon applications.

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