Theory and Practice of Solar Cells: A Cell to System Perspective

Reliability of Solar Cells: Part I

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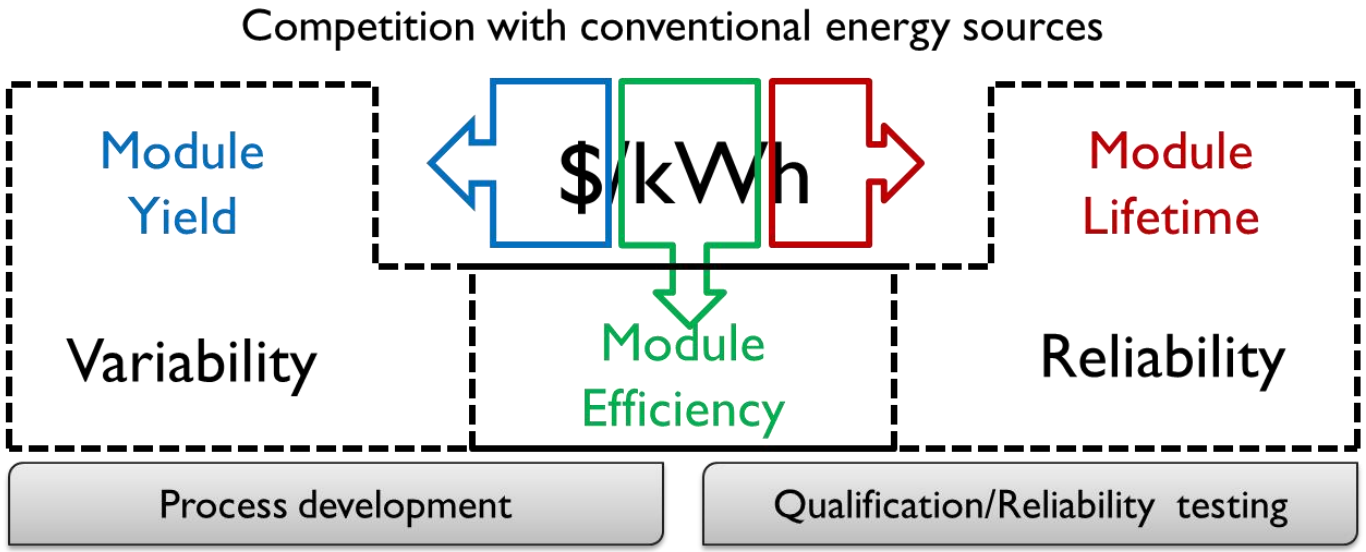
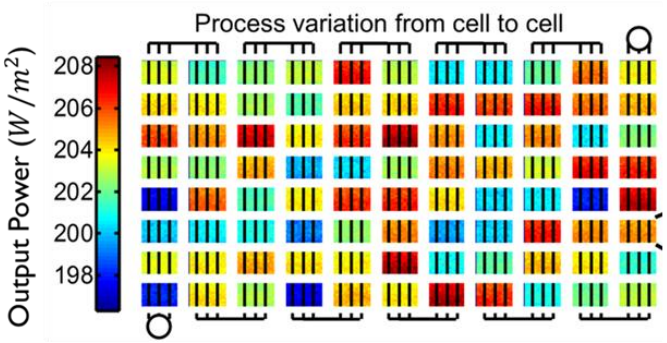
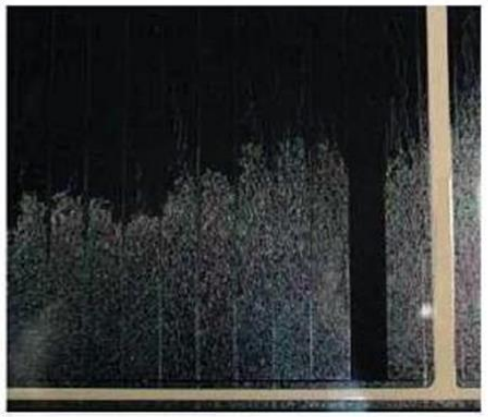
PV Reliability: A ROI Challenge





