Organic-inorganic hybrid halide perovskites have rapidly become a focal point of the photovoltaic (PV) community as a promising next-generation PV technology. Various perovskite absorbers (e.g., CH$_3$NH$_3$PbI$_3$ and HC(NH$_2$)$_2$PbI$_3$) and device architectures (e.g., mesoporous, planar, and mesoporous-planar hybrid cell configurations) have been examined with promising results by using either solution processing or thermal evaporation. The certified efficiency of single-junction perovskite solar cell (PSC) has reached over 22% after only several years of active research. In addition to solar cell application, the fascinating optical and electronic properties of these perovskite systems have enabled their usage for various electronic devices including light emitting diodes, photodetectors, and transistors. Despite this remarkable progress associated with perovskites, there are still many fundamental questions regarding the material/physical/chemical properties of these materials. Further improvements are required to advance our understanding on the material effects on the fundamental physical and chemical processes that are important to device operations. In this presentation, I will first give a general overview of recent development of material synthesis, device development, and basic characterization of perovskite solar cells. I will then discuss our recent studies toward a better understanding and control of perovskite nucleation, grain growth, and microstructure evolution using solution processing. The precursor chemistry and growth conditions are found to affect significantly the structural and electro-optical properties of perovskite thin films. I will show our recent effort on scalable deposition of perovskites by using a rational design of perovskite precursor film formation toward future perovskite PV module fabrication. The impact of grain boundary and film surface on charge transport and recombination as well as on perovskite stability will be discussed. Finally, I will discuss the R&D opportunities to make perovskite solar cells a viable photovoltaic technology in the future.