Materials Science & Engineering Doctoral Defense

Reliability of Photovoltaic Cells with Plated Copper Electrodes

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Abstract

An ongoing effort in the photovoltaic (PV) industry is to reduce the major manufacturing cost components of solar cells, the great majority of which are based on crystalline silicon (c-Si). This includes the substitution of screen-printed silver (Ag) cell contacts with alternative copper (Cu)-based contacts, usually applied with plating. Plated Cu contact schemes have been under study for many years with only minor traction in industrial production. One of the more commonly-cited barriers to the adoption of Cu-based contacts for photovoltaics is long-term reliability, as Cu is a significant contaminant in c-Si, forming precipitates that degrade performance via degradation of diode character and reduction of minority carrier lifetime. Cu contamination from contacts might cause degradation during field deployment if Cu is able to ingress into c-Si. Furthermore, Cu contamination is also known to cause a form of light-induced degradation (LID) which further degrades carrier lifetime when cells are exposed to light. Prior literature on Cu-contact reliability tended to focus on accelerated testing at the cell and wafer level that may not be entirely replicative of real-world environmental stresses in PV modules. This thesis is aimed at advancing the understanding of Cu-contact reliability from the perspective of quasi-commercial modules under more realistic stresses. In this thesis, c-Si solar cells with Cu-plated contacts are fabricated, made into PV modules, and subjected to environmental stress in an attempt to induce hypothesized failure modes and understand any new vulnerabilities that Cu contacts might introduce. In particular, damp heat stress is applied to conventional, p-type c-Si modules and high efficiency, n-type c-Si heterojunction modules. I present evidence of Cu-induced diode degradation that also depends on PV module materials, as well as degradation unrelated to Cu, and in either case suggest engineering solutions to the observed degradation. In a forensic search for degradation mechanisms, I present novel evidence of Cu outdiffusion from contact layers and encapsulant-driven contact corrosion as potential key factors. Finally, outdoor exposures to light uncover peculiarities in Cu-plated samples, but do not point to especially serious vulnerabilities.

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