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

Reliability of Solar Cells: Part 2

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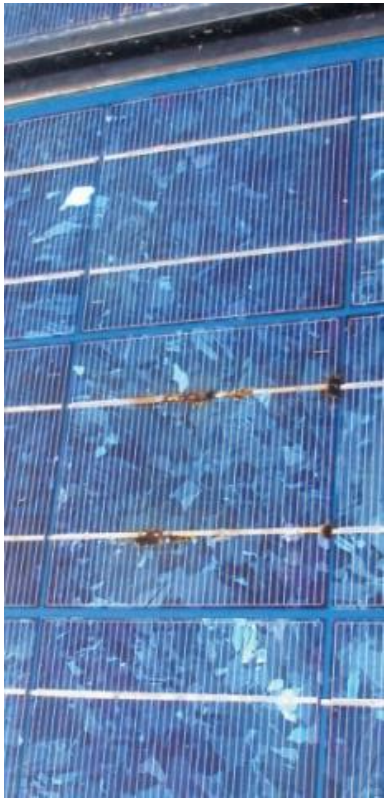
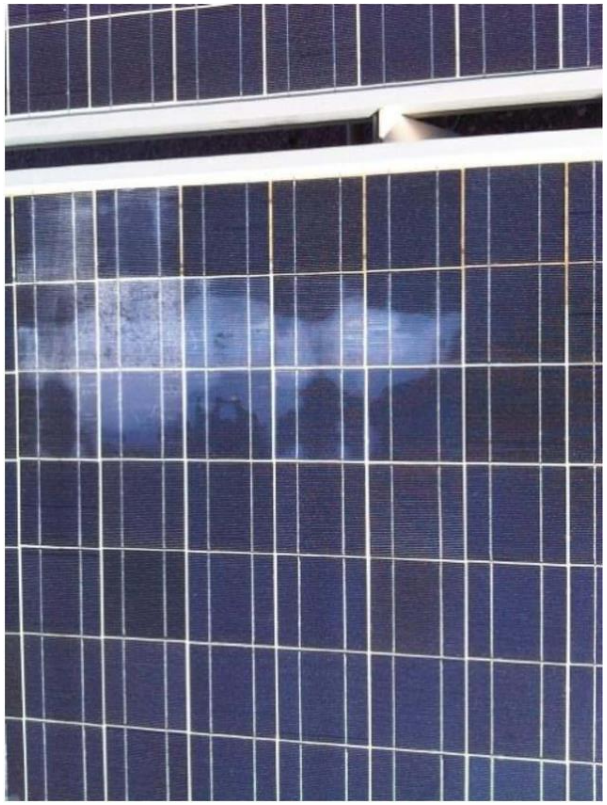
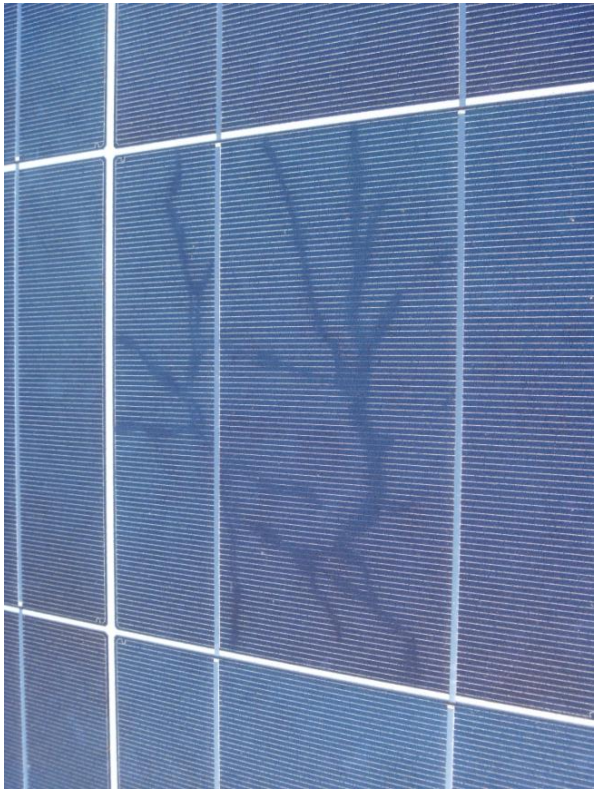
Outline

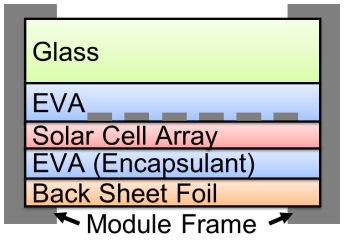
1) Background: Why does reliability matter
2) Three classes of reliability issues
    - Reversible (soiling, Shadow)
    - Metastable (PID, LID)
    - Permanent (Yellowing, corrosion, cracking)
3) Qualification and prediction
4) Conclusions

