ENFL 218: Atomic layer deposition for interfacial engineering of solar energy conversion devices

Abstract: Conversion of solar energy into useful energy, either in the form of electricity or stored energy in chemical bonds, is essential for a sustainable energy future. However, large-scale adaptation of these processes depend on our ability to increase the energy conversion efficiency and/or decrease the manufacturing cost of the active device. While silicon has dominated the current photovoltaic (PV) market, the cost of single-crystalline silicon has limited the economic viability of large-scale solar cell deployment. Therefore, a focus on earth-abundant, low-cost materials has emerged, which must also be manufactured at high throughput with low material and energy inputs.

To address this challenge, nanostructured materials have been extensively studied due to favorable properties such as photonic manipulation and the ability to decouple the spatial dimension associated with light absorption and charge separation. By fabricating non-planar junctions, either at a p-n junction or a semiconductor-electrolyte interface, the dimensions associated with charge separation and light absorption can be decoupled. However, the ability to create multi-component nanostructures with the desired chemical composition and desired thickness remains challenging with traditional material deposition techniques. Atomic Layer Deposition (ALD) is a gas-phase synthesis method that address this challenge, due to the conformal nature of film deposition with sub-nm precision in shell thickness and chemical composition gradients.

To test this hypothesis, we have explored the use of ALD to deposit thin material layers on nanostructured surfaces, both for PV and photoelectrochemical (PEC) energy conversion. These layers can either be continuous films, isolated particles, or hierarchical structures, depending on the desired application. This allows for control of the optical, electrical, and chemical properties of nanomaterial surfaces with the digital control of material thickness afforded by ALD. Therefore, rational control of light absorption, charge separation, and catalytic activity can be achieved, while minimizing the amount of raw material inputs required. Examples will be discussed for both nanostructured photovoltaics and

photoelectrodes for solar water splitting. The advantages and challenges associated with the ALD technique for device fabrication will be discussed, and a perspective on future directions will be provided.

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