Alam, JPV, 2016



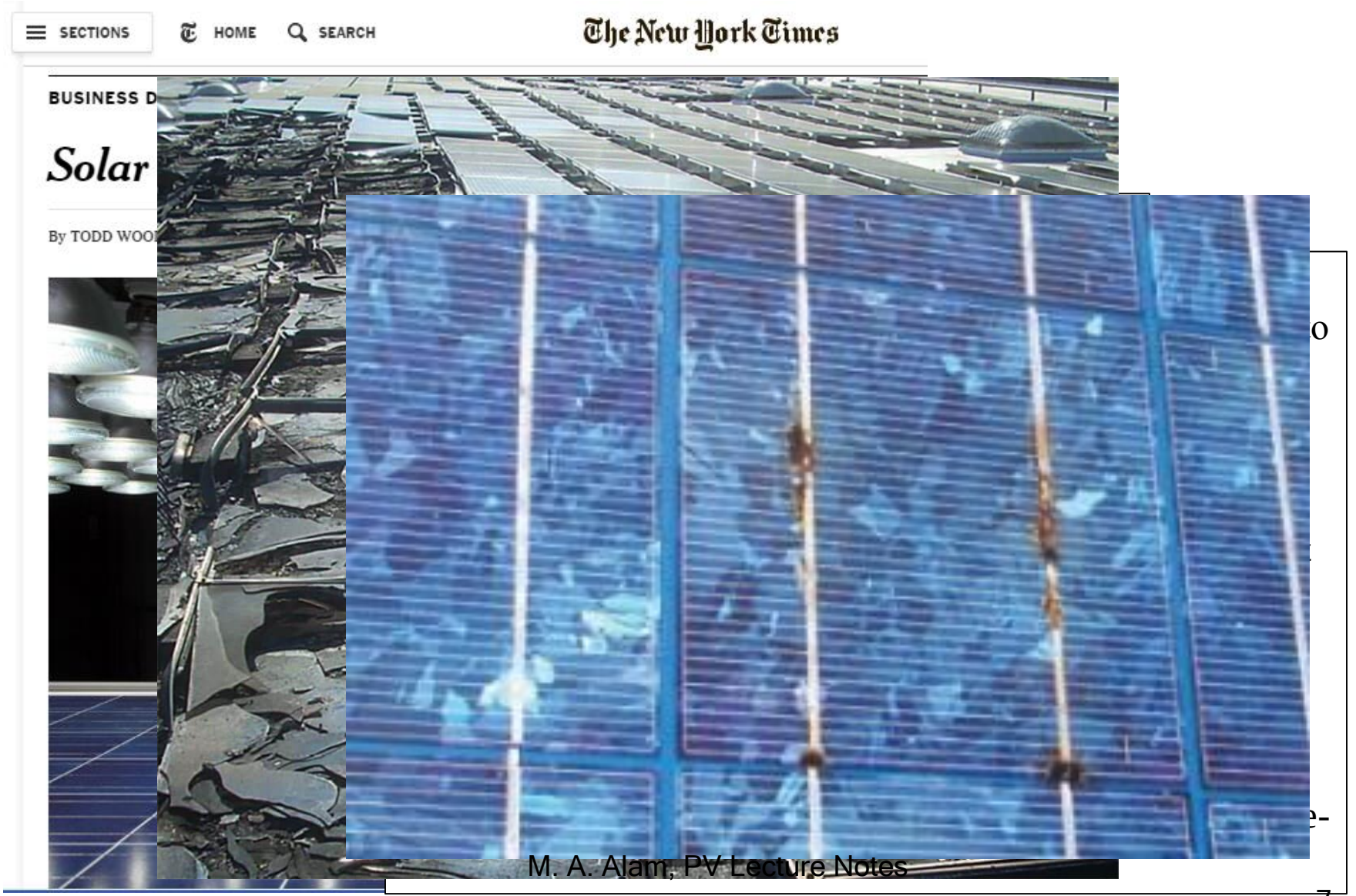
Osterwald, Sol. Mat. 2003

Solar cell exposed to variety of weather conditions

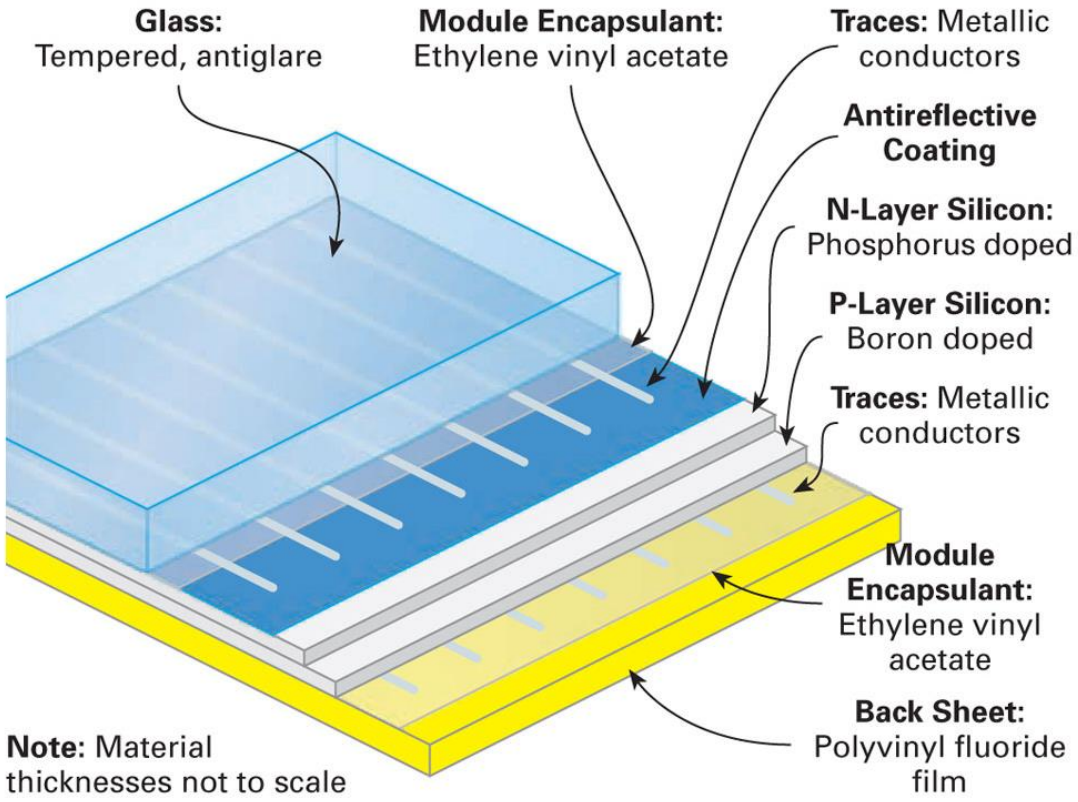


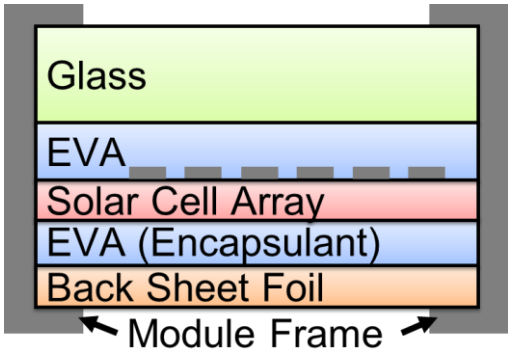


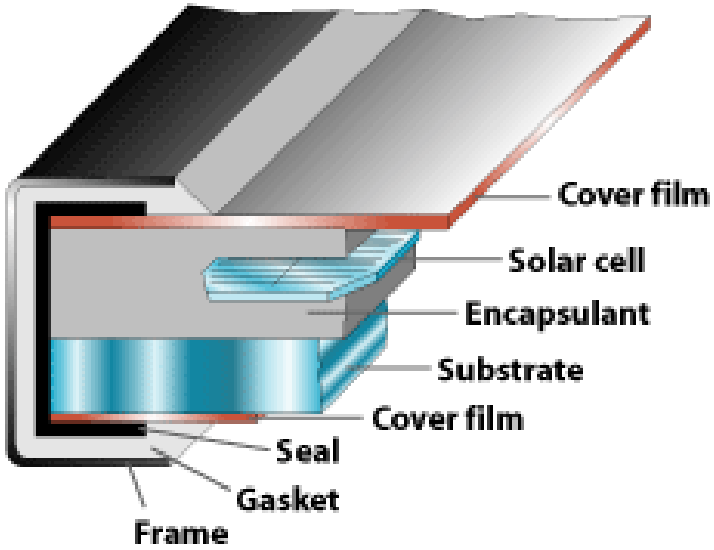

PV Field Failures Are Mounting



Fully assembled solar module

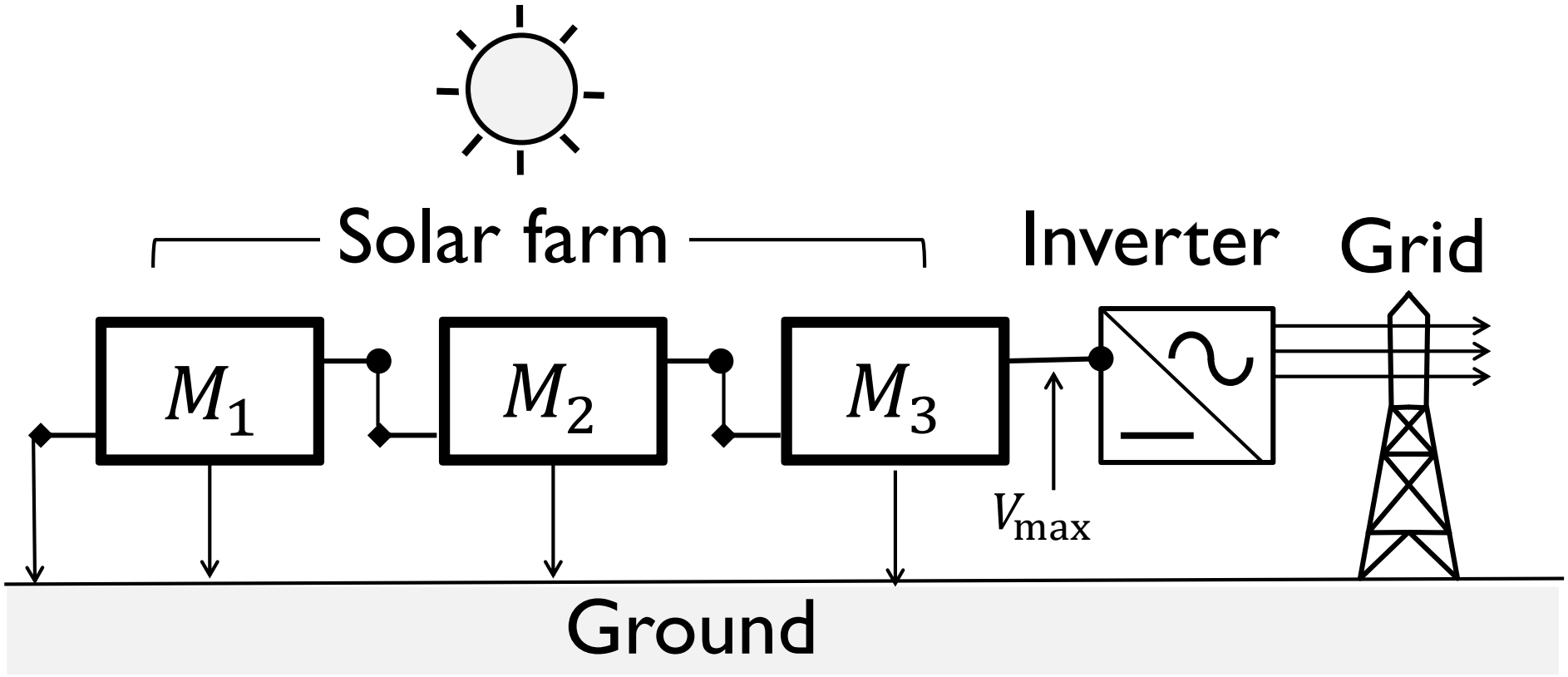






M. A. Alam, PV Lecture Notes

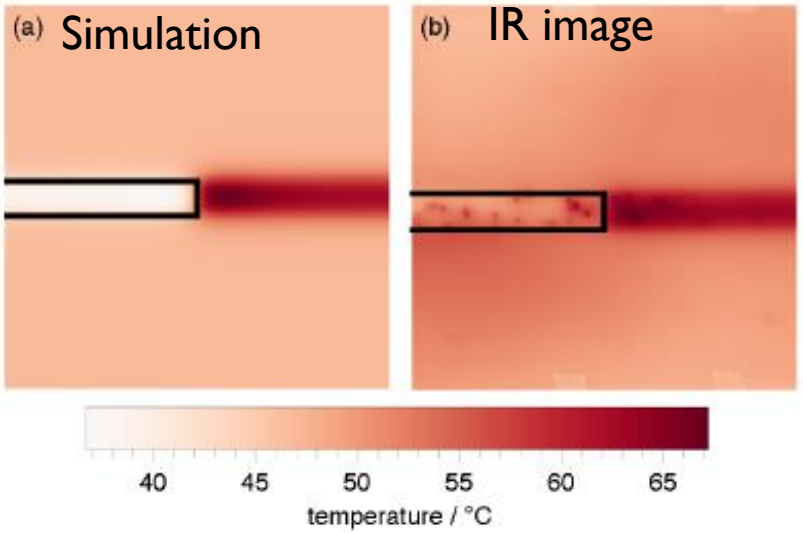
Modules, inverter, and grid



Outline

1) Background: Why does reliability matter
2) Three classes of reliability issues
    - Reversible (Shadow, Soiling)
    - Metastable (PID, LID)
    - Permanent (Yellowing, corrosion, cracking)
3) Forward and inverse reliability prediction
4) Conclusions

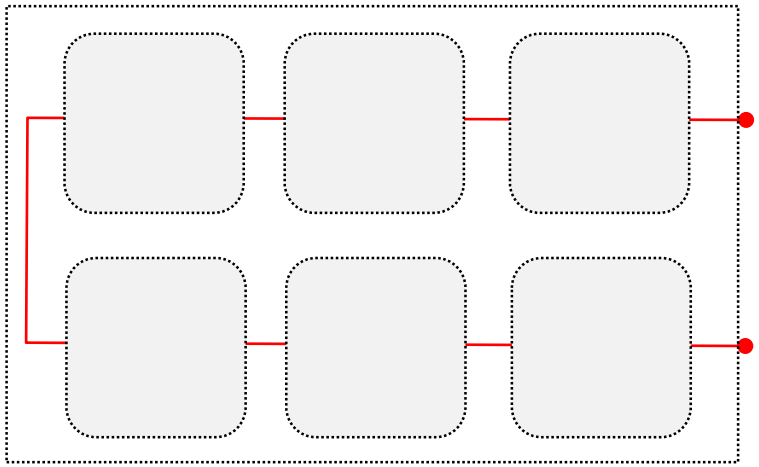
A Shadow is Dangerous



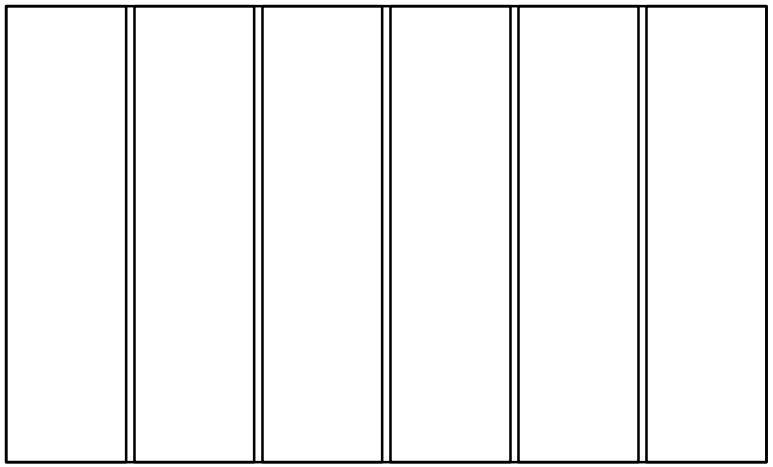
- simulation captures the temperature map of a shaded panel
- Pre-existing shunt causes local hot spots
- Self-heating due to shading leads to new shunt defects

