Abstract

Hexagonal boron nitride (hBN) is a material with exceptional optical and electrical properties, characterized by a wide bandgap of approximately 6 eV. This makes hBN an excellent electrical insulator with potential applications in deep ultraviolet (DUV) optoelectronics. Its high light emission efficiency in the DUV range opens up broad technological possibilities in areas such as water purification, sterilization, and medical and industrial applications.

The main objective of this dissertation was to develop the technological foundations for the effective use of hBN in optoelectronics, particularly in the context of DUV radiation detectors and emitters. In this regard, not only the intrinsic properties of the material are important but also aspects related to its structuring and the development of low-resistance electrical contacts.

A significant challenge in structuring BN layers is their degradation during wet lithographic processes, which can lead to unintended delamination, wrinkling, or tearing of the layers. This dissertation proposes an innovative method to counteract these problems by intentionally delaminating and repositioning BN layers onto their original sapphire substrate. This approach prevents layer degradation, enabling the fabrication of lithographically defined BN structures suitable for electrical measurements and the construction of DUV detector structures.

The conducted research reveals an intriguing doping mechanism in epitaxial BN, based on a complex process involving hydrogen release from defect complexes containing boron vacancies and the subsequent occupation of these sites by silicon atoms. During the growth of epitaxial BN layers, defect complexes (V_BC_N) containing hydrogen are formed. This dissertation demonstrates that annealing epitaxial BN samples leads to hydrogen release from these complexes while simultaneously causing thermal degradation of the protective SiC-coated susceptor. As a result, silicon atoms can occupy the vacant sites, forming Si_BC_N defects. The presence of these defects was confirmed through various methods. Temperature-dependent electrical conductivity measurements revealed shallow acceptor states with an activation energy of approximately 130 meV. These findings were further validated by Si_BC_N defect simulations using Density Functional Theory (DFT). Additional confirmation was obtained through spectroscopic techniques such as Energy Dispersive X-ray Spectroscopy (EDX) and X-ray Photoelectron Spectroscopy (XPS). The proposed model was corroborated by observations in samples where electrical conductivity was first activated and subsequently subjected to hydrogen annealing. This process led to the re-passivation of acceptor centers and restored the sample to an insulating state. The presented procedure for activating electrical conductivity represents one of the most significant outcomes of this study. It enables the achievement of exceptionally low resistivity in epitaxial BN samples, reaching 2.8 kΩ·cm at room temperature—four times lower than the best results reported in the literature for magnesium-doped epitaxial BN. Attaining such low resistivity in unintentionally doped samples marks a significant advancement in the study of epitaxial boron nitride.

Another crucial aspect of this research was the development of low-resistance electrical contacts for boron nitride, which is essential for both detector construction and efficient DUV light emitters. To systematically investigate the properties of electrical contacts to epitaxial BN made from various materials, several circular transmission line model (CTLM) test structures were fabricated. These structures included both metallic and carbon-based layers. The motivation for using carbon structures and annealing them was the potential to create a gradient BCN layer, where varying carbon concentration modulates the bandgap—from the wide bandgap characteristic of BN to the narrower bandgap of BCN. The metallic contact structures exhibited several interesting effects, the most intriguing being the formation of bubbles beneath thin platinum layers. This phenomenon was linked to hydrogen generation in epitaxial BN layers. Additionally, ohmic current-voltage characteristics were recorded for contacts made of In/Al. Despite the relatively high contact resistance, this result is significant for further research on low-resistance, ohmic metallic contacts to BN. Contact structures based on carbon layers deposited on BN were also examined. These studies revealed significantly lower contact resistance values compared to metallic layers. Moreover, despite challenges associated with stresses in carbon/BN layers, one sample exhibited a linear current-voltage characteristic.

Another approach in the study of electrical contacts to BN involved the direct growth of BCN layers in the reactor. This process allows for the *in situ* fabrication of contact structures during BN layer growth without intentional carbon doping. Optical studies demonstrated effective bandgap modulation by controlling carbon concentration in the samples. Additionally, in one sample with a high carbon content, a relatively low sheet resistance of Rsh = 1000 ± 22 Ω/□ was recorded. These findings open new possibilities for utilizing epitaxially grown BCN layers as low-resistance, ohmic electrical contacts for BN.

This dissertation also explores the use of epitaxial BN as an optically active material in light detectors. The detection capability was examined across a broad spectral range, from visible light to UV radiation. Both excitonic transitions and defect-related transitions, likely associated with Si_BC_N and carbon-related defect complexes, were observed.

A crucial result was the registration of changes in electrical conductivity caused by prolonged UV light exposure. While this effect presents opportunities for modulating BN's electrical conductivity, it may also pose challenges for using epitaxial BN layers as the active layer in photodetectors.

Another important aspect of this work was the development of technology for creating micromembranes from epitaxial BN, which exhibit the ability to enhance the intensity of Raman spectra. The study observed changes in Raman spectra intensity by even an order of magnitude. It was found that the enhancement strongly depends on the direction of the linear polarization of the excitation light relative to the directions defined by the structural elements. It was determined that the enhancement effect can be utilized for other thin layers, such as graphene, placed on the surface of the epitaxial BN membrane. This makes the technology particularly interesting in the context of Raman spectroscopy studies of various functionalized 2D material layers.

In summary, the results of this dissertation not only deepen the understanding of the fundamental properties of epitaxial BN but also provide new tools for structuring and doping the material, which are crucial for optoelectronic applications. This work represents a significant step forward in the research on this material and opens new perspectives for further in-depth technological studies.