Interfacing light and matter down to the single-photon level

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A quantum-dot (QD) efficiently coupled to a cavity mode is an extremely sensitive cavity QED device whose optical properties can be controlled and probed with single incident photons: this constitutes the building block of a large number of experiments and applications in quantum physics. A key requirement in this context is the fabrication of state-of-the-art cavity-QED devices using micropillars (Fig. 1): indeed, pillar cavities can demonstrate a maximized light-matter interaction (thanks to deterministic coupling techniques [1, 2]) together with high coupling efficiencies and very high quality factors[3]. The optical properties of these devices can then be probed using high-resolution resonant spectroscopy techniques [4].

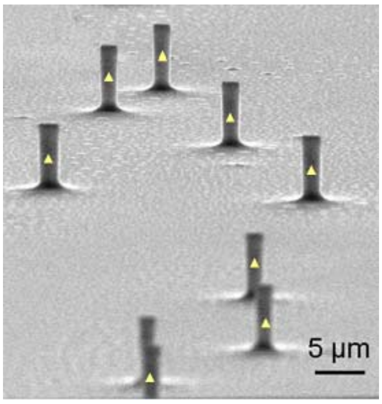

FIG. 1. Scanning electron microscope image of micropillar devices deterministically-coupled with semiconductor quantum dots (yellow triangles).

In this presentation, we will discuss a few applications for which the efficient light-matter interfacing plays a central role:

- **Optical nonlinearity and coherent control with few-photons pulses**
  We demonstrate the possibility to manipulate the quantum state of a single two-level system, and thus its optical properties, using few-photon optical pulses. Engineering an optimal interaction between an incoming pulse and a cavity-QED device allows an optical nonlinearity to be triggered by a few photons only [5]. Furthermore, as demonstrated with resonance fluorescence experiments, the coherent control of the QD state can be achieved via Rabi oscillations induced by a few incoming photons. We will discuss how these interactions can be pushed down to the single-photon level, thus opening the road towards single-photon routers and photon-photon logic gates.

- **Optical read-out of a single spin through cavity-enhanced spin-photon interaction**
  We have also developed a highly-efficient spin-photon interface, where the spin degree of freedom in a quantum dot, featuring a quantum memory, is mapped to the polarization of an optical beam [6]. Making use of cavity quantum electrodynamics effects, a huge amplification of the spin-photon interaction is obtained, three orders of magnitude above the previous state of the art. It now becomes possible to entangle and measure a single spin with a single incident photon: such a spin-photon interfacing opens new paradigms in quantum optics, by providing the unique possibility to entangle delayed photons via the spin quantum memory. It also allows experimenting at a very fundamental level on the notion of quantum measurement, at the heart of quantum physics.

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