Exploring reactive interfaces: nanoplastics, catalysts, and 2D materials

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Summary

Exploring Reactive Interfaces: Nanoplastics, Catalysts, and 2D Materials

This thesis explores fundamental and applied questions in surface science, addressing three distinct but interconnected challenges: the study of catalyst surfaces under realistic conditions, the development of protocols for nanoplastic research, and the controlled synthesis of two-dimensional (2D) materials. The work combines advanced microscopy, novel instrumentation, and operando experimental approaches to push the boundaries of what can be observed at the nanoscale.

Chapter 2 introduces the experimental framework, including ultra-high vacuum (UHV) environments, sample preparation methods, and a suite of characterization tools which were essential to the experiments conducted for this thesis. The primary setups are introduced here, namely the ReactorAFM/STM, an instrument that enables simultaneous atomic force microscopy (AFM) and scanning tunneling microscopy (STM) at elevated pressures and temperatures, while also allowing operando monitoring of catalytic reactions. The other setup introduced is that of the synchrotron BESSY II endstation, SMART, where most of the experiments of Chapter 5 were conducted.

Chapter 3 demonstrates the capabilities of the ReactorAFM/STM. Studies of Pd(100) oxidation and Fischer–Tropsch synthesis on cobalt nanoparticles show that the ReactorAFM/STM can reveal both structural and electronic changes in catalysts under near-industrial conditions, bridging the longstanding “pressure gap” and “materials gap” in surface science.

Chapter 4 shifts focus to the environmental challenge of nanoplastics, which arise from the degradation of plastics in nature and pose emerging risks to ecosystems and human health. Here, new laboratory protocols are presented for generating and studying nanoplastics on well-defined surfaces. Physical vapor deposition is introduced as a method to create controlled nanoplastic samples, paving the way for systematic research into their behavior and impacts.

Chapter 5 explores 2D materials, specifically hexagonal boron nitride (h-BN), using a novel molecular precursor (hexamethylborazine) on Ni(111) substrates. Through a combination of in-house and synchrotron-based techniques (XPS, PEEM, ARPES), the growth mechanisms and structural properties of h-BN are elucidated, advancing the controlled synthesis of insulating 2D materials for applications in electronics and nanotechnology.

This thesis presents a unifying theme of reactive interfaces. Whether in the context of catalysis, environmental pollution, or advanced materials, understanding processes at surfaces under realistic conditions is critical. The methodological advances, especially the ReactorAFM/STM, provide powerful new tools for operando nanoscale science, while the application studies contribute both to environmental research and to the development of next-generation nanomaterials.