Summary

This thesis presents the development of cost-effective methods to modify two-dimensional (2D) Van der Waals materials property through fabrication techniques, substrate effects, controlled deformation, functionalization, and strain engineering. By manipulating these materials at the nanoscale, new strategies to alter their (opto)electronic structures have been demonstrated, paving the way for advanced applications in electronics and optoelectronics.

Revamping of the dry transfer technique led to superior suspended heterobilayers on silicon nitride (SiN) grids, improving interlayer coupling as evidenced by moiré patterns and controllable twist angles. This advancement facilitated the examination of interlayer properties in MoS_2/WS_2, MoS_2/graphene heterobilayers and enabled the construction of dielectric-based optical cavities (hBN/MoS_2/hBN). Investigations into interlayer coupling and substrate interactions in heterobilayers revealed significant shifts in trion and exciton peaks, along with changes in Raman modes. These findings highlight manipulable factors for tailoring material properties and suggest future research into polariton formation within cavities and exciton dynamics in hBN/MoS_2/hBN heterostructures.

A novel method was developed to determine graphene thickness on native oxide surfaces using Raman spectroscopy combined with a machine learning model comprising eight classifiers. Accurate predictions were achieved for both chemical vapor deposition (CVD) and exfoliated graphene samples, with engineered features such as the intensity ratio on native oxide proving critical. This method enables precise control over graphene's properties and offers potential for rapid, high-resolution quality assurance in industrial processes, as demonstrated by a developed cloud-based application.

A technique was introduced for imprinting sinusoidal nano/microscale wrinkle patterns into soft polymer substrates using graphene as the imprinting agent. The wrinkle dimensions correlated linearly with graphene thickness and the polymer's modulus, enabling patterning at wavelengths as low as ~50nm. This approach provides a simple route for nanoscale manipulation and tailoring of surface properties, with applications in altering graphene's properties through out-of-plane deformation and enhancing polymer functionalities.

A method to exert biaxial tensile deformation on graphene supported by a swelling polymer (SU8) was established, achieving strain levels up to 0.7% and allowing simultaneous chemical functionalization with a diazonium salt. Raman spectroscopy confirmed successful functionalization. The combination of mechanical strain and chemical modification effectively tailored graphene's physical properties, providing insights into reaction mechanisms and highlighting the need to account for non-graphene Raman bands when quantifying functionalization.

Polymer swelling was also utilized to induce biaxial strain up to 1% in monolayer MoS_2 and WS_2, tuning their electronic and optical properties. This strategy offers a powerful means to tailor the optoelectronic properties of 2D vdW materials, with significant implications for optoelectronic applications and straintronics. The results are particularly suitable for studying exciton funneling dynamics and aim to deepen the understanding of strain-induced exciton phenomena in transition metal dichalcogenides.

In summary, this thesis successfully developed methodologies for tailoring the physical properties of 2D van der Waals materials through controlled deformation, strain engineering, and functionalization. Advancements in sample preparation, characterization, and manipulation have contributed valuable tools and knowledge to the field. The findings enhance the fundamental understanding of 2D material behavior and pave the way for practical applications in optoelectronics and materials science. Future research will focus on refining these methods, exploring their limitations, and extending them to other 2D materials and heterostructures to unlock new functionalities and applications.