# A single spin magnetically coupled to a nanomechanical oscillator

**The intense experimental efforts of several groups worldwide during the last six years have very recently culminated by demonstrating what the scientific community considered unrealistic only 10 years ago: cooling a macroscopic mechanical oscillator down to its quantum ground state of motion. Experiments going beyond ground state cooling and aiming at generating non-classical states of motion require an actual engineering of the quantum mechanical state of the oscillator. This can best be achieved by coupling the ultracold oscillator to a second quantum system through which one can interact with the oscillator.**

The combination of these two components defines a "hybrid" mechanical system. The goal of our research is to investigate these novel hybrid quantum systems consisting of a nano-mechanical oscillator and a fluorescent Nitrogen-Vacancy (NV) defect centre in a diamond nanocrystal. In the work presented here, our system is at room temperature, but we plan to do experiments with ultracold resonators in the future. The electronic spin state of the defect represents a unique quantum system for our purpose: it features ultralong coherence times and can be read out and manipulated with optical and microwave fields. The ultimate goal of the project is to enter the quantum regime of a hybrid nano-mechanical system, where the spin and the oscillator dynamics are entangled, and to investigate phenomena at the interface between the classical and quantum worlds.

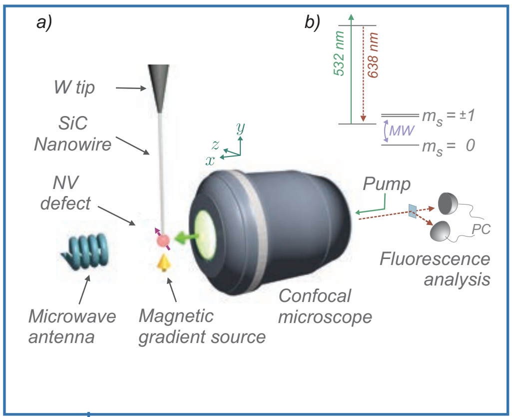


Figure 1 : a) Schematics of the experiment. b) Electronic structure of the NV centre in diamond, which is excited off resonance at 532 nm and fluoresces at 638 nm. The centre's ground state is manipulated with microwave fields (MW).

We have recently taken the first steps in this direction by attaching an NV centre on the vibrating extremity of a SiC nanowire. In order to obtain mechanical control over the nanowire, it was attached at the apex of a tungsten tip, which was positioned on a piezo-electric crystal. The NV fluorescence was collected through a high numerical aperture microscope objective on ultrasensitive avalanche photodiodes (see Fig. 1). The electronic structure of the NV defect exhibits an optical transition in the visible which constitutes a stable single photon source. By recording the emitted photon rate, we observed the effect of the resonator's motion across the optical spot of the microscope. More precisely, with an autocorrelator optical setup, we observed the influence of the nanoresonator vibrations (625 kHz for the mechanical mode used in this experiment) on the collected photon statistics.

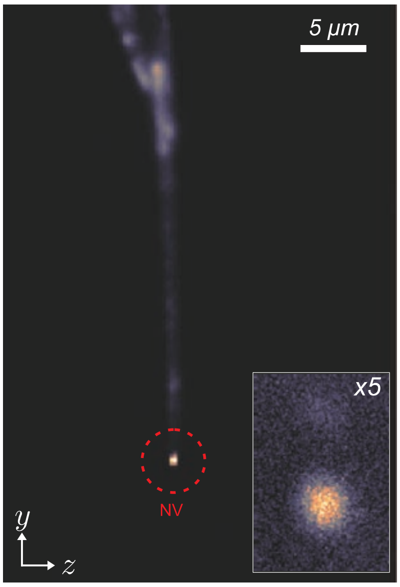


Figure 2 : Fluorescence map of the hybrid nano-resonator with a zoom onto the photon-emitting NV defect (red dashed circle) at its vibrating extremity.

Furthermore, the NV defect ground state is a spin triplet state with an ultralong coherence time that can be manipulated with microwave fields. We achieved magnetic coupling of the NV defect spin state to the oscillator's position via the combination of an external strong magnetic field gradient and the Zeeman splitting of the energy levels of the NV centre. More precisely, we immersed the system in a field gradient of 100 000 T/m (by approaching a structured permanent magnet). As the nanoresonator is set into motion, the NV centre sweeps through the magnetic field gradient, thereby experiencing large variations in the magnetic field. Thus, the energy levels of the NV centre, which depend on the magnetic field through the Zeeman effect, are subject to oscillations as well, and consequently are coupled to the nanoresonator motion.

The NV spin energy levels were probed by scanning a microwave field across the transition energy, while having the nano-resonator vibrating. By combining the microwave spectroscopy and a simultaneous optical read-out, a clear splitting in the spin energy spectrum, induced by the nano-motion, was observed in the fluorescence spectrum. In reverse, this coupling intrinsically generates a spin dependent force, whose magnitude is quantized and depends on the NV defect's spin state. This represents the key ingredient for mapping the quantum state of the spin onto the nanoresonator and thus creating non-classical states of motion. The possibility of generating spin-dependent forces combined with groundstate cooling of mechanical resonators will in the future allow us to perform quantum physics experiments with nano-mechanical oscillators.


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FURTHER READING


A SINGLE NV DEFECT COUPLED TO A NANOMECHANICAL OSCILLATOR
O. Arcizet, V. Jacques, A. Siria, P. Poncharal, P. Vincent, and S. Seidelin
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