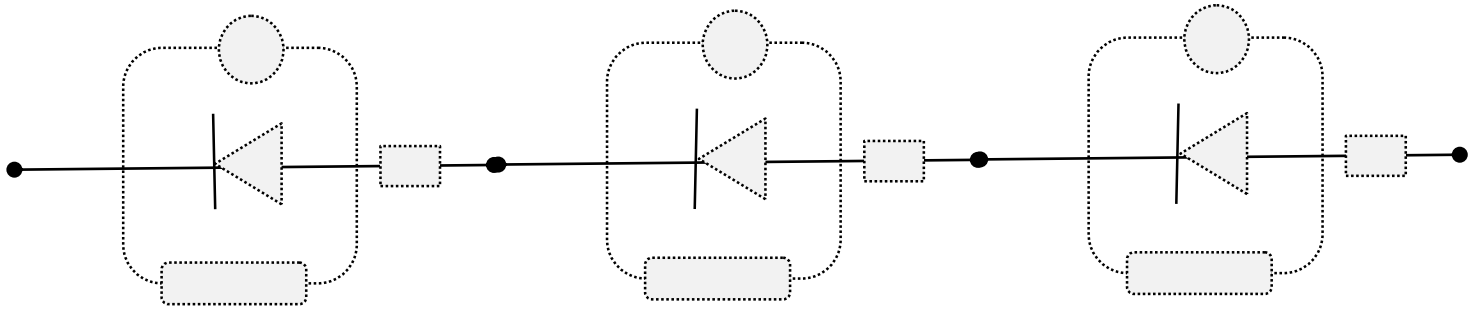
Modules have cells connected in series

Si module

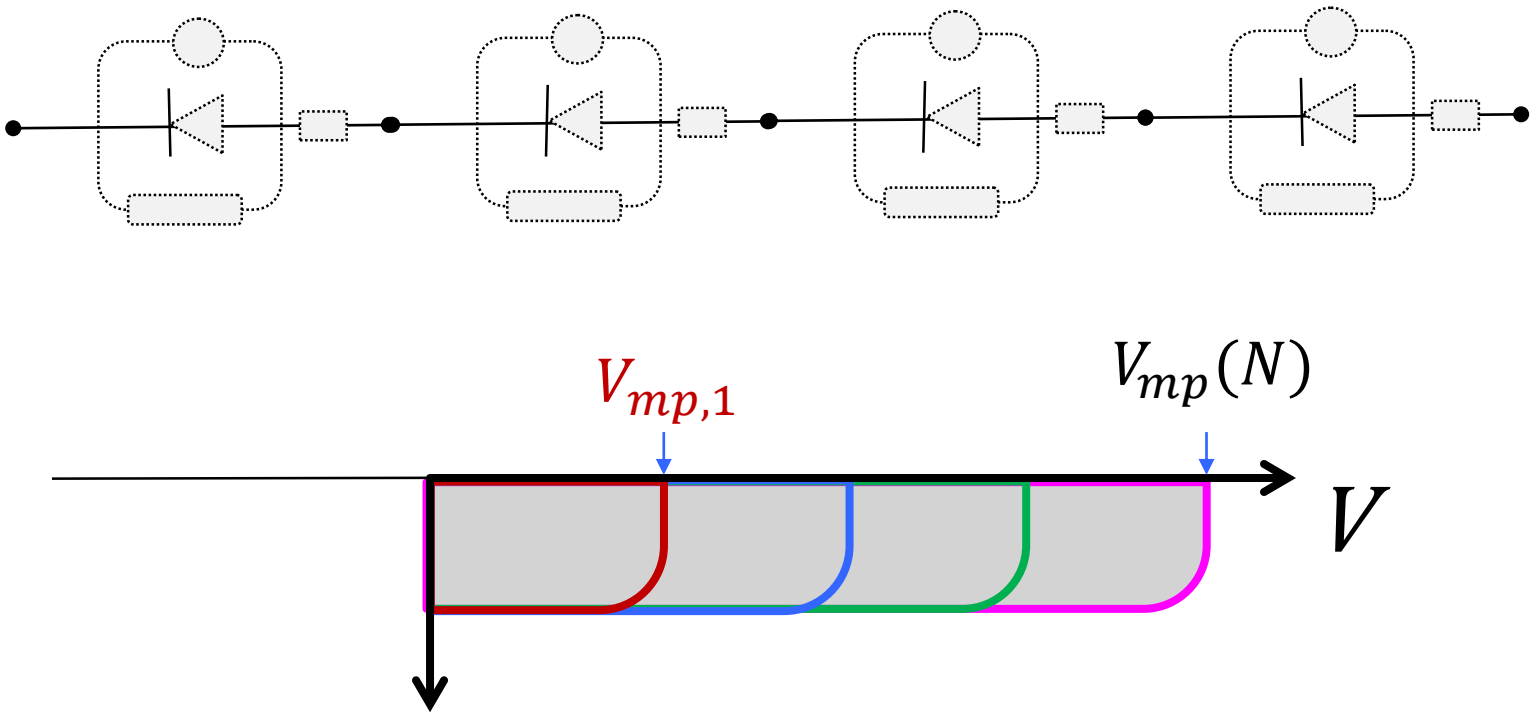


Thin-film module

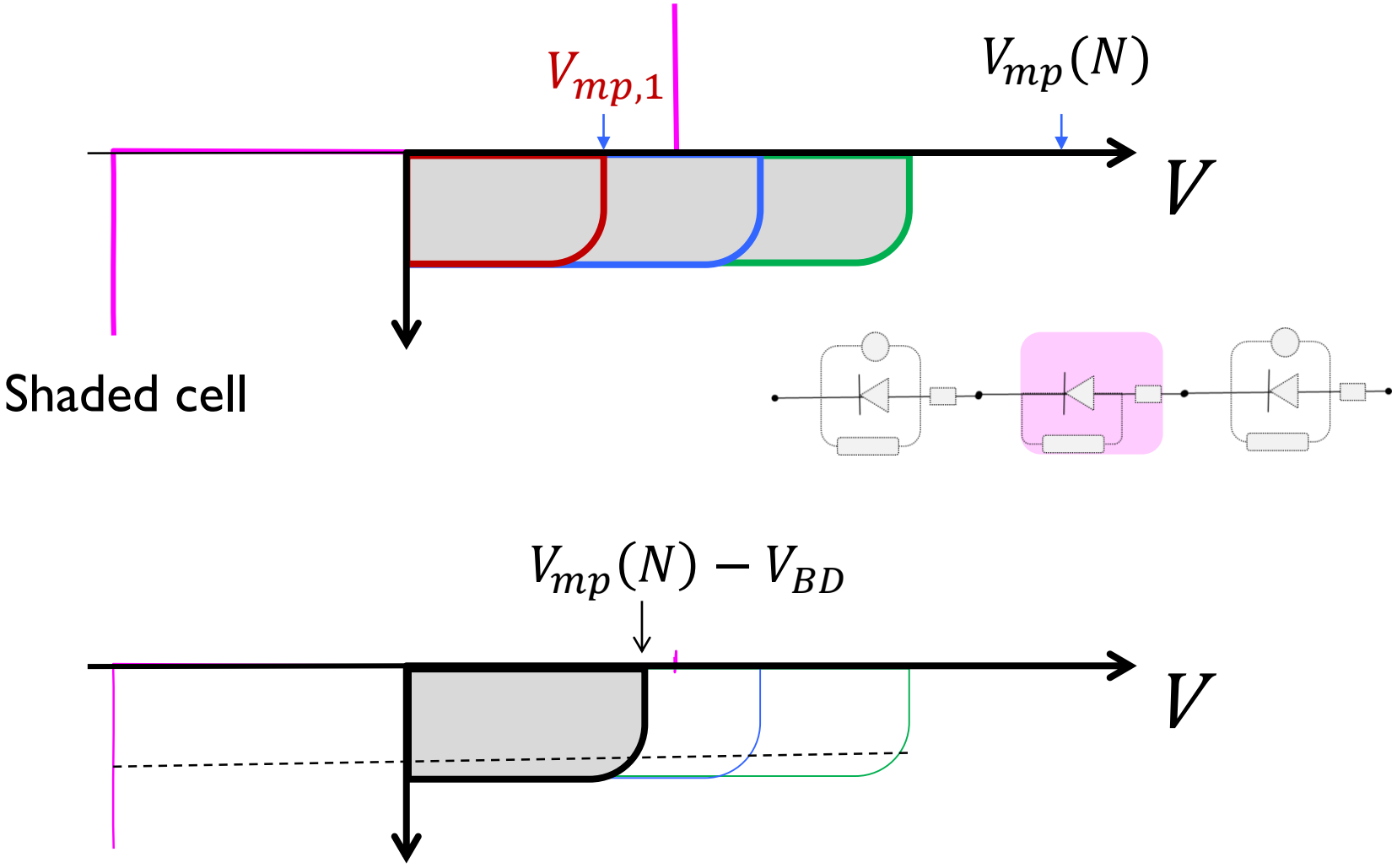




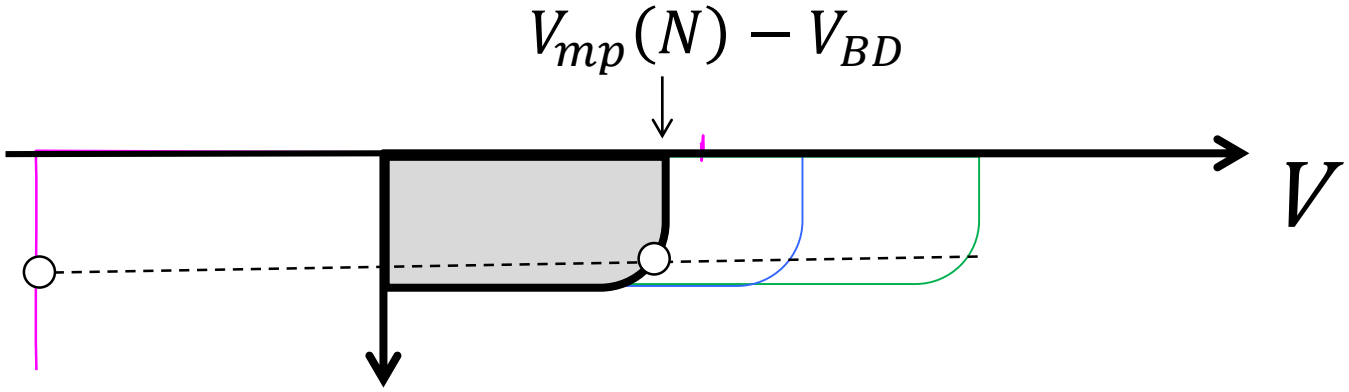
I-V Characteristics of a module: Graphical representation



