Spontaneous Superradiance from Single Diamond Nanocrystals

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Nanocrystalline diamond ($\leq$ 100 nm) is a unique material that combines the extreme physical and optical properties of diamond with the high surface area and chemical reactivity of nanomaterials. Nanodiamond has attracted increasing attention over the past few decades due to its striking potential for applications in nanotechnology. Besides the extraordinary material properties, nanodiamond is host to a large variety of fluorescent colour centres [1], including the nitrogen-vacancy (NV) centre. The NV is among the most studied defects in diamond, with proposed and realised applications in quantum optics [2], quantum information [3, 4, 5] and ultra-high resolution sensing [6, 7]. In life science, diamond nanoparticles containing fluorescent NV centres are also used as non-toxic bio-labels for biomedical imaging and drug-delivery [8, 9].

The feasibility of many of these nanodiamond-based applications heavily relies on the spin and optical properties of the centre. In diamond nanoparticles containing a high density of NVs, one such property is called superradiance. Superradiance occurs when several identical emitters are highly confined in space ($V \ll \lambda^3$) and become coherent with each other. Proposed by Dicke in 1954 [10], superradiance was first demonstrated in a limited sense in hydrogen fluoride gas [11] and later in quantum dots [12].

Here we report the observation of room-temperature superradiance for single nanodiamonds containing $\sim 10^3$ NV centres in a single crystal. This leads to a significant speed-up in the photon emission rate and to non-trivial correlations between the emitted photons, which we observe experimentally in our nanodiamond-NV centres. We then look at the characteristics of this effect as a function of the sample temperature.

Our observation of cooperative effects in nanodiamond NV centres [13] is the first for a solid-state, room-temperature system meeting the condiditons (like physical volume) that were proposed by Dicke. We also discuss how our findings are relevant for ultimately developing diamond-based quantum engineered superradiant systems at room temperature, which could improve efficient photon detection, energy harvesting and quantum metrology.

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