Potential-induced degradation of n-type crystalline silicon photovoltaic modules

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Acknowledgment
This work is supported by NEDO.
Outline

- Importance of PID research for n-type PV modules
- PID of front-emitter c-Si PV modules
- PID of rear-emitter c-Si PV modules
- PID of silicon heterojunction PV modules
n-type c-Si PV modules

😊 High conversion efficiency → Increasing market share
😊 Insufficient understanding
  for the mechanism of their potential-induced degradation (PID)

Cells with n-type wafers

Front emitter (FE)
Rear emitter (RE)
Si heterojunction (SHJ)
Back contact (BC)
PID of n-type FE and RE cell modules

Bifacial cells

- $p^+$ side up → Front-emitter (FE) module
- $n^+$ side up → Rear-emitter (RE) module
Experimental procedures

PID-stress experiment

![Diagram of PID-stress experiment]

**Conditions**

- ~1000 or ~2000 V
- 85 °C
- No intentional humidity stress (<2%RH)
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PID of FE c-Si PV modules

- Characterized by reductions in $V_{oc}$ and $J_{sc}$
- Due to enhanced surface recombination of minority carriers

K. Hara et al., SOLMAT 140, 361 (2015).
Proposed PID mechanism

“Surface polarization effect”

1. Leakage current induced by negative bias
2. Positive fixed charges in SiN$_x$
3. Enhancement in surface recombination due to the fixed charges in the SiN$_x$

K. Hara et al., SOLMAT 140, 361 (2015).
Detailed observation of PID for FE c-Si modules

Rapid reduction and following saturation in $J_{sc}$ and $V_{oc}$

Limited number of fixed charges?
Voltage dependence

Constant saturated $P_{\text{max}}$ independent of applied voltage

→ Limited positive fixed charge density

Possible origin: $K^+$ centers in SiN$_x$

For more details
P-06 Yamaguchi (JAIST)
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**PID of rear-emitter PV modules | J–V**

-1000 V

- $V_{oc}$ reduction $\rightarrow$ Saturation
- Slight $J_{sc}$ and FF reduction

S. Yamaguchi *et al.*, SOLMAT 151, 113 (2016).
EQE reduction in short-wavelength region
Enhancement in surface recombination
→ Reduction in $V_{oc}$

S. Yamaguchi et al., SOLMAT 151, 113 (2016).
Mechanism of PID for p-type modules

Na accumulation from outside (e.g. cover glass)
Decoration of stacking faults in c-Si by Na
(serious shunting in p-type c-Si PV modules)

V. Naumann et al.
120 (2014) 383.

$J-V$ of p-type c-Si PV modules
Mechanism of PID for n-type RE modules

Na-decorated stacking faults
Recombination centers in n-type RE modules
→ Enhanced surface recombination, $V_{oc}$ reduction

Consistent with the saturation behavior
Observation of enhanced surface recombination

For more details
P-14 Nishikawa (JAIST)
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Open-circuit voltage ($V_{oc}$)

Fill factor (FF)

No reduction in $V_{oc}$ and FF
No variation in $I$–$V$ curves

→ No degradation in p–n junction
Decrease in $I_{sc}$ with PID-stress duration

$P_{max}$ reduction simply governed by $I_{sc}$

No significant recovery
PID of SHJ modules | EQE

EQE spectra

- Reduction in EQE in entire wavelength region
- More reduction in edge parts
PID of SHJ modules | EL

**Possible PID mechanism**

- Optical loss (TCO and/or EVA)
- Reaction with Na?
- Ununiform EL and EQE: Property distribution of TCO films?
PID of SHJ modules | Ionomer

Suppression of PID by the usage of ionomer encapsulant

For more details about the PID of SHJ modules
P-15 Yamamoto (AIST)
Performance stability

Higher stability than conventional p-type c-Si PV modules

Summary

PID of n-type c-Si PV modules

Front-emitter c-Si PV modules
- Rapid reduction in $J_{sc}$ and $V_{oc}$
- Enhanced surface recombination of minority carriers
- Positive fixed charges in SiN$_x$

Rear-emitter c-Si PV modules
- Reduction mainly in $V_{oc}$
- Enhanced surface recombination of minority carriers
- Na accumulation into c-Si

SHJ PV modules
- Reduction only in $J_{sc}$
- Optical loss

Performance stability of n-type c-Si PV modules
- Higher than conventional p-type c-Si PV modules