Corrosion, delamination, Snail trails



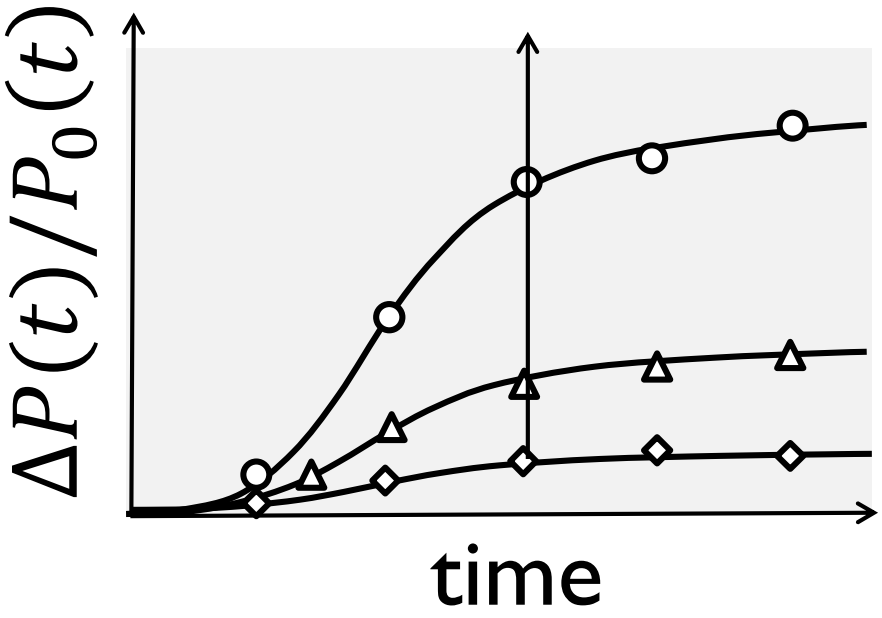


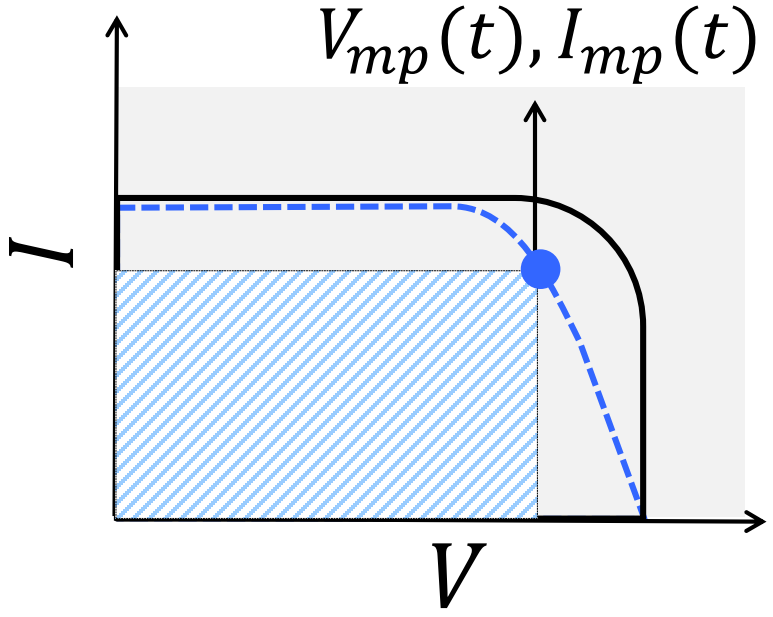




Power loss due to corrosion

T, RH