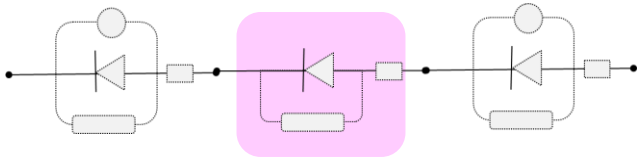
One cell under full shadow



Full shadow degradation



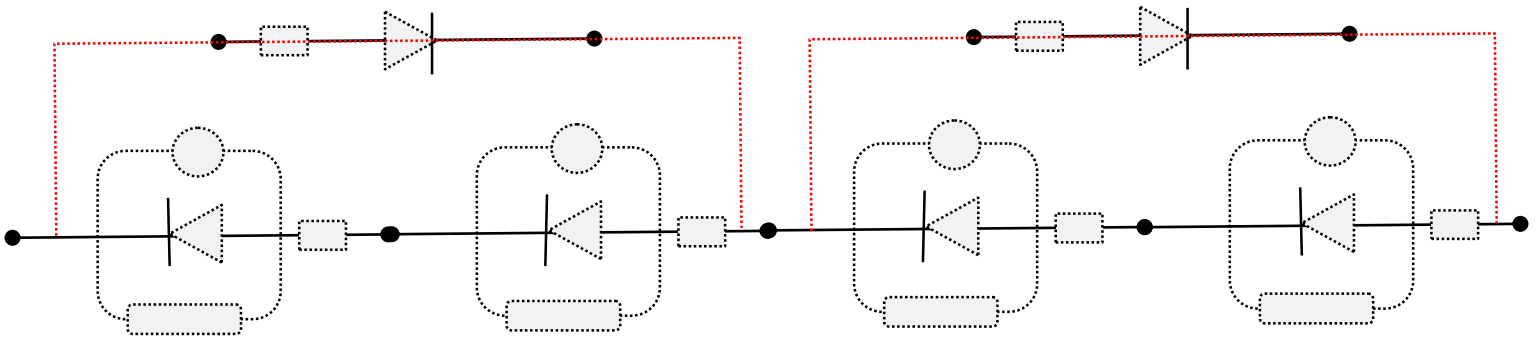
$$V_{op} = -V_{BR} + V_{mp}(N-1)$$

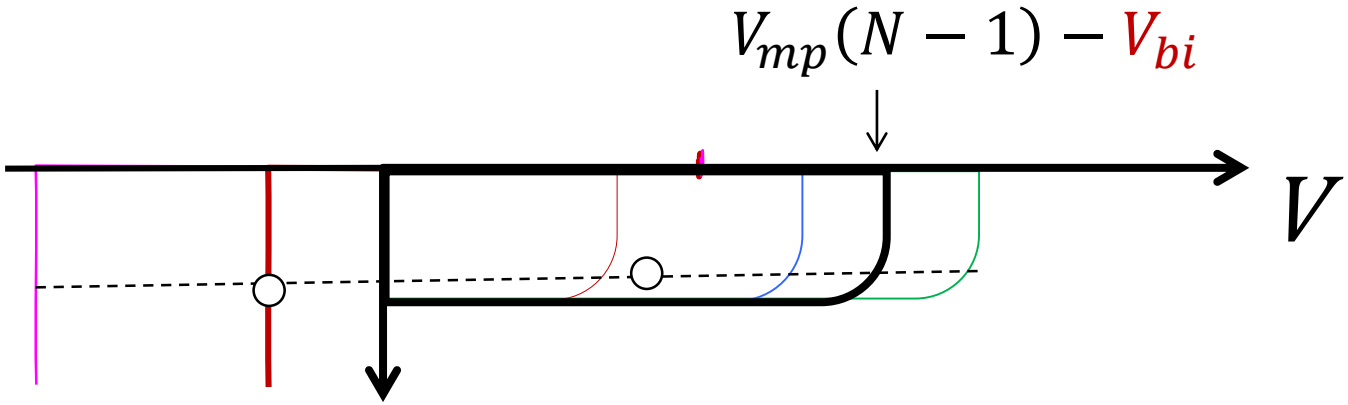


$$I = I_{ph}(N) - I_0(N-1,R)\left(e^{\beta V} - 1\right)$$

$$P_{out} = V_{op} \times I_{ph} = I_{ph}(V_{mp}(N-1) - V_{BR})$$

Solution strategy: bypass-diode



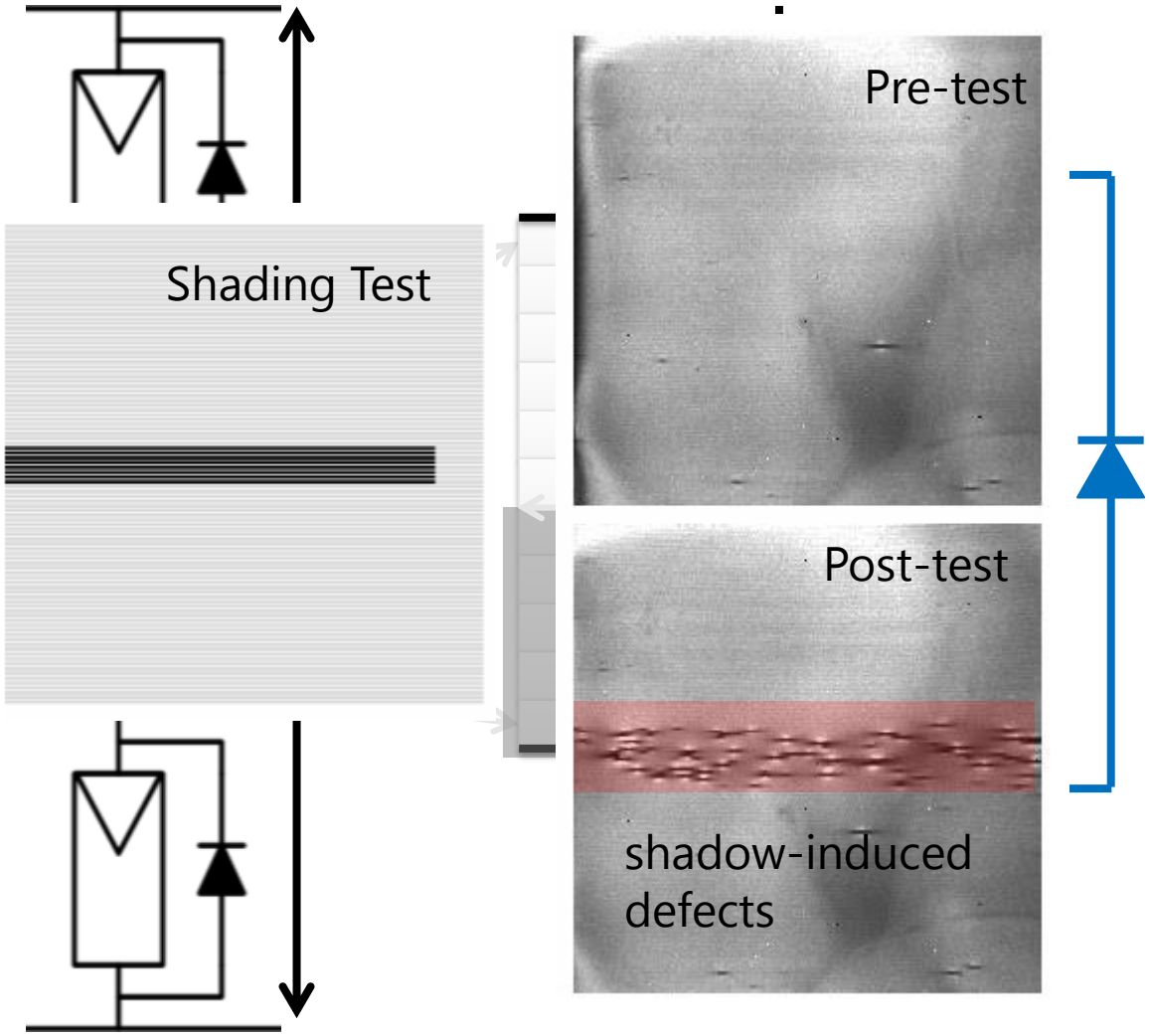


Little diode carrying a lot of current, may itself fail

$$P_{out} = V_{op} \times I_{ph} = I_{ph}(V_{mp}(N-1) - V_{bi})$$

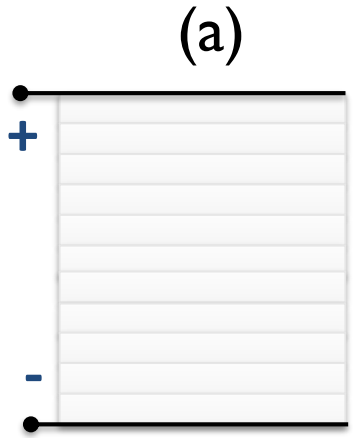
Monolithic thin-film solar module

Electroluminescence Images

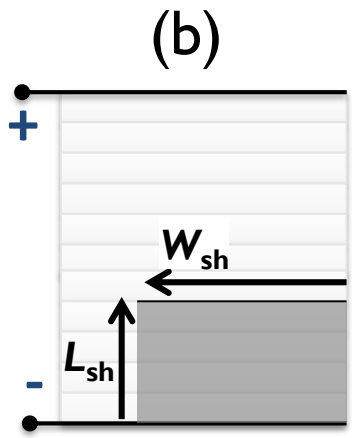


- Typical module architecture for thin film (**CIGS,** CdTe, etc.)
- Only **ONE** external bypass diode for one module (~100 cells)
- Bypass diodes can **NOT** prevent partial-shading induced gradation

