Photonic quantum information processing in Grenoble

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Photons are the only way to propagate quantum information over long distances. They have already allowed quantum key distribution over more than 100 km in free space or over optical fibers; they are the ideal candidate for secure quantum networks, which rely on quantum communication but also on quantum computation. Long-distance quantum communication requires quantum repeaters to overcome the propagation losses, while a quantum network needs efficient optical quantum interconnects between flying qubits (photons) and quantum memories. The key technological challenges are the realization of efficient sources of quantum states of light such as undistinguishable single photons, or entangled photons, as well as their efficient detection.

Grenoble has built over the last decade a pioneering experimental and theoretical activity in quantum photonics ranging from single photon sources (Fig. 1) to non-linear optics (Fig. 2), photon counting detectors, hybrid optomechanical devices (Fig. 3), and plasmonics (Fig. 4). The theoretical concepts are also relevant for superconducting physics.

Photonic quantum engineering in Grenoble addresses the following challenges:

- **Single photon sources.** Building on our strong expertise in the nanofabrication of semiconductor nanostructures and quantum optics theory, we develop electrically-driven, tunable sources of single photons and entangled photon pairs, based on quantum dots in photonic waveguides. We also develop quantum photonic circuits integrating efficient single photon sources and detectors, in collaboration with LETI, a leading European player in the field of Si photonic circuits.
- **Hybrid optomechanics.** Original optical interconnects are developed by investigating hybrid coupling between photons and nanomechanical oscillators in systems based on semiconducting quantum dots or NV centers in diamond. We use these hybrid systems to achieve full quantum control over a mechanical oscillator, opening opportunities for both information storage and sensing.
- **Quantum plasmonics.** Our experimental and theoretical activity is oriented towards efficient light-matter coupling with quantum emitters using home made near-field scanning optical microscopes, plasmonics cavities, chiral systems, antennas and optical wave guides.
- **Parametric optical sources**. Non-linear optics produces quantum states such as photon triplets.
- **Nonlinear hybrid plasmonics**. Hybrid structures are investigated from both experimental and theoretical points of view for producing and manipulating entangled photon pairs at the nanoscale.
- **Quantum thermodynamics.** When information becomes quantum, new questions emerge: can we convert entanglement into energy? What is the energy cost of a quantum computation? These questions are addressed theoretically in a strong connection with experimental implementations in optically-driven solid-state systems. The behavior of nano-heat engines and refrigerators in the quantum regime is also investigated, leading to fundamental bounds for power and efficiency.

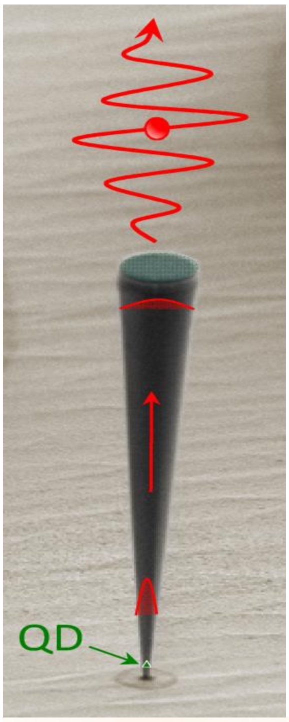

Fig. 1: **Single-photon source**: a semi-conductor quantum dot (QD) embedded in a photonic waveguide with tailored ends, offers efficient light emission[1] and giant non- linearities.[2]

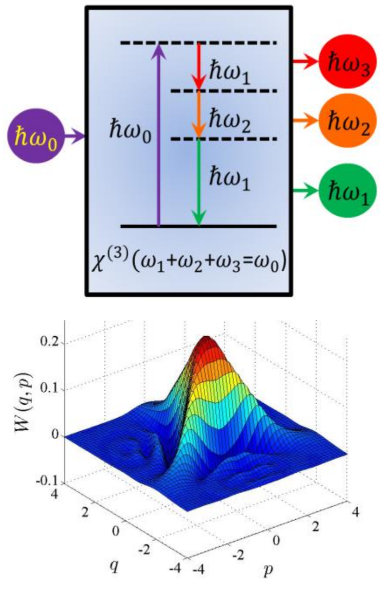

Fig. 2: **Triple photon generation** governed by the third-order susceptibility $\chi^{(3)}$ in a nonlinear medium[3] and the Wigner function for a three-photon quantum state.

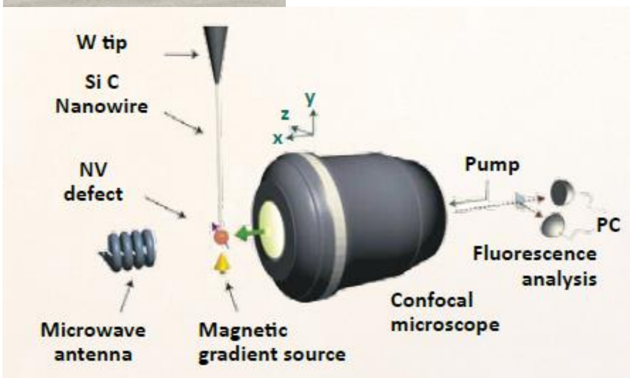

Fig. 3: **Hybrid mechanical systems**: a mechanical oscillator is coupled to an individual quantum system, such as an NV center in diamond[4] or a quantum dot,[5] for quantum information storage or sensing.

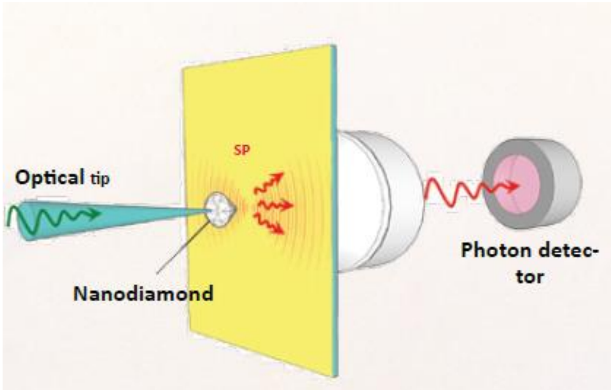

Fig. 4: **Quantum plasmonics**: a single NV center in a diamond nanocrystal at the tip of a near-field scanning optical microscope creates individual surface plasmons (SP) in a metal film.[6] Plasmonic nanoantennas can also be tuned to enhance the linear and nonlinear processes at the nanoscale.[7]

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