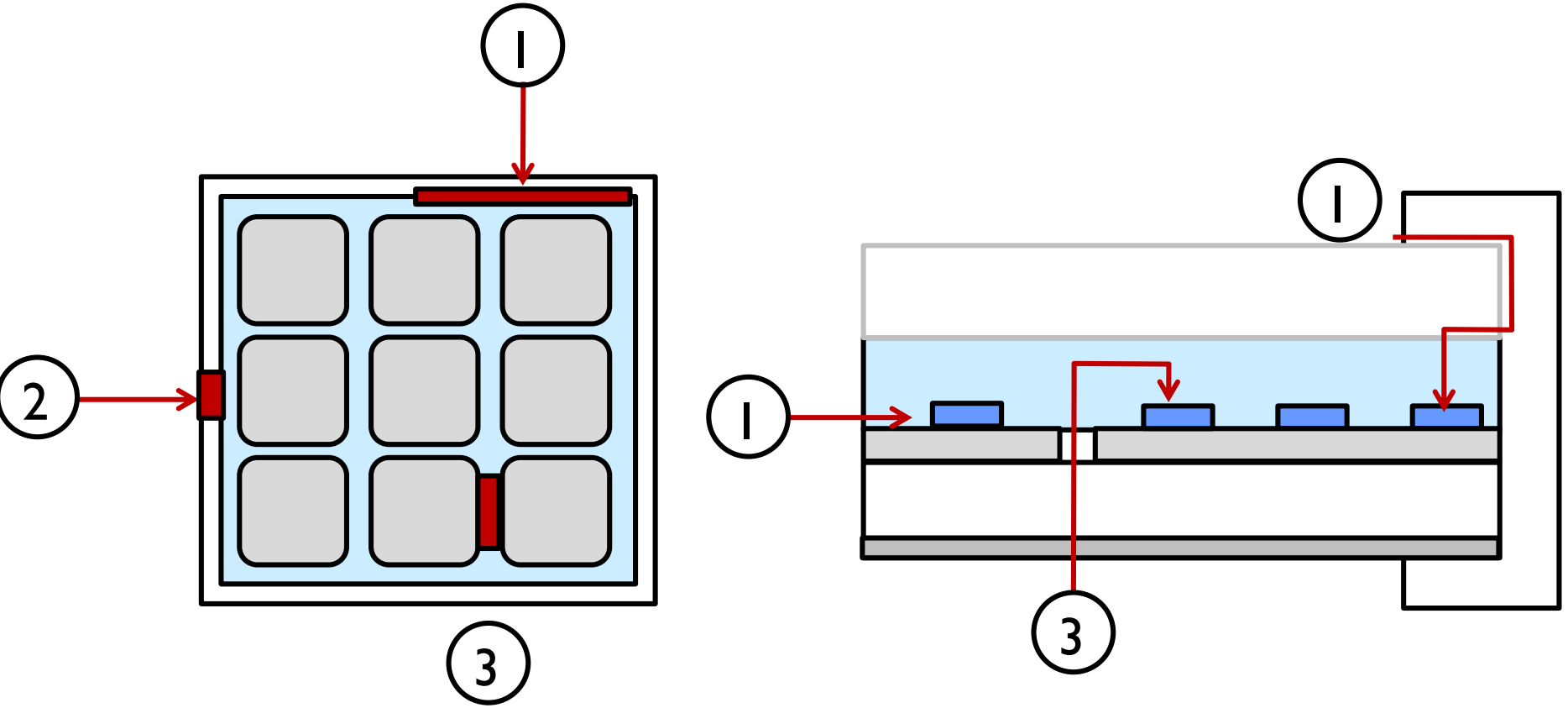




$$\frac{\Delta P}{\Delta P_\infty} = \frac{1}{1 + e_D^{-(t-t_H)R_D}}$$

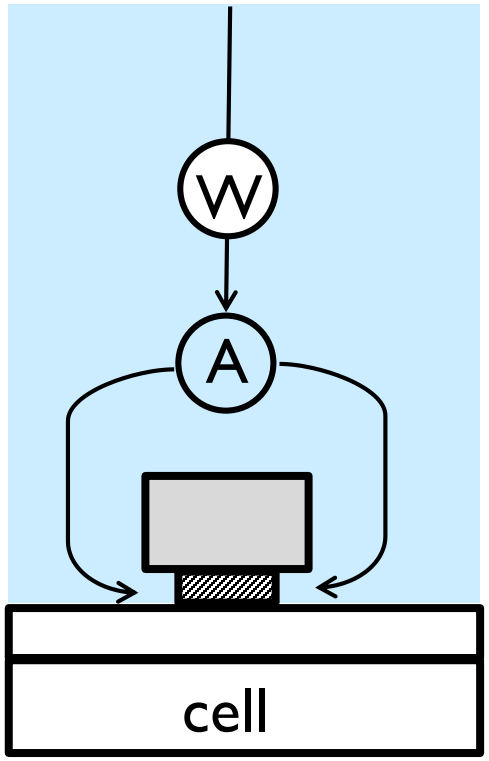
$$t_H = AV^n e^{-\frac{E_A}{k_B T}} [RH]^B$$

