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Rare-earth ions-doped ferroelectric nanocrystals for optical sensing of electric potential in biological systems

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Many biological cells exhibit at their membrane a difference of electric potential between their inner compartment and the outer medium. In a neuronal circuit, this difference experiences transient changes of polarity during the propagation of action potentials. Outside the cells, it reflects as changes of electrical potential, referred to as “local field potential” (LFP). Sensing of such signal at high spatiotemporal resolution (sub-micrometer/millisecond) using minimally invasive probes would help to study and better understand neuronal circuits functions in normal and pathological conditions.

We aim to develop such nanosensors based on ferroelectric nanocrystals (FENC) of size ≈150-200 nm doped with rare-earth ions (RE^{3+}) able to realise photon up-conversion (UC). Due to its ferroelectric property the FENC possesses an intrinsic electric polarization resulting in surface charges. When exposed to a change of electric potential in its environment, the FENC surface charge density is modified, leading to a change of polarisation that induces, by converse piezoelectric effect, changes of the RE^{3+} crystallographic environment. The latter is finally converted into a change of UC spectrum, enabling the optical sensing of electric potential.

In our work we synthesize barium titanate nanocrystals (nanoBTO) doped with Er^{3+}(1%) by a combination of co-precipitation and hydrothermal methods. To investigate UC spectrum from individual particles, we use a raster scanning fluorescence microscope with laser excitation at 980 nm wavelength combined to an imaging spectrograph equipped with a cooled CCD array detector. As a first step to check the effect of an external electric potential, we embedded the Er-doped nanoBTO in a 300-nm thick non-conductive polymer layer deposited on an ITO-coated glass substrate, and placed ≈10 mm below a tungsten needle connected to 6 kV electric potential (Fig.1a). This corona discharge configuration leads to electric charge deposition on top of the polymer layer, generating a large electric field across it. While increasing the voltage applied to the needle up to 6 kV, we observed an 14 % increase of UC 550 nm peak intensity whereas the other peaks stayed constant (Fig.1b).

These promising results will be presented as well as on-going developments especially on the control of the applied electric field by using piezo-electric force microscopy (PFM).

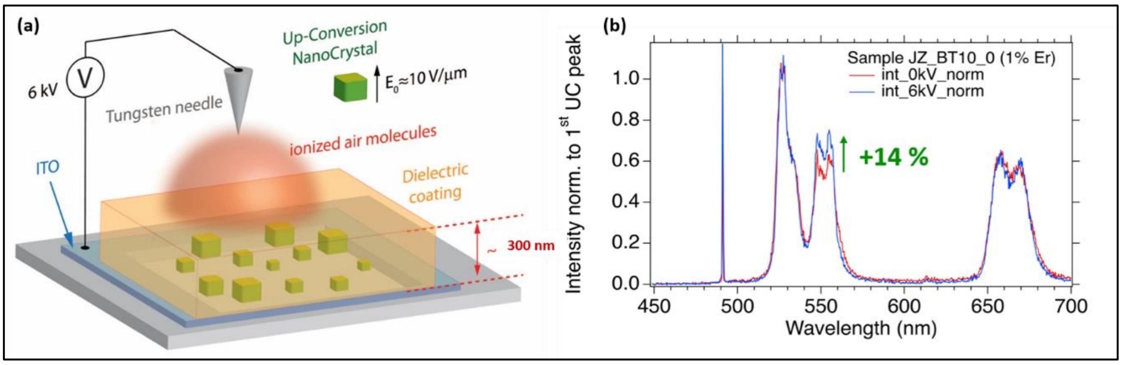

Figure 1: (a) Corona discharge configuration used to apply an electric field across the nanocrystals. (b) Change in UC spectrum of a single Er-doped nanoBTO. (red curve: no voltage; blue: 6 kV).