Abstract

Boron nitride (BN) is an sp^2-hybridized two-dimensional (2D) material with a wide bandgap ($\sim$ 6 eV). Its crystal lattice hosts color centers that emit across a wide spectral range, from the near-infrared (NIR) to the ultraviolet (UV). These defects can be utilized in modern quantum technologies. In particular, negatively charged boron vacancies (V_B^-) function as ultra-sensitive quantum sensors of magnetic field, temperature, and pressure, whereas visible-range-emitting point defects serve as single-photon emitters (SPEs) for applications in secure quantum communication.

Most research on quantum emitters in BN relies on small flakes, with an area of several tens of μm^2, exfoliated from bulk crystals. While this approach is useful for studying the fundamental properties of color centers, it cannot be used in practical applications due to limited scalability and reproducibility. This problem may be addressed using metal-organic vapor phase epitaxy (MOVPE), which enables the growth of large-area BN layers on few-inch substrates.

This work focuses on the fabrication, characterization, and engineering of quantum emitters in BN obtained by MOVPE. Importantly, color centers form already during the material growth, and no post-growth fabrication is necessary to obtain them. The scope of the research discussed covers both the formation of defects during growth and their subsequent modification.

First, the results of the optical characterization of point defects in high-quality BN layers are discussed. The studied material hosts numerous color centers emitting in the green spectral range, acting as SPEs even at room temperature. Statistical analysis indicates the presence of at least three types of defects emitting in this spectral range, which may differ in atomic structure or symmetry of local environment. The investigated emitters are strongly coupled to out-of-plane phonons, as revealed by temperature-dependent measurements. The next part encompasses optimization of growth conditions for the generation of quantum emitters. Among many parameters that determine the properties of BN, layer thickness and TEB flow rate, which govern the amount of carbon available during the growth, were analyzed. The results show that a higher thickness of the BN layer leads to higher emitter stability. On the other hand, an excessively high TEB flow rate applied during growth leads to a decrease in emission purity. In addition, it

is found that, with all other growth parameters kept constant, the concentration of green emitters is controlled exclusively by a single effective parameter incorporating both layer thickness and TEB flow rate.

In the subsequent study, the influence of electron beam-induced bubbles on the emission of BN-based color centers is examined. The results demonstrate that interference effects between the bubbled material and the substrate can enhance the emission by several fold. Importantly, electron irradiation alone does not result in the formation of new emitters or the modification of existing ones. The practical application of this phenomenon requires control over the position and size of the generated bubbles. This goal was achieved through electron exposure assisted with lithographically fabricated masks.

In the final part, the effect of thermal neutron irradiation on defect-related emission in rhombohedral boron nitride (rBN) was studied. While this procedure is typically used to fabricate boron vacancies in exfoliated flakes, in MOVPE-grown, carbon-doped material, it additionally generates color centers. This result suggests an important role of vacancy-carbon complexes in the formation of these emitters. Furthermore, for the first time, neutron-induced formation of luminescent centers emitting in the blue region has been observed. Importantly, until now, the only known mechanism for creating blue emitters was electron irradiation. Should future studies demonstrate that the blue centers generated by electron and neutron irradiation originate from the same defect, the currently accepted model of their formation, which assumes the crucial role of the electric field of the electron beam, would need to be reconsidered.

The results presented in this dissertation provide a new insight into quantum emitters in epitaxial BN. The most important achievements are the determination of the relationship between growth parameters and the properties of color centers, the enhancement of their emission through the deterministic fabrication of BN bubbles, and the identification of new neutron-based mechanisms of green and blue emitter formation. The obtained results constitute an important step toward the controlled and scalable fabrication of quantum emitters in BN, advancing their prospects for practical applications.