Moisture ingress pathways

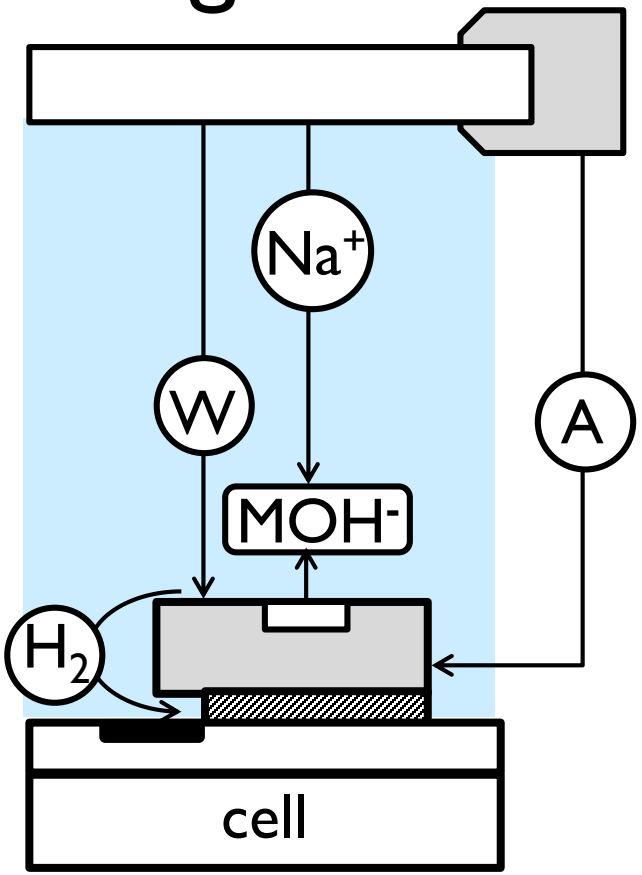


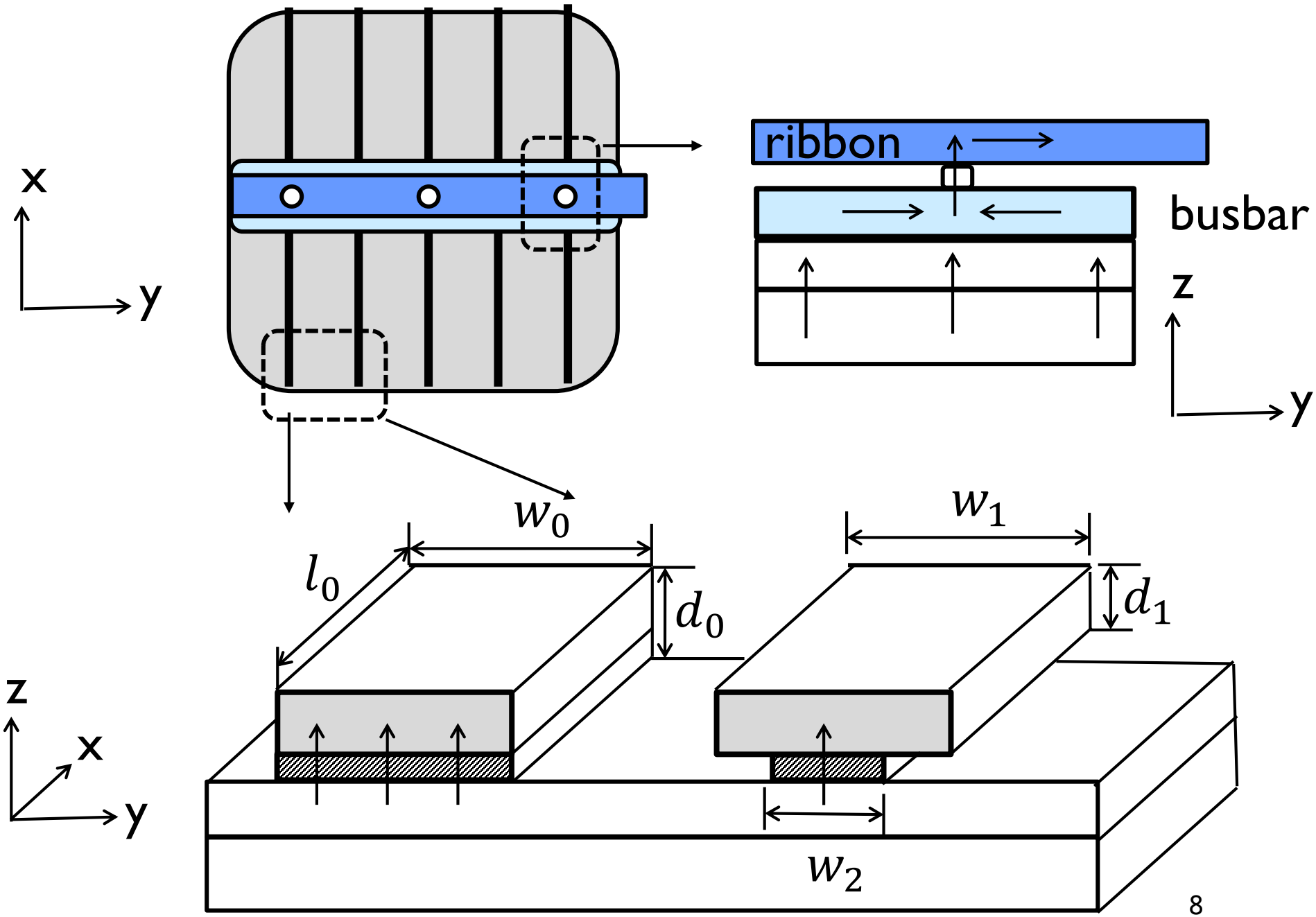
Two different of corrosions

Dark

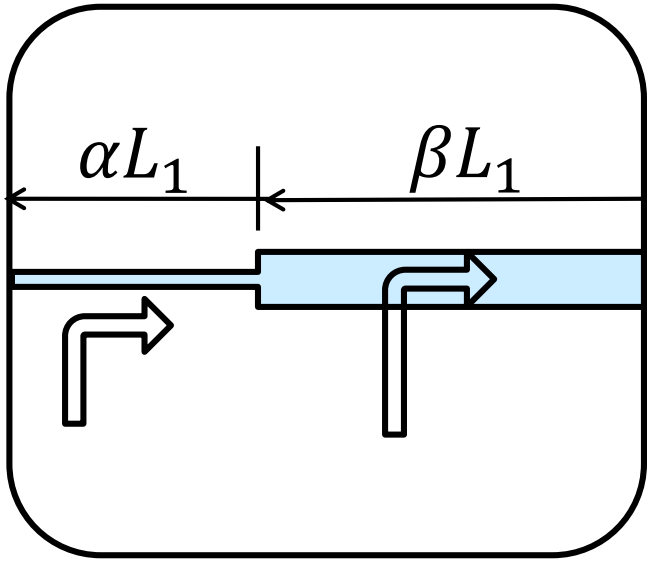


Light

