Protein Engineering and Processing of Plant Viral Templates for Controlled Nanoparticle Synthesis

Abstract:

Nanotechnology has been on a tremendous rise in recent years. One of its key challenges lies in the synthesis of nanomaterials with defined structures and controlled properties. Bottom-up solution processing techniques facilitate the synthesis of low-dimensional, ordered structures at a low cost through the self-assembly of basic building blocks. Among the emerging fields, biotemplating stands out, utilizing natural biomolecular objects to create functional, hierarchical structures with nanometric precision. This approach is cost-effective, eco-friendly, and energy-efficient. Viral biotemplating, in particular, has shown significant potential in applications such as electronics, environmental technologies, and biomedical devices. Recently, the Tobacco mosaic virus (TMV) and its variant, the Barley stripe mosaic virus (BSMV) or BSMV virus-like particle (BSMV-VLP) have been employed to fabricate monodisperse metal nanorods and nanowires under mild conditions, without the need for harsh chemical treatments. However, the underlying mechanisms involved in virion mineralization have not been sufficiently studied to allow for directed synthesis. This thesis focuses on the fundamental study of the hydrothermal synthesis of palladium on biotemplates, a process that produces uniform, controllable, monodisperse palladium nanorods. Moreover, synthetic methods for Au/Pd bimetallic materials have been established. Two experimental studies are outlined.

The first section of this thesis focuses on the hydrolysis of palladium precursor, a well-known reaction that has not received much attention during biomineralization process. The equilibrium constants of tetrachloropalladate and its hydrolysis-resulting species were investigated. The hydrolysis reactions in precursor solutions and formation of hydrolyzed particles during mineralization were minimized by introducing dilute hydrochloric acid. The findings in the section shed light on the underlying mechanisms of the mineralization process.

The second section explores the synthesis of bimetallic materials. His-tagged BSMV-VLP was first tested for gold reduction. External histidine was used to reduce the gold precursor for the formation of gold nanoparticles on palladium coated BSMV. The key aspects such as reacting solution pH and concentrations of histidine that affect the morphology of gold nanoparticles were investigated. EDS and XAS were used to confirm the formation of metallic Au nanoparticles.

In conclusion, this thesis has significantly advanced the understanding of biotemplating for the synthesis of monodisperse nanomaterials, particularly focusing on palladium and gold-based systems. By addressing the overlooked role of hydrolysis in the biomineralization process, this work provides new insights into the mechanistic steps involved in nanoparticle formation on viral templates. The successful synthesis of Au/Pd bimetallic materials and the exploration of adsorption mechanisms between metal precursors and plant templates further contribute to the optimization of biotemplating strategies. These findings pave the way for more controlled and efficient production of functional nanomaterials, which hold great promise for applications in fields such as electronics, environmental technologies, and biomedicine. Ultimately, this research enhances the potential of biotemplating as a sustainable, scalable, and precise method for nanomaterial fabrication.