Generation of light in a pure quantum superposition of 0, 1 and 2 photons

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The ability to generate light in a pure quantum superposition is central to the development of quantum-enhanced technologies such as distributed quantum computing, long distance quantum communications or quantum sensing. Light offers many degrees of freedom to encode the quantum information including polarization, frequency, time bin, orbital angular momentum among others, allowing for large encoding Hilbert spaces. While the photon-number basis is natural for discrete variable encoding, the generation of light in coherent superpositions in photon-numbers remains challenging. So far, this has mostly been demonstrated through quantum-state engineering via the interference between heralded single-photon sources and coherent light [1].

Here we show that a single semiconductor quantum dot in a cavity can directly generate quantum superpositions of zero, one, and two photons. We investigate devices consisting of a single semi-conductor quantum dot positioned with nanometre scale accuracy at the centre of a connected-pillar cavity [2,3]. The quantum dot layer is inserted in a p-i-n diode structure and electrical contacts are defined as to control the quantum dot optical resonance through the confined Stark effect. These devices show strong suppression of decoherence processes arising from charge noise or coupling to phonons. They generate highly indistinguishable single-photons with high extraction efficiency [3]. We coherently drive the quantum dot transition with short laser pulses and observe Rabi oscillations as a function of the pulse area. We perform interferometric measurements that evidence that the quantum dot emits a coherent superposition of vacuum-, and one-photon in a well-defined propagating mode of the electromagnetic field. Below the π-pulse, the zero- and one-photon populations are controlled through the laser intensity and exhibit near to maximal quantum coherence.

Driving the quantum dot with a 2π-pulse produces coherent superpositions of vacuum, one and two photons where the 2-photon Fock state population is larger than the 1-photon population. This state shows phase super-resolution in interferometric measurements. Our results demonstrate that quantum dot based artificial atoms are now controlled to such a degree that they can perform as text-book idealized systems. They open new paths for optical quantum technologies where generalized multi-photon interferences, including the photon-number degrees of freedom, can be exploited.

References

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