Proposition de stage / Internship proposal

Date de la proposition : 19/09/2025

Responsable du stage / *internship supervisor*

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Nom du Laboratoire / *laboratory name*

Etablissement / *institution* : Laboratory **LuMIn**   Code d'identification : 202023513A

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Adresse / *address:* 4 avenue des Sciences, 91190 Gif-sur-Yvette

Lieu du stage / *internship place*: ENS Paris-Saclay, University Paris-Saclay

Titre du stage / *internship title*: **Quantum sensing of neuronal electrical activity at the nanoscale**

Résumé / *summary*

Neurons communicate with each other via synapses. Little is known about **electrical potential at the synapse submicron scale**, even though it plays a key role in synaptic transmission. The project aims at developing an optical array sensor of **neuron electric field** that exploits the quantum properties (spin S=1) of negatively charged **nitrogen-vacancy** (NV^-) defects in **diamond nanopillars (Figure 1)**, and that achieves nanometric scale and millisecond resolutions, in a wide field. While NVs have been largely used to sense magnetic field, their ability to sense electric field has been less employed but the large electric field taking place during a **neuron action potential** (AP, 100 mV across the 5 nm thick cell membrane, *i.e.* 200 kV/cm) is predicted to be easier to detect than the 1 nT magnetic field associated the AP current [**Hanlon2020**].

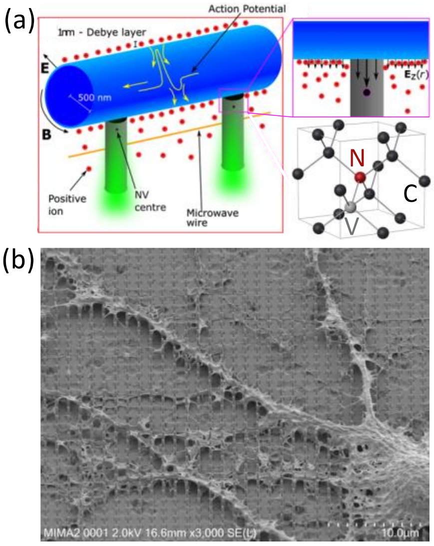

Figure 1 – ***(a)*** *Sensing neuron electric field* ***E*** *with NV center in diamond nanopillars [Hanlon2020]. As* ***E*** *can be screened by culture medium ions at a distance as short as 1 nm (Debye layer), it is critical that branches are tightly connected to the pillars as it seems to be the case based on our preliminary electron microscopy images* ***(b)*** *(diamond nanopillars: X. CHECOURY [C2N] & L. HANLON, neuron culture: B. POTIER & B. GRIMAUD; SEM: V. COSTACHE [INRAe]).*

The experimental setup relies on a commercial microscope that is well adapted to live cell imaging in epifluorescence configuration. Mouse neurons are grown on the nanopillar (1 µm tall, with [NV]≈1 ppm) array structured on a 80 µm thick transparent diamond membrane (**Fig. 1b**). NV^- spin state is prepared and readout with a laser at 532 nm wavelength, and can be coherently manipulated with a microwave field resonant with the transition between two spin states (≈2.87 GHz). For the wide-field detection, we use a **pixel-wise lock-in array sensor** (heliCam C4) well adapted to sensing with a pulsed protocol (*e.g.* Ramsey interferometry). The **current status** of the experiment is: the software operating the sensing protocols with the lock-in array is operational, NV-doped diamond membranes with long spin coherence time T_2* (hence a better sensitivity) have been fabricated, and 3D electromagnet that generates a bias magnetic field (required for electric field sensing) is in use. We are also able to culture hippocampal primary neurons dissociated from mouse embryo brains onto a diamond nanopillar array (**Fig. 1b**).

The **internship** will focus on **imaging a test electric field** applied between two interdigitated gold electrodes deposited onto the NV-diamond layer. This configuration will serve to estimate the electric field sensing sensitivity of different measurement protocols in air and in a cell culture medium.

The **PhD thesis** will then aim to (i) optimize the E-field sensing sensitivity of flat and nanopillar-structured NV-diamond; (ii) implement the optimal sensing approach to image the electrical activity of primary neuron (or other electro-active cells, *e.g.* cardiomyocytes) cultured on the nanopillar array. As the high laser intensity needed to initialize the NV in the m_S=0 state might photodamage the cells, the illumination will be structured (*e.g.* with a spatial light modulator) to address only the nanopillars.

The thesis will take place in the continuity of the thesis of Gizem YAPICI and benefit from the highly **interdisciplinary environment** of LuMIn "Biophotonics" team. Primary neuron culture will be handled by Brigitte POTIER (CNRS neurobiologist). Furthermore, the PhD student will be part of the ANR SINFONIA (2024-2028) project consortium, involving experts in quantum grade NV-diamond production, nanofabrication and quantum sensing.

[**Hanlon2020**] Hanlon, L. *et al.* Diamond nanopillar arrays for quantum microscopy of neuronal signals. *Neurophotonics* **7**, 035002 (2020).

Ce stage pourra-t-il se prolonger en thèse ? *Possibility of a PhD* **? : Yes**

Si oui, financement de thèse envisagé ou acquis / *financial support for the PhD* **?**

Financement acquis / *Secured funding*		Nature du financement /*Type of funding*	
Financement demandé / *Requested funding*	X	Nature du financement /*Type of funding*	Quantum Saclay; CDSN, Doctoral School