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Probing Nanoscale Defects in Emerging Photovoltaic Materials using Scanning Probe Microscopy

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Abstract

In a semiconducting material, most forms of defects have undesirable electronic properties. Defects can introduce localised regions of high charge-carrier recombination rates by introducing the extra energy levels into the band gap, thus reducing the overall minority carrier lifetime of the material. Single crystalline silicon (sc-Si) solar cell, which is almost free from the defects, has a record efficiency of 25.6% and reaches >75% of its S-Q value which is the maximum theoretical efficiency of solar cells. Theoretically, single crystalline silicon solar cells stacked with large band gap materials (1.5 eV) in a tandem configuration can boost the efficiency above 40% theoretically by absorbing broader spectrum of incident light. There are several candidates of photovoltaic materials that can be stacked with silicon such as CZTS, perovskites, colloidal quantum dots, and GaAs. Unfortunately, these materials possess large number of nanoscale defects such as grain boundaries and point defects that not only limiting their S-Q value (<75%) but also the overall tandem solar cell performance. Therefore, it is critical to understand properties of such nanoscale defects in those materials in order to further improve the device performance.

At UNSW scanning probe microscopy (SPM) laboratory, we employ unique scanning probe microscopy techniques such as conductive atomic force microscopy, scanning Kelvin probe force microscopy, and scanning tunneling microscopy to visualise local charge separation mechanisms, as well as to quantify the band alignment, photovoltage, and photocurrent in nanometre scale. SPM image is constructed by moving a sharp probe across a sample surface while using a feedback mechanism to maintain the tip−sample separation. As the tip is scanned along the surface, electronic, topographical, force, optical, and other properties are mapped out at resolutions that range from the atomic scale up to tens of nanometres. It allows identifying various defects by a topography map and extracting various information including the location of the pn junction, charge separation/generation, and trapped charges. Fig. 1 shows the schematic of a SPM setup. An external laser with tuneable wavelength and intensity can be used to illuminate the sample surface for charge-carrier generation.

In this presentation, nanoscale imaging results published by the author on halide perovskite will be mainly discussed. Halide perovskites have gained considerable attention for next-generation photovoltaic cells due to rapid improvement in power conversion efficiencies. However, fundamental understanding of underlying mechanisms related to light and bias induced effects at the nanoscale is still required. Particularly, structural variations of the perovskites induced by light and bias are systematically presented using scanning probe microscopy techniques. We show that periodically striped ferroelastic domains, spacing between 40 nm to 350 nm, exist within grains and can be modulated significantly under illumination as well as by electric bias.