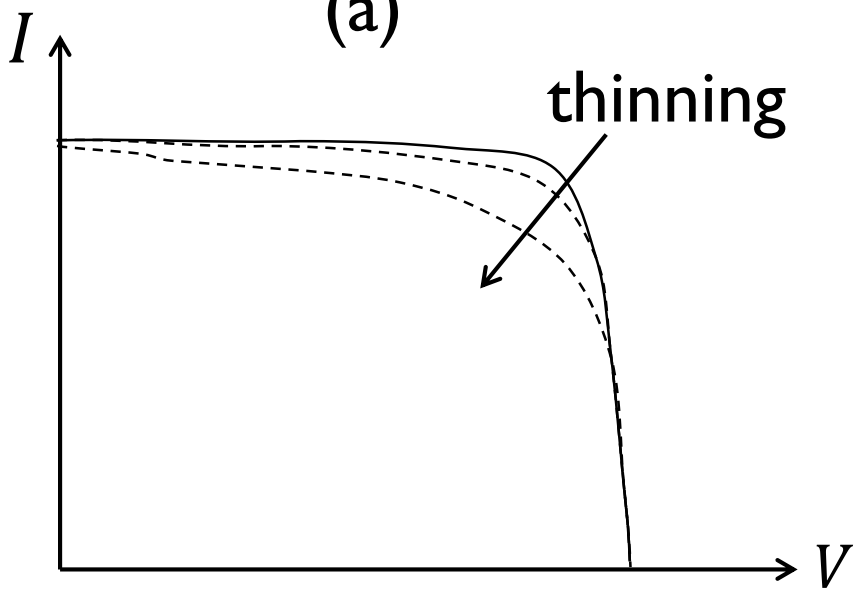


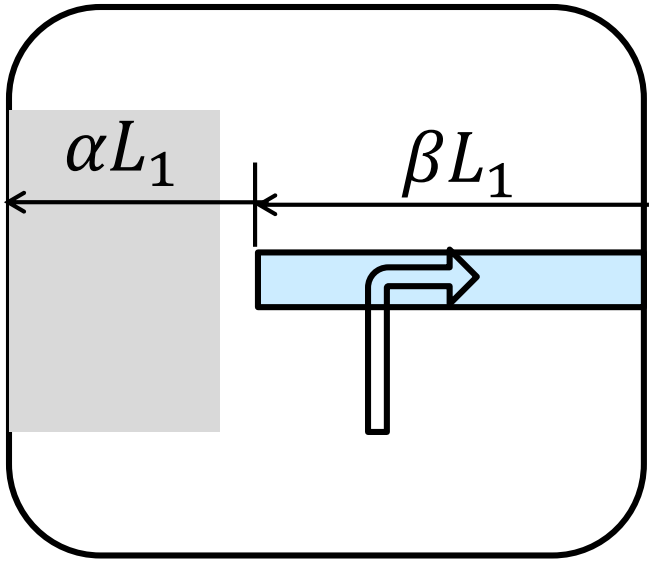

x
y
ribbon
busbar
z
y
w_0
l_0
d_0
w_1
d_1
z
x
y
w_2

Shunt and photocurrent loss

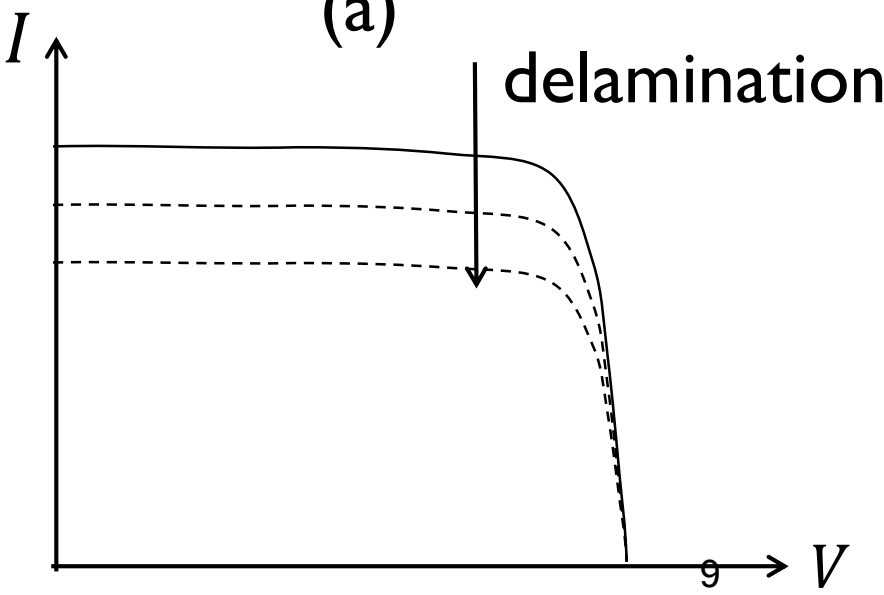


(a)