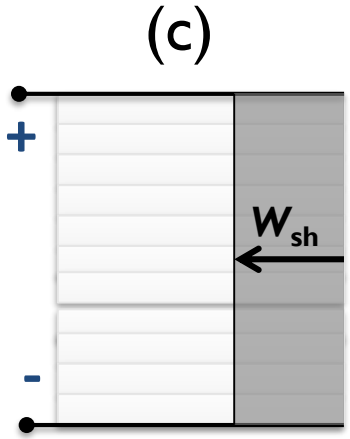
Shapes and sizes of shadow



Fully illuminated

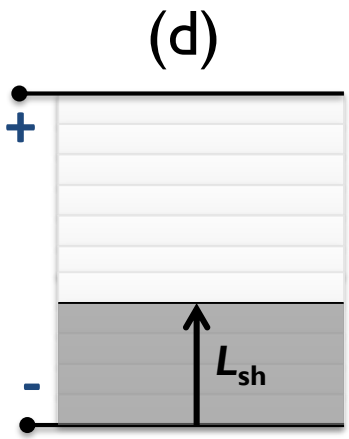


Partial Shadow



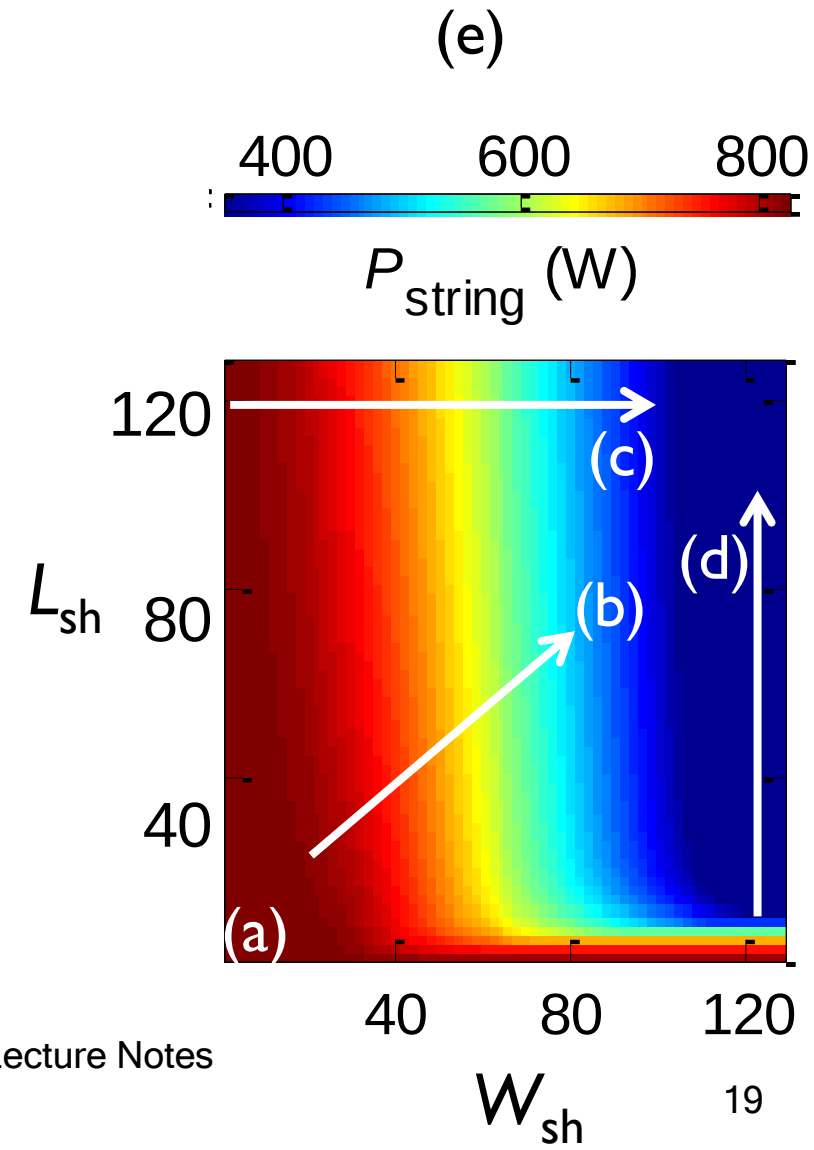
Full vertical

$L_{sh}=L_{module}$

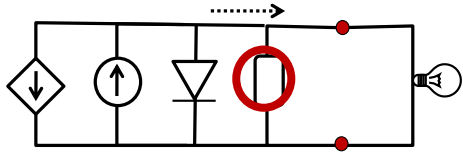


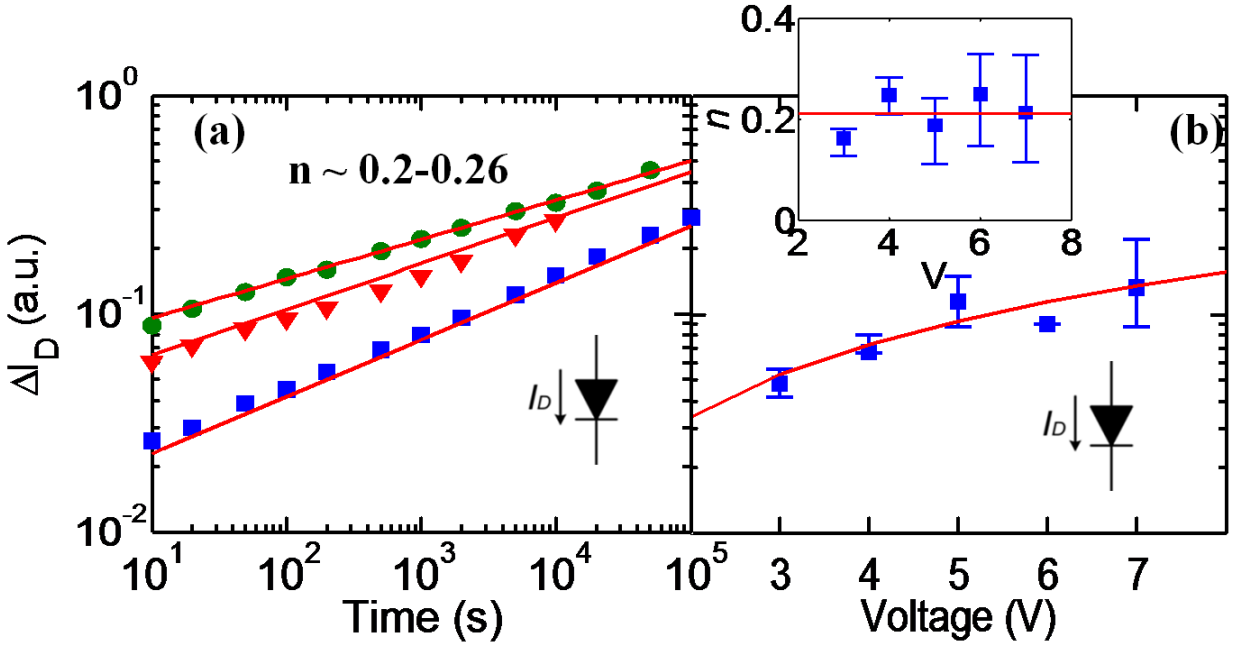
Full horizontal

$W_{sh}=W_{module}$

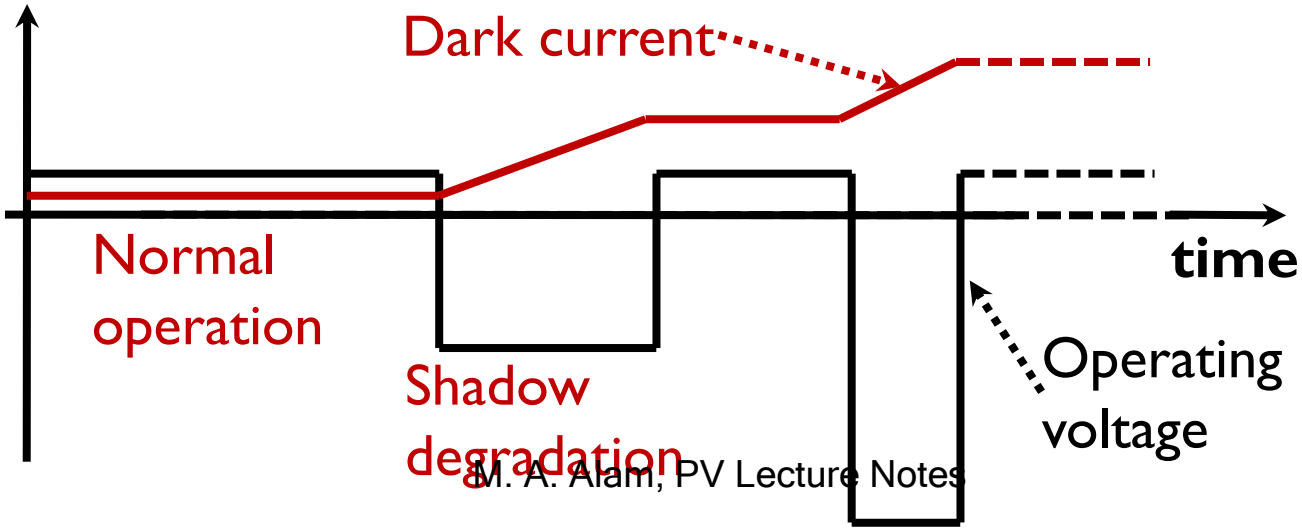


Shadow degradation

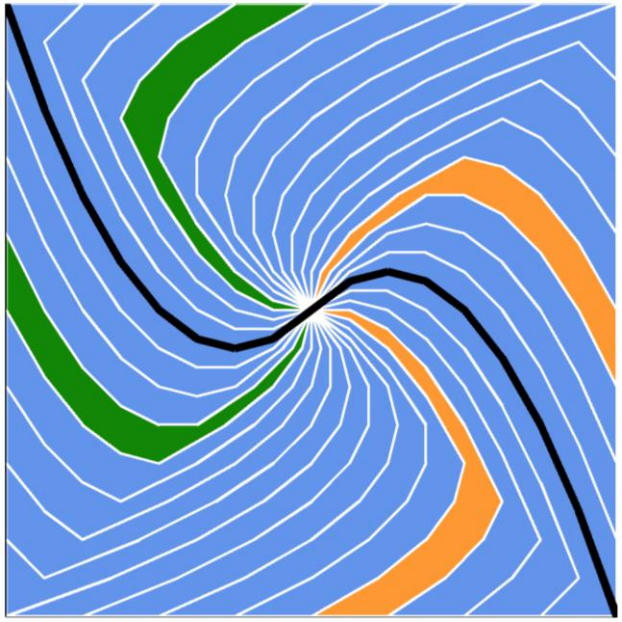


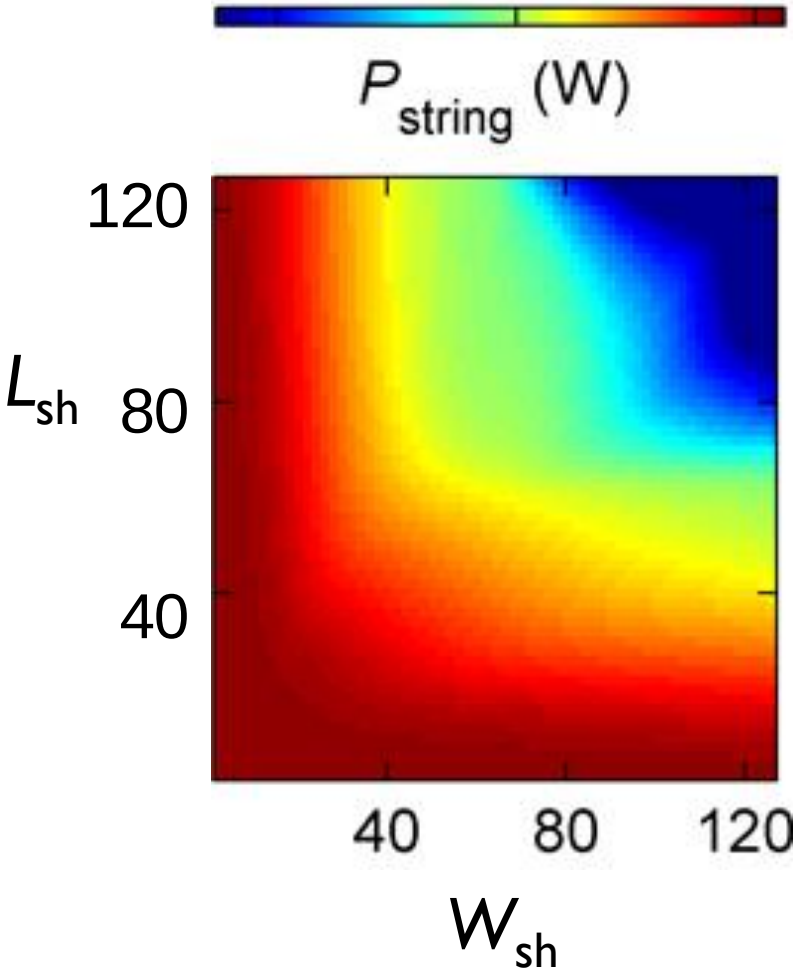


Dongaonkar et al.
IRPS 2011



Solution strategy: Geometry



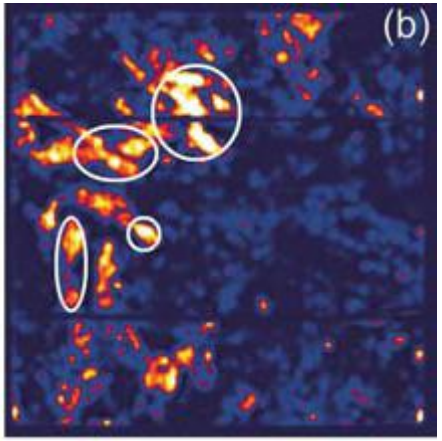


Solution strategies

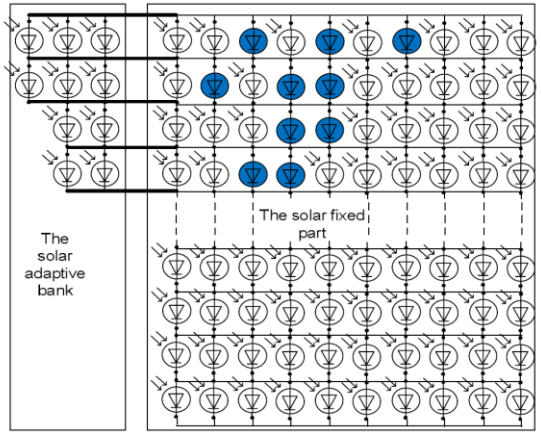
May lead to runaway process.

Solutions:

- *Device*: Characterized and qualified
- *Circuits*: Overvoltage Protection diode
- *Systems*: Redundant SRAM-like array



