Self-Assembled Nanocrystal Microresonators: From Colloidal Photonics to Future Platforms for Quantum Light

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Colloidal semiconductor nanocrystals provide a versatile platform for engineering light–matter interactions across multiple length scales, from quantum-confined emitters to mesoscale photonic architectures. In this work, we investigate the self-assembly of nanocrystals into three-dimensional superstructures that act as optical microresonators supporting whispering-gallery modes (WGMs). These assemblies combine a solution-processable gain medium with an intrinsic optical cavity, enabling tunable light confinement, amplification, and lasing within a single colloidal object.

We show that the optical response of these systems can be programmed through control of nanocrystal composition,[1] interparticle coupling,[2] and mesoscale geometry.[3] In particular, we highlight recent advances in wavelength-tunable lasing,[4] ultrafast modulation of cavity modes,[5] and hybrid architectures[6] that exploit energy transfer pathways to reduce lasing thresholds and enhance stability. These results demonstrate the emergence of collective photonic behavior in nanocrystal superparticles, where structural and chemical design directly translate into tailored optical functionalities.[7]

While our current focus is on classical and stimulated emission regimes, these systems provide a promising materials framework for future single-photon technologies. The integration of narrow-linewidth emitters, control over the optical density of states via microcavities, and scalable bottom-up fabrication offer potential routes toward cavity-enhanced single-photon sources and quantum light–matter interfaces. By bridging colloidal nanochemistry, self-assembly, and photonics, we aim to establish a pathway from solution-processed materials to functional architectures relevant for quantum optics.

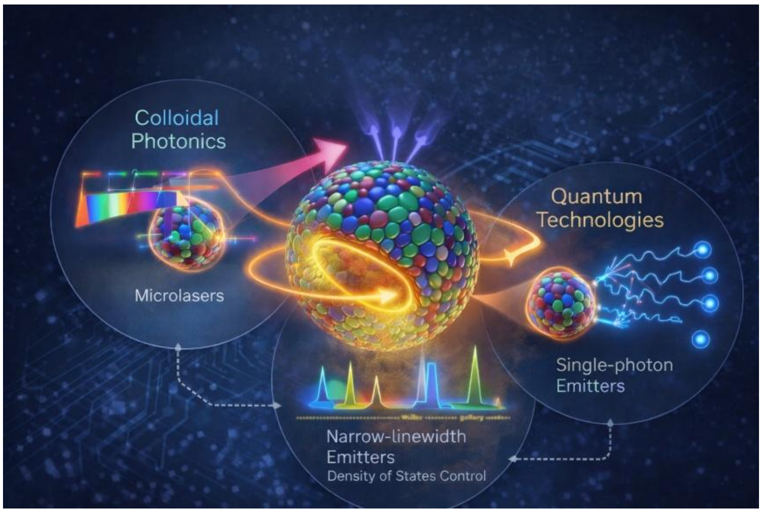

Fig. 1: Concept art: From Colloidal Photonics to Future Platforms for Quantum Light

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