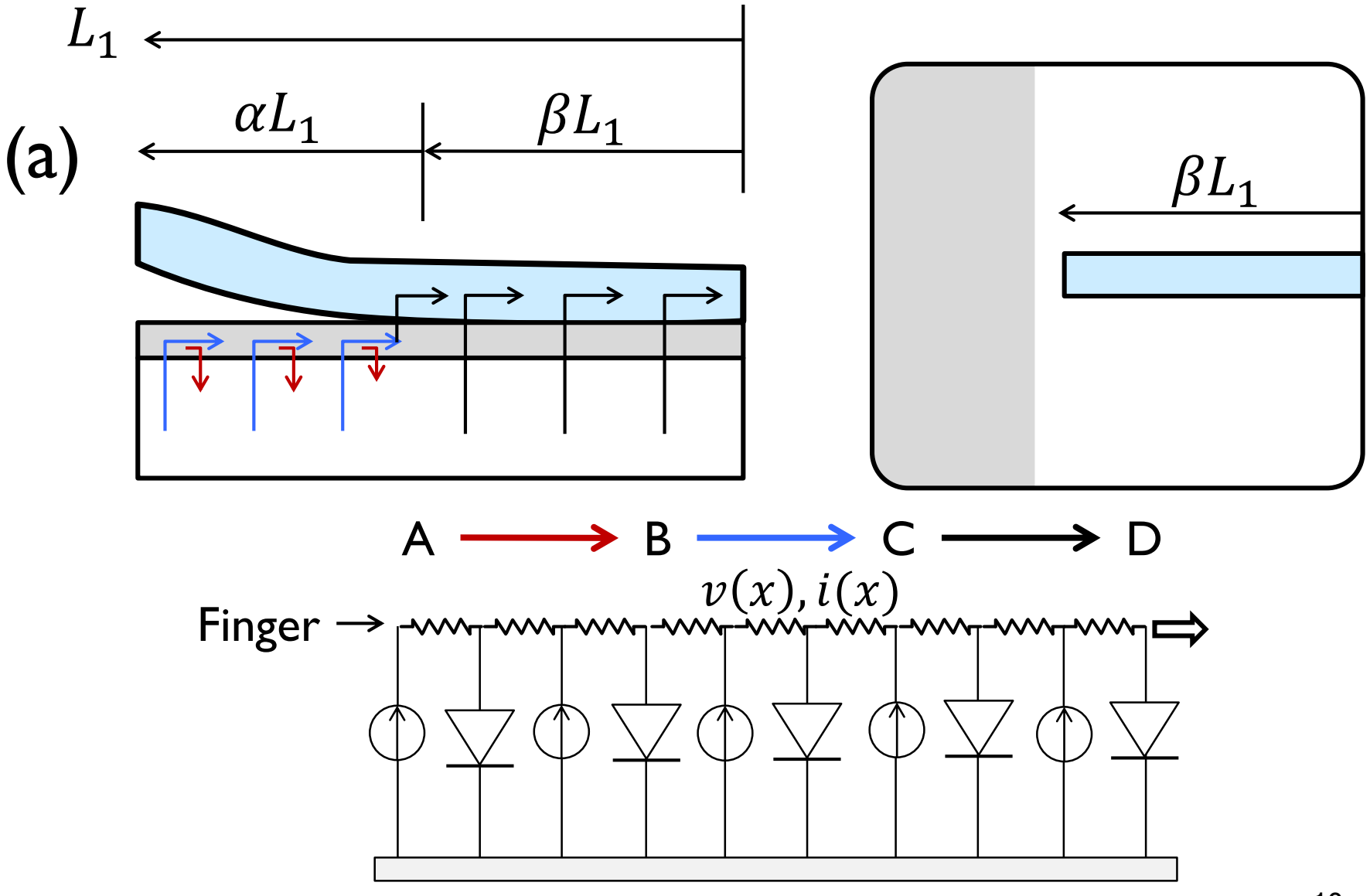




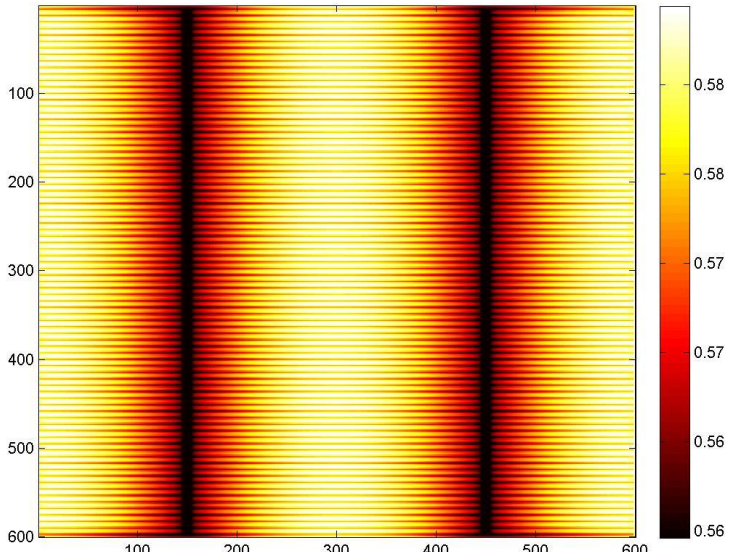
(a)