O. Breitenstein, *et al., PSS, 2009*



D. Nguyen, *et al., APEC, 2008*

Outline

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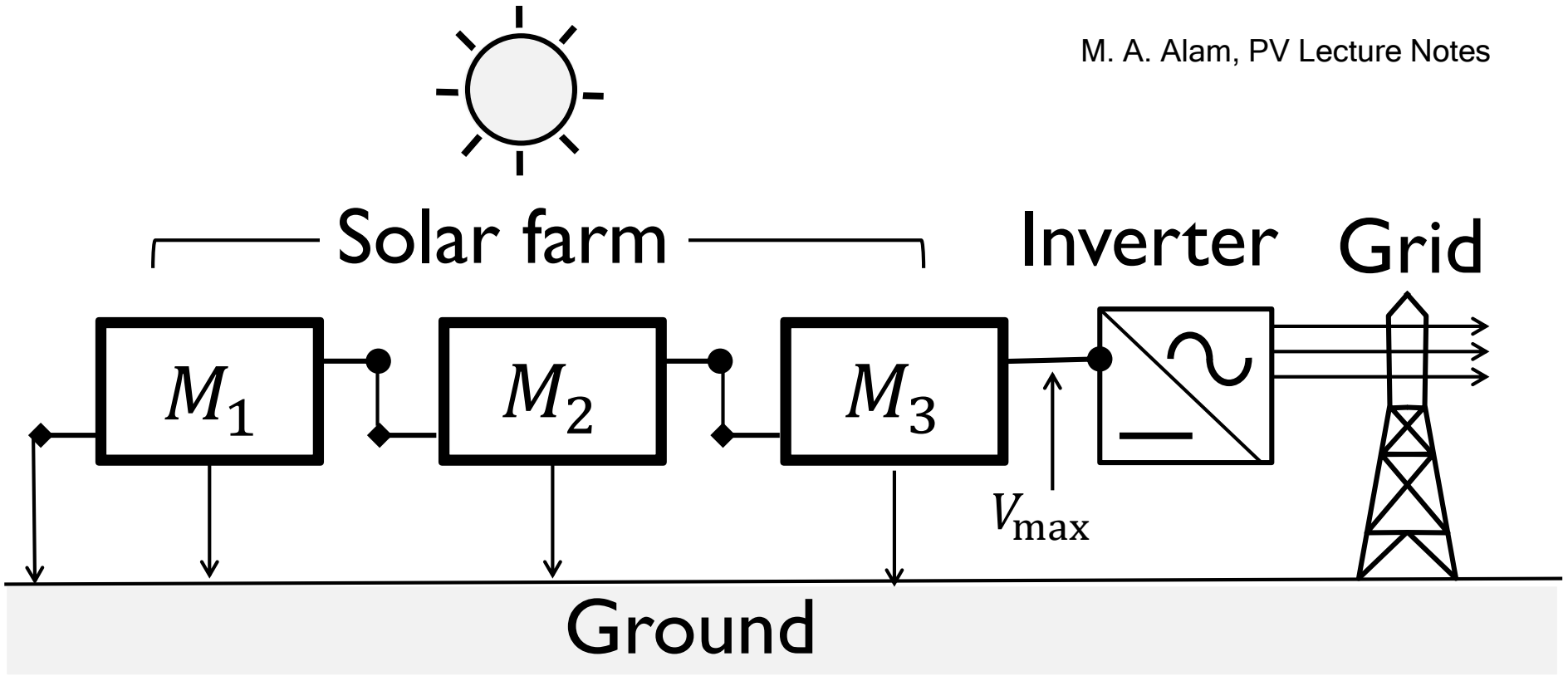
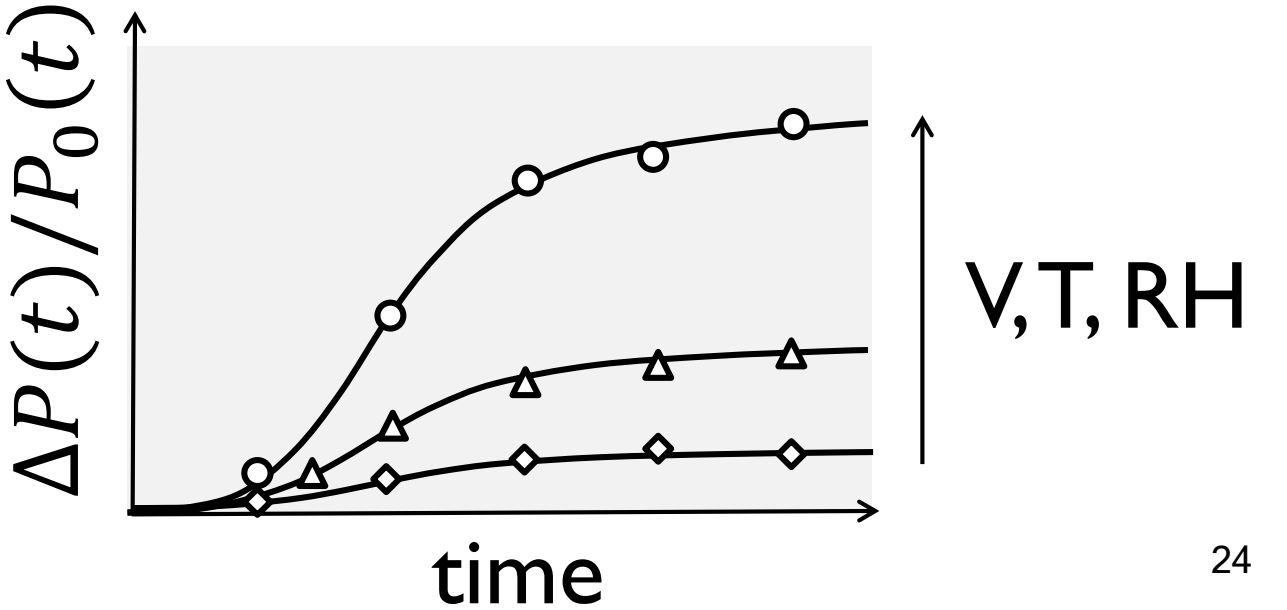
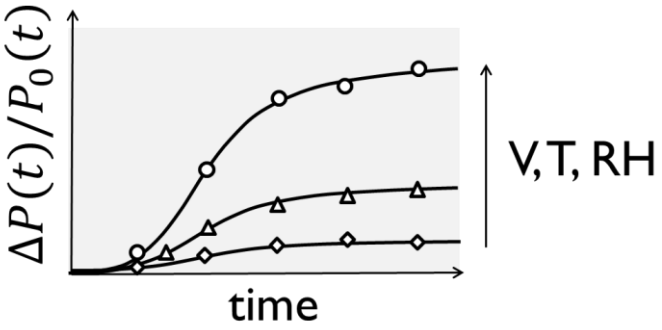
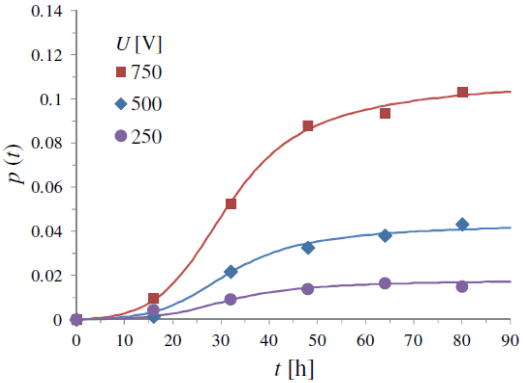
4) Conclusions

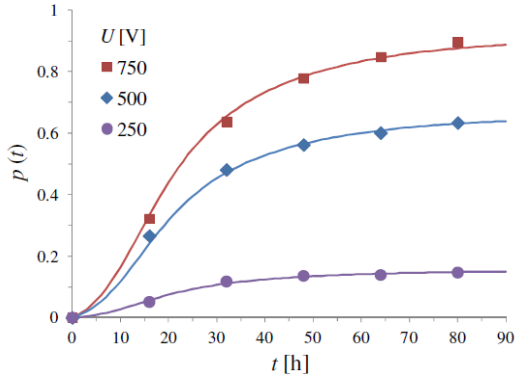

Solar farm
Inverter
Grid
M_1
M_2
M_3
$V_{\max}$
Ground


$\Delta P(t)/P_0(t)$
V, T, RH
time

PID Degradation

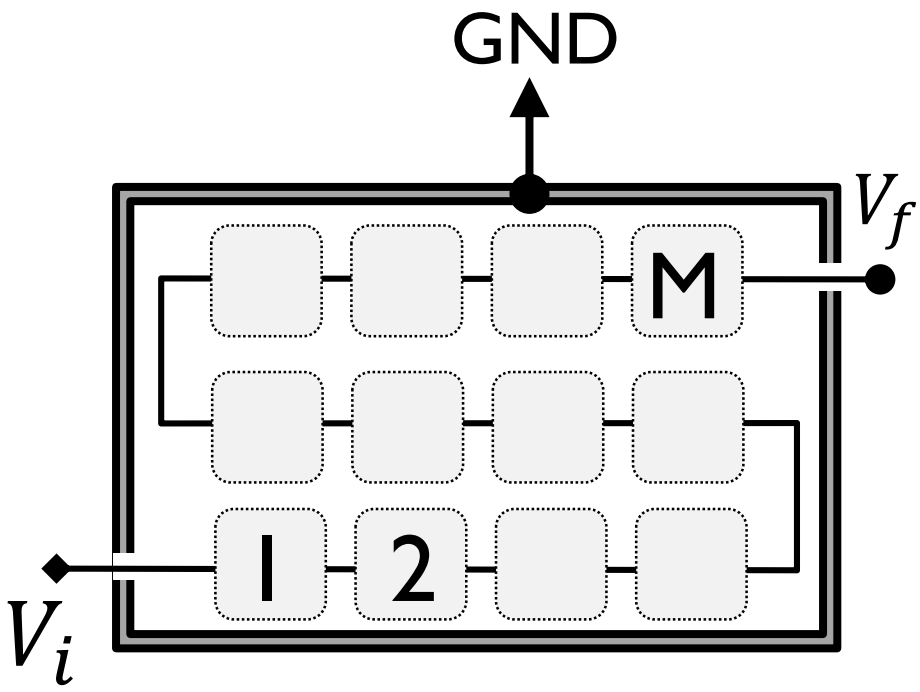


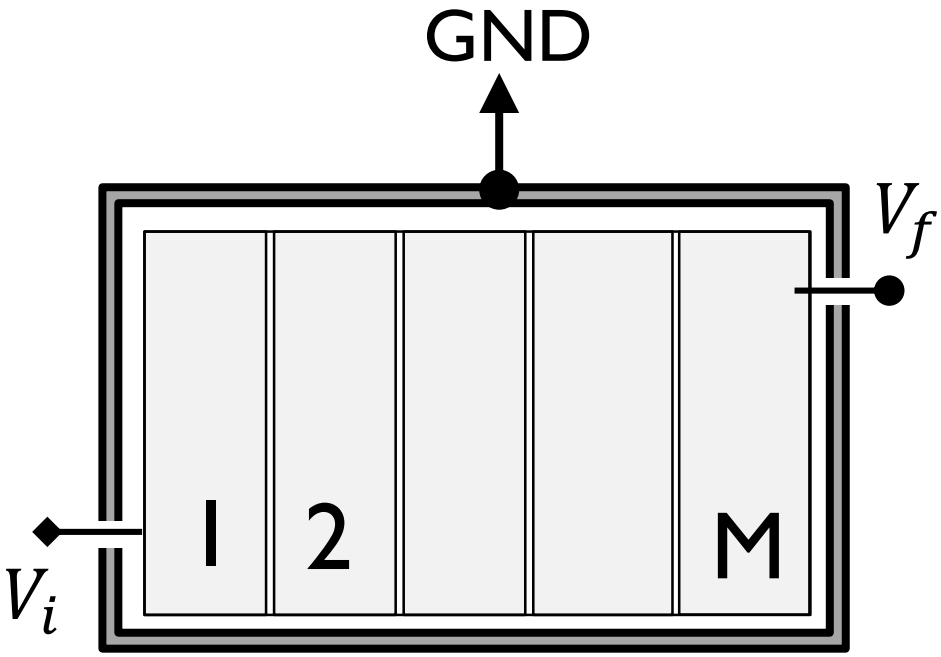




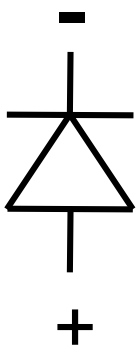
$$\frac{\Delta P}{\Delta P_\infty} = \frac{1}{1 + e^{-(t-t_H)R_D}}$$

