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## Fracture analysis of silicon PV Wafers: Residual stresses, impurities and nano precipitates

**K Youssef**
Qatar University, Qatar

The effort in this research is mainly carried out in response to the persistent photovoltaic (PV) industry problem of product loss due to wafer breakage at the various stages in the production of a silicon wafer based solar module. The wafer breakage problem is of particular importance today given the strong trend in the silicon solar cell industry to reduce material costs by introducing thinner wafers into cell production, which in turn leads to higher product loss rates for each crystal growth/device process technology. Impurities (e.g., O, C, N) and structural defects (dislocations, twins, and grain boundaries) are known to influence the mechanical and electrical properties of mono and multi-crystalline PV silicon. Additionally, our recent investigation on slow diffusing metals, such as molybdenum, revealed the formation nanoprecipitates (~10 nm in size) inside the silicon lattice. These nanoprecipitates exhibit significant influence not only on the electrical behavior but on the mechanical behavior of PV silicon as well. Therefore, the objective of this research is to shed light on the influence of such nano impurities/precipitates on the mechanical properties e.g., hardness, elastic modulus and fracture toughness of mono- and multi-crystalline PV silicon. Additionally, in order to understand influence of these defects on the deformation processes, in-situ electrical characterization is a powerful means to track phase changes, residual stresses associated with precipitates during indentation. In the present paper, we report on HRTEM analysis of various nano precipitates in Si, as shown in Figure (1). Additionally, we report the influence of these defects on in-situ electrical measurements during nanoindentation in mono-crystalline silicon using the Hysitron nanoECR™ system. All indentations were performed using a Hysitron TriboIndenter (Minneapolis, MN) fitted with a Berkovich conducting diamond tip that is boron-doped to a nominal resistivity of ~ 3 Ω-cm. NanoECR tests consisting of a constant applied voltage during loading/unloading and a series of voltage sweep at the maximum load were performed and the resulting current was simultaneously measured. Figure 2 shows current-time data (with the corresponding load/unload curve) acquired during indentation in mono-crystalline silicon with an constant and sweep voltage.

kyoussef@qu.edu.qa