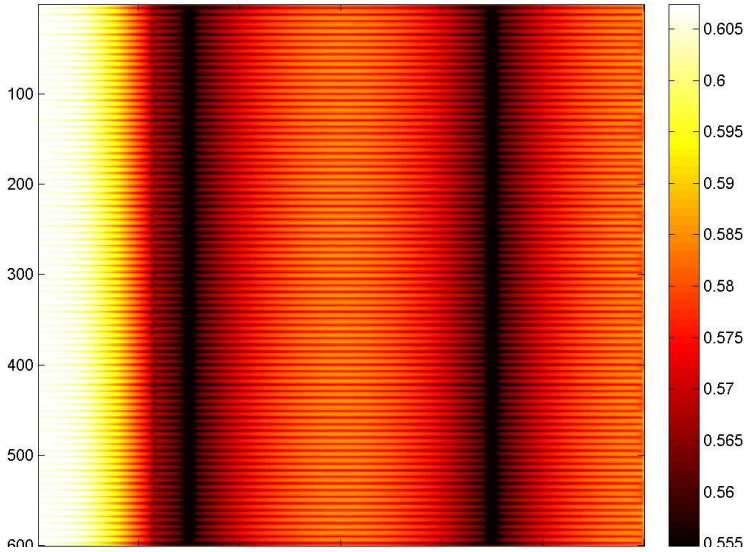


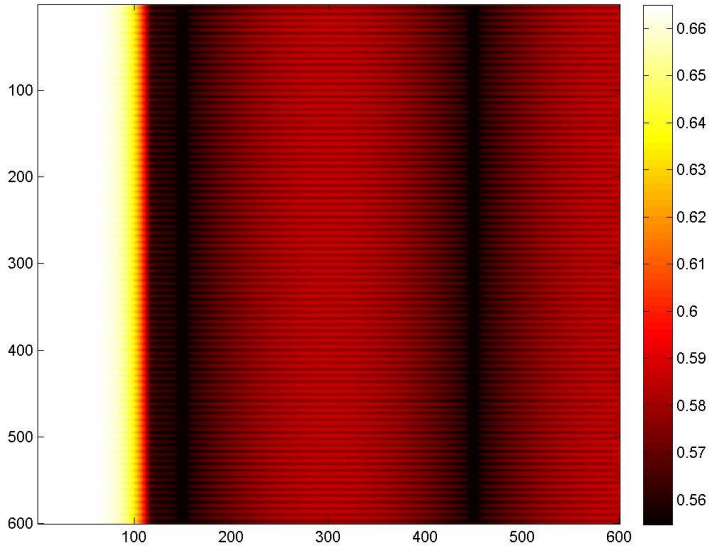
Power loss due to corrosion

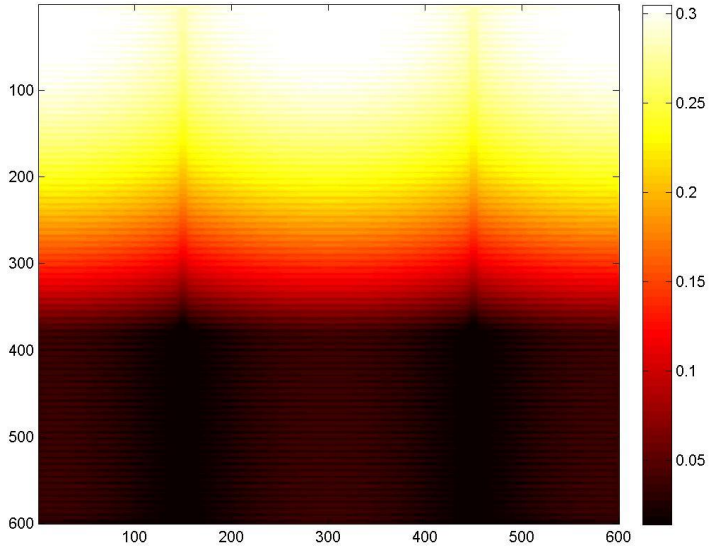


Corroded module: voltage distribution

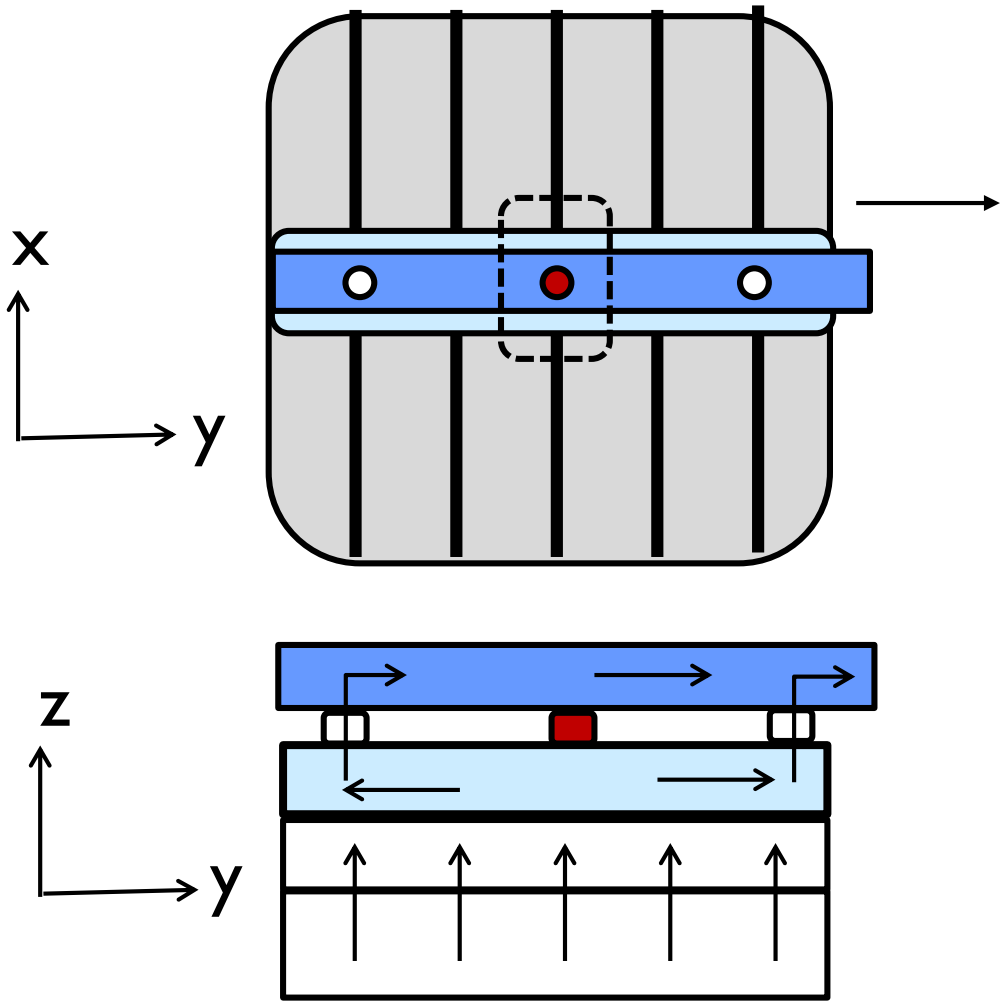