$$t_H = AV^n \, e^{-\frac{E_A}{k_B T}} \, [RH\%]^B$$

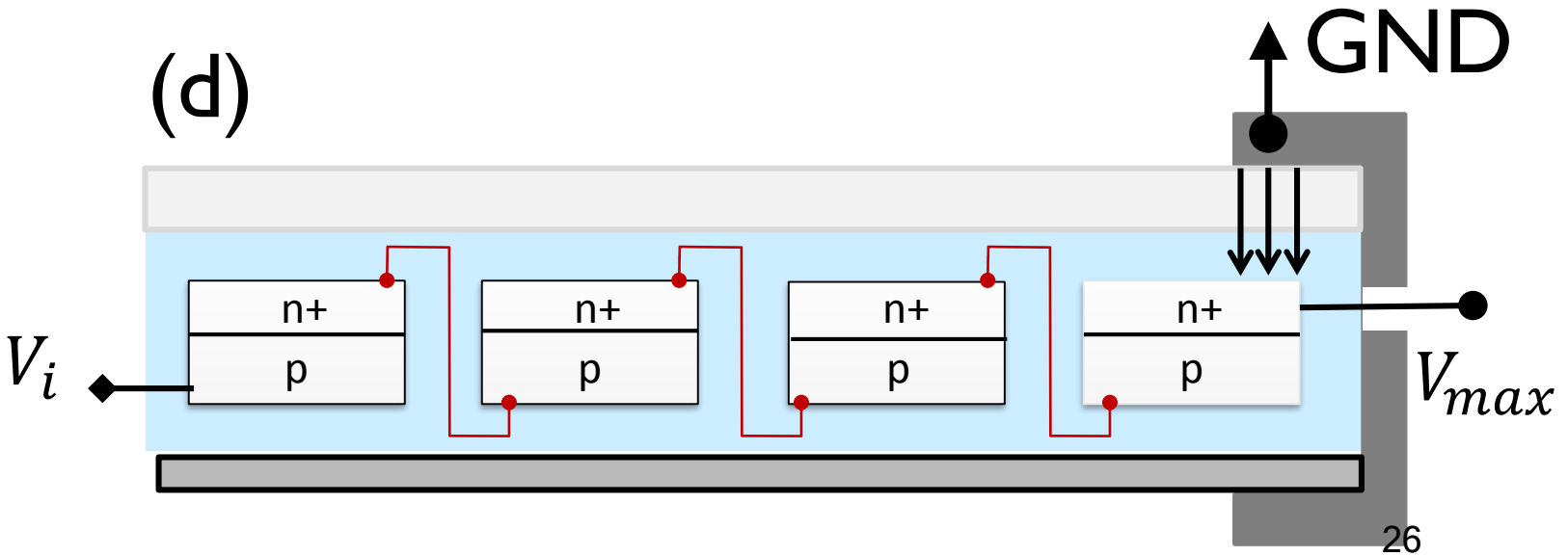




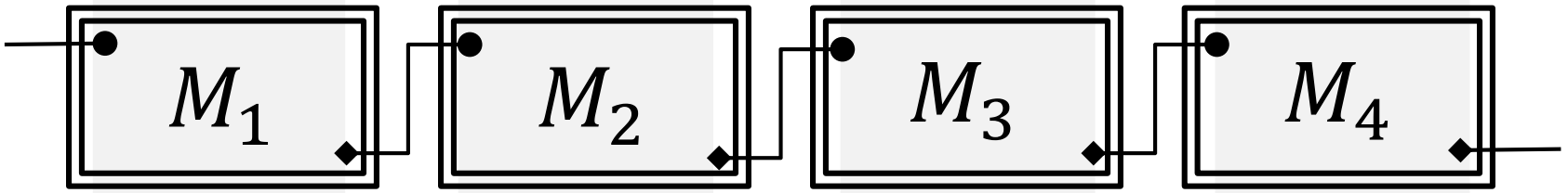
(c)

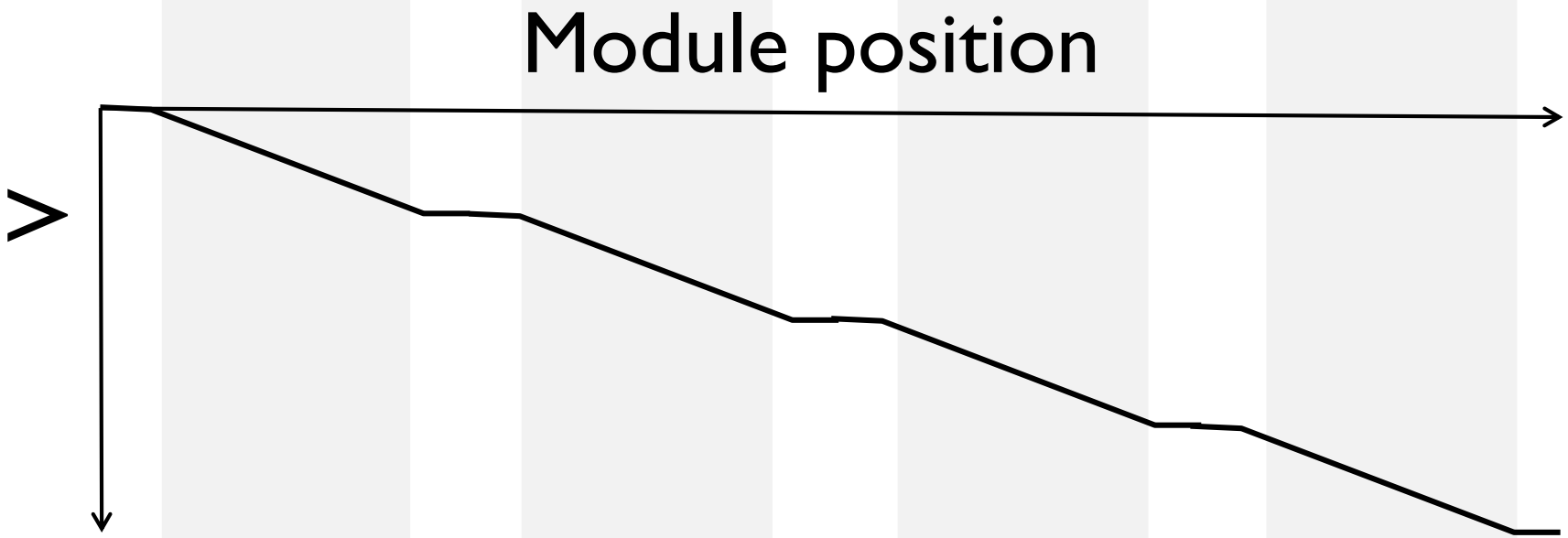


(d)

