M2 Internship Proposal 2022-2023

Diamond Quantum Microscopy of Neuronal Electrical Activity

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How electrical signals propagate in a neuron and across neuronal assemblies is still poorly understood. Theoretical modeling struggles to explain the subtle nature of neuron network connectivity and experimental measurements of individual neuron electrical signals across large networks remain elusive. Whilst many techniques exist to measure neuron activity, none of them can perform at high spatiotemporal resolution with wide-field imaging capacity and low invasiveness. To achieve this, we are developing a quantum sensor based on the optically detectable electron spin magnetic resonance (ODMR) of negatively charged nitrogen-vacancy (NV^-) center in diamond nanostructures (Fig. 1). This three-year duration project (2022-2025) is supported by a Human Frontier Science Program (HFSP) cross-disciplinary fellowship.

The first steps of this project consist in 1) fabricating the diamond nanopillar array with NV^- centers at the pillar's tips (collab. with J.-F. ROCH [LuMIn] and Xavier CHECOURY [C2N, Palaiseau]) on which neuron grow efficiently as already established (Fig. 1a); and 2) constructing a "quantum microscope" combining wide-field electrometry (continuous wave or pulsed ODMR) and live primary neuron culture imaging at large magnification. This experimental effort will be matched with theoretical modeling of the neuron electrodynamics in the presence of a nanopillar.

The master internship will focus on the construction of novel wide-field "quantum microscope". The candidates should have a good background in quantum physics with an interest in both experimental and theoretical approaches. Understanding of neuroscience concepts, nanofabrication steps, and Python programming is also very helpful but not mandatory. Finally, candidates should have a good grasp of English.

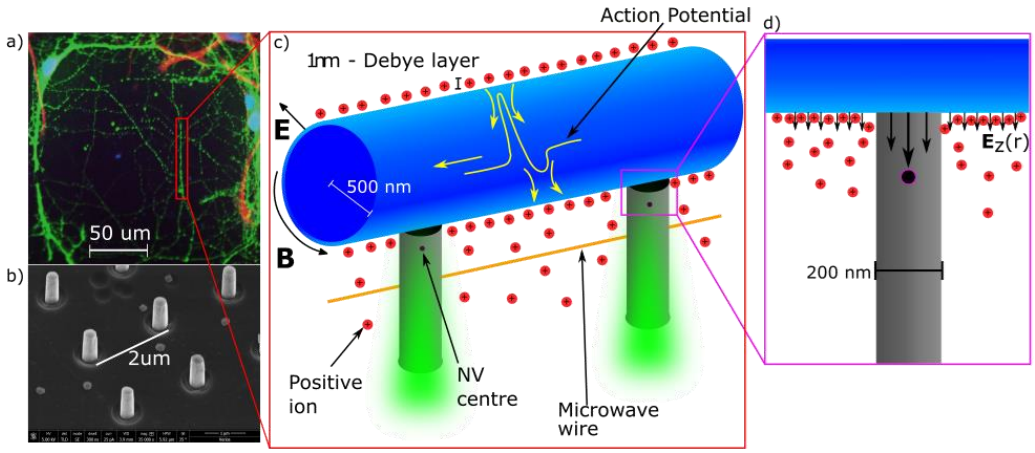

Figure 1: Experimental configuration for the measurement of neuron electrical activity with a NV-diamond nanopillar-based quantum microscope (from Ref. [1]), a) confocal scan of stained green neurons grown on a bed of diamond nanopillars shown in b). c) Neuronal branch (blue) which grew along NV-doped nanopillars. The NV quantum sensing process is performed with green laser and microwave excitation. d) Intimate contact between the pillars and neuronal branches limits detrimental effect of Debye screening by ions, allowing efficient electrometry.

Reference : [1] L. Hanlon et al., *Neurophotonics* **7**, 035002 (2020)

PhD opportunity : The internship is open to a follow-up by a PhD thesis (funding applications to be done to ENS Paris-Saclay CDSN and Doctoral School programs).

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