Recently, hexagonal boron nitride (hBN) has attracted a lot of interest as a candidate for a broad range of applications, related to so-called van der Waals heterostructures, which are composed of atomically thin layers of materials, sometimes called NanoLego. Lately, it has also been shown that hBN is an excellent host for optically active spin defects, with the prime example of the negatively charged boron vacancy ($V_B^-$). The electronic spin of this defect if extremely sensitive to perturbations like magnetic and electric field, pressure and temperature. The readout is possible due to a bright spin-dependent photoluminescence signal making it an excellent quantum sensing platform. This novel hBN platform may become competitive with the best-developed platforms based on the nitrogen-vacancy (NV) centre in diamond, which have already shown huge potential to cover the growing need for high precision sensors of the local magnetic field used in condensed mater physics, geophysics and live sciences. However these systems suffer from several obstacles resulting mostly from the 3D nature of the host diamond crystal, like limited proximity between the quantum sensor and the target object and the difficulty to produce flexible, ultrathin structures, which would be transferred to the sample surface being probed. It was already demonstrated that hBN layers hosting $V_B^-$ spin defects can serve as atomically thin quantum sensing foil offering atomic-scale proximity to the probed object. Such experiments were demonstrated only using flakes exfoliated from small isotopically enriched, with $^{10}$B isotope, bulk h-BN crystals irradiated by thermal neutrons. There is no doubt that industrial applications of hBN-based quantum spin sensors can only be realized using a technology that offers high-quality, large-area layers grown on commercially available substrates. These requirements can be fulfilled using MOVPE (Metalorganic Vapor Phase Epitaxy). Recent progress in MOVPE technology in our laboratory allowed us to achieve high-quality epitaxial hBN layers on 2” sapphire substrates. We have developed effective methods of delamination of our hBN layers from the 2” substrates, which is crucial from the point of view of assembling different van der Waals heterostructures. Natural boron nitride is composed of two isotopes: $^{11}$B (~80%) and $^{10}$B (~20%). It is known that the thermal neutron capture cross-section of $^{11}$B is about three orders of magnitude smaller than that of $^{10}$B. Thus, irradiation of h$^{10}$BN likely creates boron vacancy-related defects through nuclear transmutation. Conversely, the h$^{11}$BN isotope is expected to be almost transparent to neutrons.

In this application, we propose to investigate epitaxial boron nitride enriched with $^{10}$B grown by MOVPE on 2” sapphire substrates. The aim is to verify the possibility of obtaining a scalable platform for the effective creation of boron vacancies via nuclear reaction with neutrons provided by the National Centre for Nuclear Research (Świerk, Poland). Advanced characterization including XRD, SEM/TEM, AFM, STM, optical spectroscopy (transmission/reflection measurements, Raman effect, luminescence, cathodoluminescence), EPR will provide information about isotopically enriched material before and after neutron irradiation. The obtained results will be correlated with PAS (Positron Annihilation Spectroscopy) in collaboration with the University of Helsinki, which is sensitive to the presence of vacancies in the material, and finally tested by ODMR (Optically Detected Magnetic Resonance), in collaboration with the University of Montpellier. Theoretical modeling of different defects and their expected signal in EPR and ODMR will be performed in collaboration with the Wigner Research Centre for Physics in Budapest. Moreover, monoisotopic hBN material will be used as a “spectroscopic marker” and as a spin defect rich layer, e.g. in stacks of layers with different isotopic composition. This “marking” of layers will serve as a tool to study the basic properties and defects in isotopically enriched hBN including the influence on decoherence time of the $V_B^-$ spin defect, which is important for future quantum sensing technology. Experiments with different isotopic compositions, and different neutron fluxes, will be used to evaluate the efficiency of the creation of desired spin defects in comparison to other defects. Despite the large interest in the topic, there is so far no systematic study that concerns the irradiation of hBN with thermal neutrons and the processes involved in spin defect creation. However, this knowledge is crucial from the point of view of understanding the basic properties of spin defects in epitaxial h-BN as well as potential applications of this material as an atomically thin, elastic platform for quantum sensing technologies. Only a deterministic tuning of the properties will allow to deepen the understanding of spin defects in hBN and harvest the full potential of hBN for local magnetic imaging and information technologies.