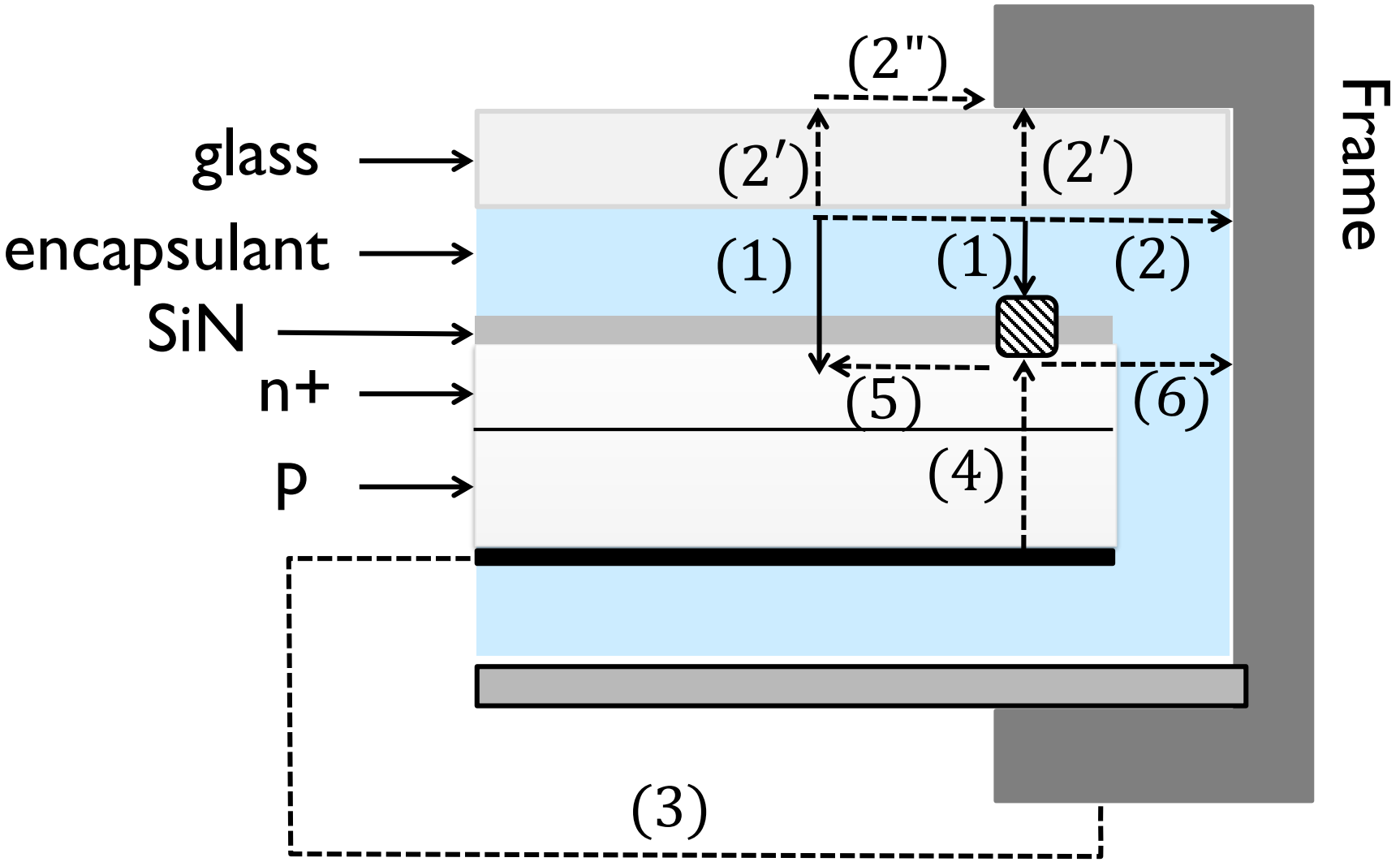


Cascading voltage in a string



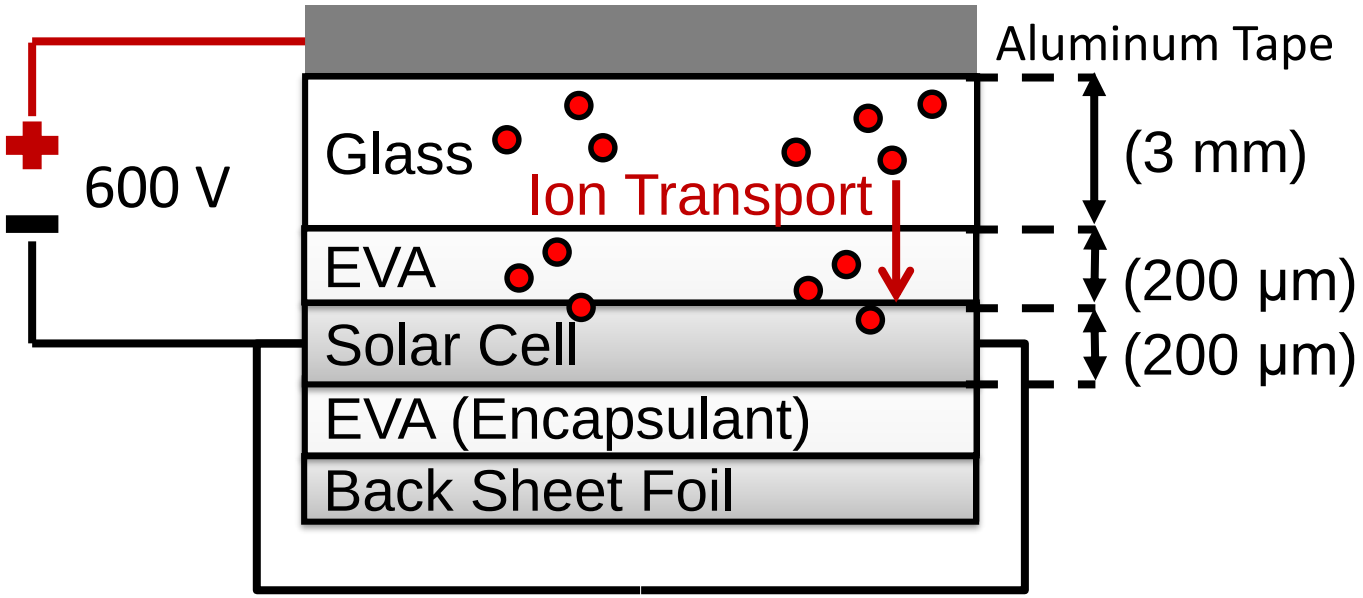


Variety of PID leakage paths



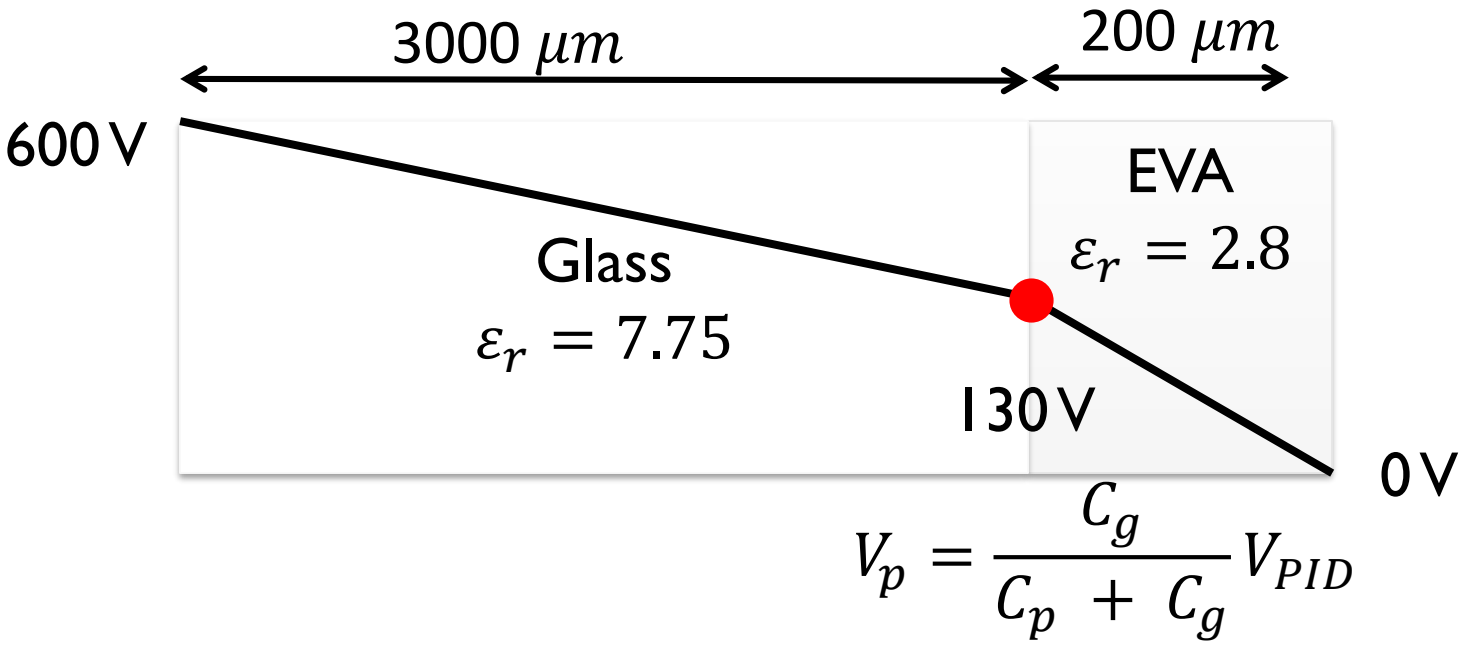
A Model for PID Degradation

An aluminum tape covers the front surface



The tape makes the field inside the structure uniform and hence one dimensional transport simulation is done.

Potential and Drift-Diffusion Geometry

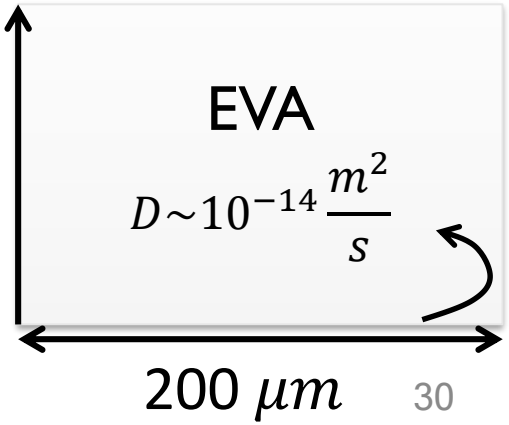


$$V_p = \frac{C_g}{C_p + C_g} V_{PID}$$

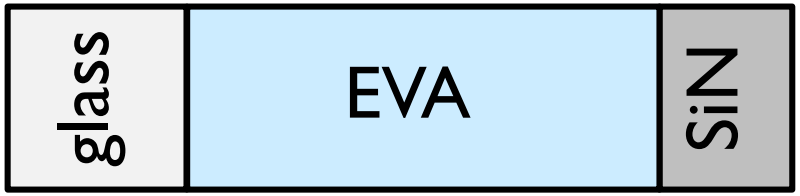
Transport Boundary Condition:

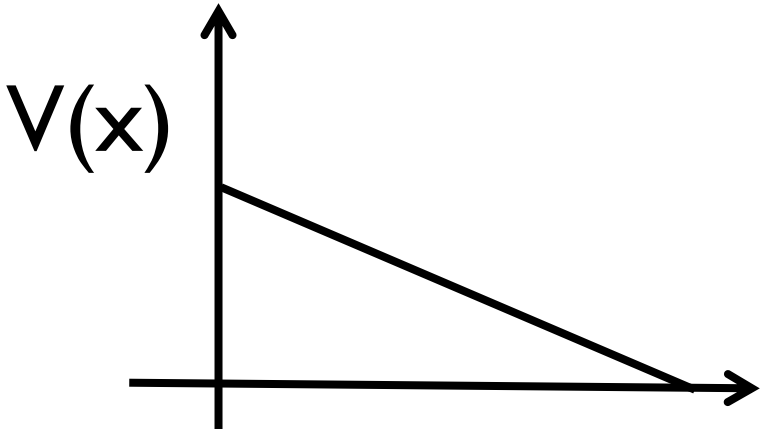
Left side: Constant $10^{20}\ /m^3$

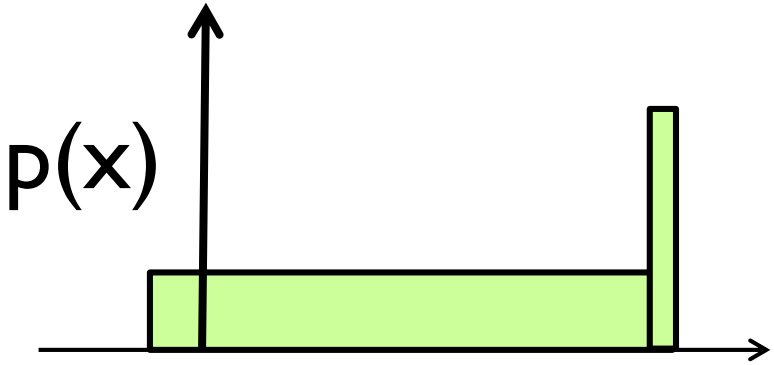
Right side: Reflective Boundary



Linear Response: Low Na glass







$$Q_p(= qp_0L_p)$$

$$J_{Na} = Q_p/t_p = qp_0\mu_pV_p/L_p$$

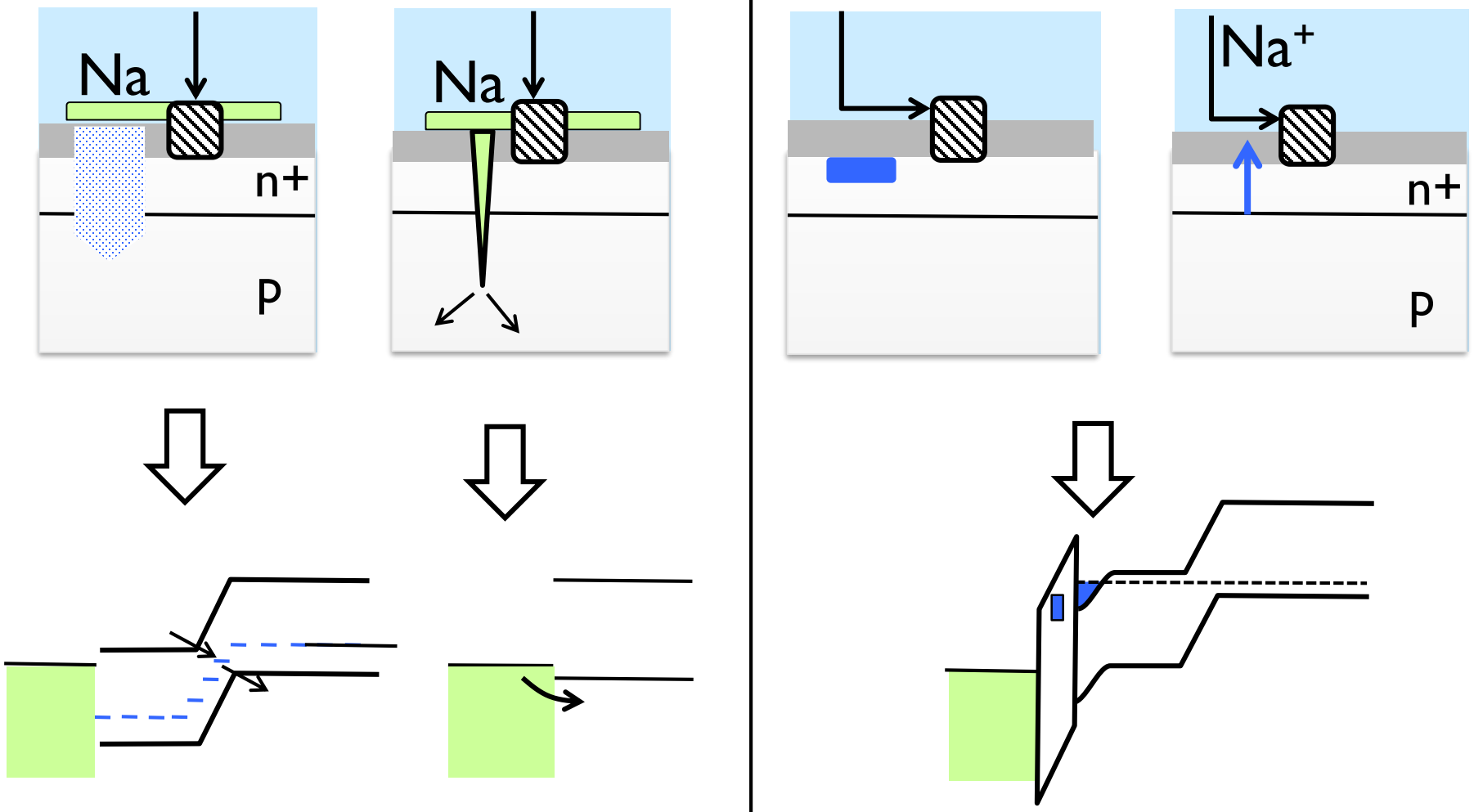
$$\mu_p = \mu_0^* e^{-E_A/k_BT}$$

$$\mu_0^* = \mu_0[RH\%]^B$$

$$R_D \propto J_{Na} = A\, e^{-E_A/k_BT}[RH\%]^B V_p$$

$$A \equiv qp_0\mu_0/L_p$$

Types of PID degradation



Conclusions

1. Solar cells must survive the weather outside for 25-40 years. Reliability is a key concern and a very important research topic.
2. The power loss may be reversible or irreversible. Many of the irreversible reliability issues arise from how the cells are series-connected to form a module and how modules are series-connected to form a string.
3. Shadow degradation and potential induced degradation are two very important reliability issues of a PV system. A set of solution methodologies have been developed to address these concerns.
4. We will discuss other reliability fundamental reliability issues, such as corrosion, and UV-degradation in the next lecture.

Self-assessment Quiz

1. How does reliability affect the cost of electricity?
2. A partial shadow is more dangerous than a complete shadow. Explain.
3. Explain three different ways the effects of partial shadowing can be minimized.
4. Is partial shadow degradation reversible or irreversible?
5. Name the ion responsible for PID degradation.
6. Name two types of PID degradations discussed in this tutorial.
7. Explain why n+-p vs. p+-n have very different PID degradation. How does this polarity dependence implicate Na transport in creating PID?
8. Suggest two methods to suppress PID.