Proposition de sujet de stage **2024-2025**

Laboratoire :	**Equipe :**
Groupe d'Etude de la Matière Condensée CNRS/UVSQ - UMR8635 Université de Versailles (Bâtiment Fermat) 45, av des Etats-Unis 78035 VERSAILLES	Axe Semi-conducteur – Activité Diamant **Encadrante :** Marie-Amandine Pinault-Thaury Tel : 01 39 25 44 89 Email : marie-amandine.pinault-thaury@uvsq.fr

Si intéressé.e, envoyez à marie-amandine.pinault-thaury@uvsq.fr, avant le 6 février 2025, les pièces suivantes :

- Certificat d'inscription en master 1, master M2 ou année spécifique
- Lettre de motivation (une page maximum)
- Curriculum vitae
- Copie d'une pièce d'identité
- Derniers bulletins de notes disponibles

Nitrogen-Vacancy centers in diamond: effect of a phosphorus delta-doping

Due to long coherence times and high sensitivities with nanometer-scale resolution, the negatively charged nitrogen-vacancy center (NV-) in diamond is a versatile atomic sized spin system for applications in quantum sensing and quantum-information science. For nanoscale imaging and nanoscale nuclear magnetic resonance, the NV centers are required to be produced with nanometer spatial accuracy, while retaining their spin and optical properties. Among the techniques to generate NV centers, the ion-implantation technique is the most effective for producing them close to the surface, and for fabrication of arrays with nanoscale resolution.

Recently, huge improvements on the properties of NV centers have been obtained. By doping diamond with phosphorous, which is an electron donor impurity, an almost perfect stability of the charge state of NVs have been demonstrated. Moreover, record spin coherence time, which is the key parameter for many applications, have been obtained. This effect is attributed to the suppression of the creation of multivacancy complex or vacancy-impurity complex defects during chemical vapor deposition (CVD) of diamond, by Coulomb repulsion among charged defects. Therefore, the enhancements for the shallow NV centers in n-type diamond-semiconductor are significant for future integrated quantum devices. To improve n-type doping effect on NV centers, it is proposed to optimize the dopant profile by using, for example, delta-doping.

GEMaC is a joint unit between CNRS and Versailles University. For 20 years, work on n-type phosphorus-doped diamond CVD growth is carried out successfully. Indeed, it is the leader in Europe and one of the extremely rare worldwide that controls phosphorus doping on a large range and on several crystallographic orientations. In the last 3 years, growth process has been developed to realize, on (100) orientation, highly-phosphorus delta-doped structure with abrupt interfaces between the delta and both low doped layers that encapsulate it (see figure 1). To our knowledge, such stacking layers are unique.

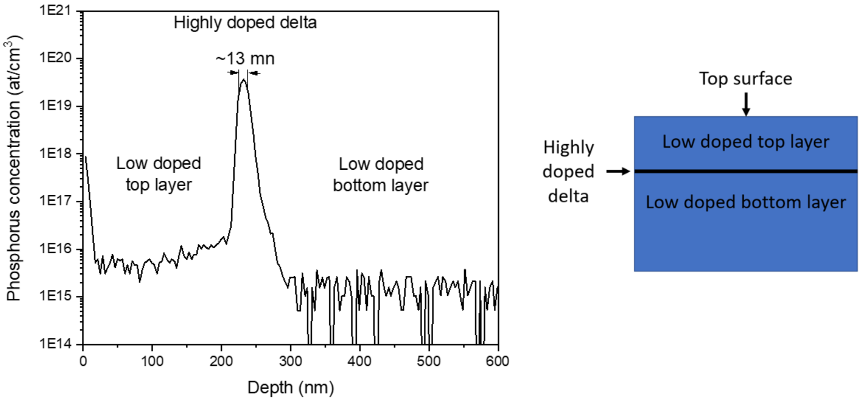

Figure 1: Depth profile of the phosphorus concentration of the (100) diamond delta sample with its schematic sectional view.

In collaboration with IRCP, the delta sample is going to be etched by focused ion beam (FIB) to create a stair with several steps from the top surface up to the low doped bottom layer. Then, implantation of 14N will be performed, on each step of the stair, in spot areas (~20 µm of diameter) under different fluences. Thanks to the thermal ability of vacancies to move into to the lattice and form N-V complexes, an annealing will end the formation process of NV centers in the spot areas (see figure 2). As a result, set of NV centers will be created form the top surface, meaning far from the delta, up to the delta (or close to) and even into to the bottom layer. This will allow the study of the influence of the delta onto the NV center characteristics (ex: coherence times), depending on the distance to the delta and even without interaction with it.

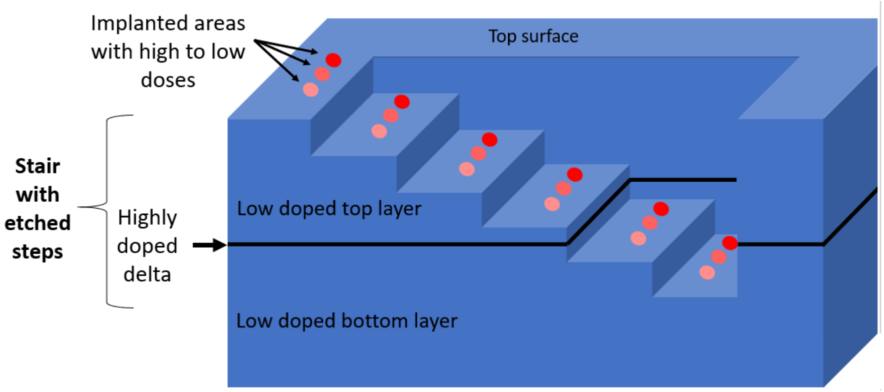

Figure 2: drawing of the sample with stair of set of 14N implanted areas.

The goal of the internship will be, at GEMaC and on each steps of the etched stair, (1) to measure the step-height and -length by atomic force microscopy (AFM) and to map the photoluminescence (PL) of the NV centers implanted areas surrounded by untreated area. After these first characterisations, the student will participate to optically detected magnetic resonance (ODMR) measurements at IRCP and investigate the coherence times of NV centers in each implanted area compared to untreated area and for each step of the etched stair. Hence, characteristic values extracted from experiments will be plotted for each step to highlight the effect of the delta onto the NV centers behaviour.