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Towards a New Era of Electron Microscopy: Probing the Properties and Dynamic Behaviors of Materials with the Atomic Resolution in Real-Time

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The recent advancement of aberration-corrected transmission electron microscopy (TEM) and *in situ* techniques unlocks a door to a new era of discovery in materials science. It allows us to study the local structure, chemical composition, and electronic properties of nanostructures with the atomic resolution, and observe the dynamic evolution of materials in response to applied fields and to changes in environments in real-time. In this talk, I will first present our TEM studies of the polarization ordering and electronic properties of domain walls and novel polarization states in multiferroic thin films. It was found that the charged domain walls can be created or erased by an electrical bias, and the local polarization state and charge density strongly depend on electrical and mechanical boundary conditions. By the combination of TEM and scanning probe microscopy, we directly observed the emergence of strongly anisotropic polarization-induced conductivity at a ferroelectric/insulator ($BiFeO_3/TbScO_3$) heterostructure interface, caused by an alternating polarization associated with the ferroelectric domains, producing either electron or hole doping of the interface. Similarly, we observed a spin-polarized 2DEG forms at the PZT/STO interface, which is strongly localized at the interfacial Ti atoms, due to the interplay between Coulomb interaction and band bending, and can be tuned by the ferroelectric polarization.

In the second part of my talk, I will present our in-situ TEM studies of nanostructured catalysts using a MEMS-based, electron-transparent windowed gas cell. In a palladium/titania (Pd/ TiO_2) catalyst, we directly observed the formation of the oxide overlayers on the supported Pd particles with atomic resolution under atmospheric pressure and high temperature. It shows that an amorphous reduced titania layer is formed at low temperatures, and that crystallization of the layer into either mono- or bilayer structures is dictated by the reaction environment. Using this novel gas cell, we also reveal details of a counter-intuitive core-shell formation process in platinum-cobalt nanoparticles at elevated temperature under oxygen at atmospheric pressure with the atomic resolution. Initial segregation of a thin platinum, rather than cobalt oxide, surface layer occurs concurrently with ordering of the intermetallic core, followed by the layer-by-layer growth of a platinum shell via Ostwald ripening during the oxygen annealing treatment. Calculations based on density functional theory demonstrate that this process follows an energetically favorable path. These findings are useful for the future design of structured platinum alloy nanocatalysts.