Title	高効率n型結晶シリコン太陽電池における電圧誘起劣化のメカニズム解明
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Citation	
Issue Date	2019-06
Type	Thesis or Dissertation
Text version	ETD
URL	http://hdl.handle.net/10119/16067
Rights	
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Abstract

Potential-induced degradation (PID), which is caused by potential differences between a grounded frame and cells, has been identified as one of the central issues of photovoltaic (PV) modules deployed in very large-scale PV systems. This is because PID causes a relatively large degradation in a short time. The PID of conventional p-type crystalline silicon (c-Si) PV modules has been mainly investigated. On the other hand, there have been few studies on the PID of n-type c-Si PV modules. However, their PID is a very important issue because n-type PV cells have higher energy conversion efficiencies than p-type ones. In this study, investigated is the PID of two kinds of n-type c-Si PV modules, n-type front-emitter (n-FE) c-Si and silicon heterojunction (SHJ) PV modules.

In accelerated PID tests in which a bias of −1000V was applied to n-FE PV modules at 85 °C, they started to degrade within 5 s and their degradation saturated within 60 s. This behavior suggested that the PID was caused by positive charge accumulation in the front SiN_x passivation films. Performing tests with a larger bias of −1500V revealed that the degradation rate strongly depended on the applied bias whereas the saturation value was independent of the magnitude of the applied bias. Regeneration tests on modules degraded, in advance, in PID tests for durations of 5 and 10 min were performed by applying a positive bias of +1000 V at 85 °C. Both degraded modules almost completely recovered their performance losses within 60 s regardless of the pre-degradation test duration. On the basis of these results, I proposed that these positive charges accumulating in the front SiN_x films originate from positively charged K centers formed by extracting electrons from neutral and negatively charged K centers. This model readily explains the observed degradation and regeneration behavior. To test the model, I determined the fixed positive charge densities (Q_f) of a silicon nitride passivation film before and after PID, for which it was found that Q_f showed similar saturation behavior. Additionally, the saturated Q_f value was of the same order as K center density. These results strongly support my model involving a charging process of K centers.

A negative bias of −1000 V was applied to SHJ PV modules (fabricated from n-type SHJ cells with tungsten-doped indium (In) oxide (IWO) films on both sides) with respect to the cover glass surface at 85 °C, which significantly reduced their short-circuit current density (J_{sc}) within several days. The results of dark current density–voltage measurements implied that the reduction in the J_{sc} was attributed to optical losses rather than carrier recombination. X-ray absorption fine structure spectroscopy suggested the formation of metallic In in the IWO layers of a degraded cell, which implies that the root cause of the optical loss was a darkening of the front IWO layers caused by the precipitation of metallic In. In extremely severe PID tests, the SHJ PV modules exhibited not only a further reduction in the J_{sc} but also a moderate reduction in the open-circuit voltage (V_{oc}). These J_{sc} and V_{oc} reductions were probably caused by sodium being introduced into the n-type base of the cells. A comparison of the PID test results of the SHJ PV modules with those of other types of PV modules indicates that SHJ PV modules have a relatively high resistance to PID. As a module with an ionomer encapsulant exhibited little degradation, their high PID resistances may be further improved by using encapsulants with high electrical resistances.

These findings are significantly important to understand PID phenomena in n-FE c-Si and SHJ PV modules. Additionally, they help us develop low-cost measures to prevent the PID. In future, the proposed mechanisms will have to be further verified by additional experiments.

Keywords: n-type crystalline silicon solar cell, photovoltaic module, photovoltaic system, potential-induced degradation, reliability