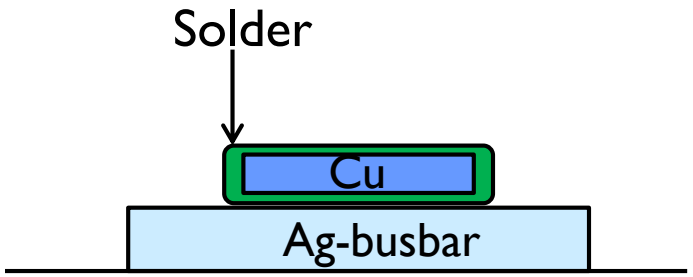


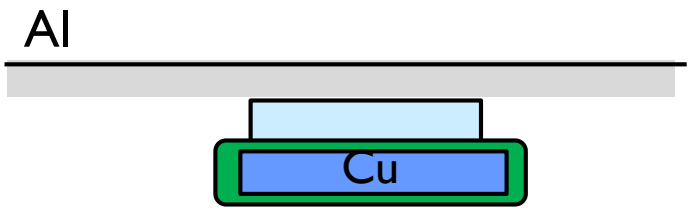




Ribbon/busbar corrosion







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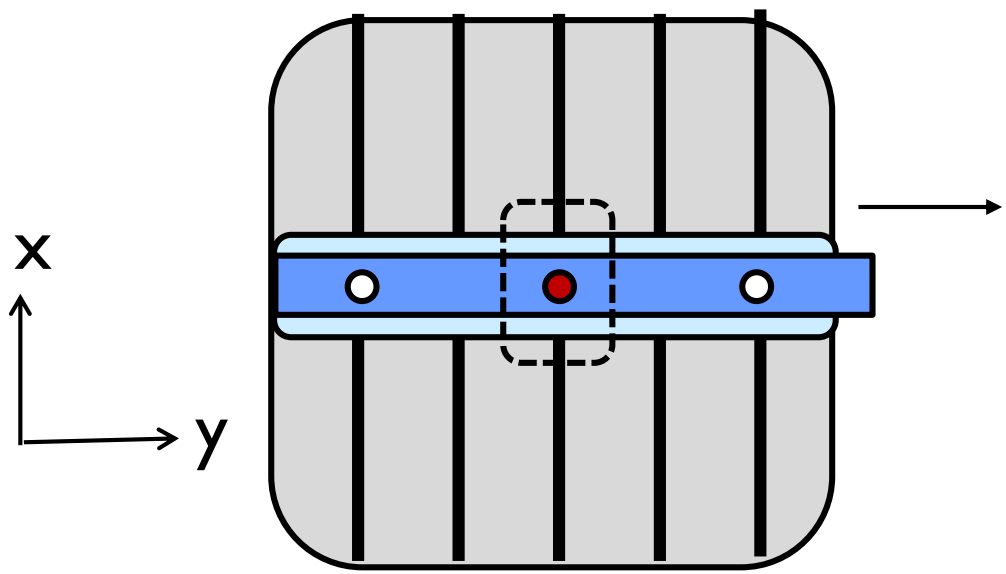
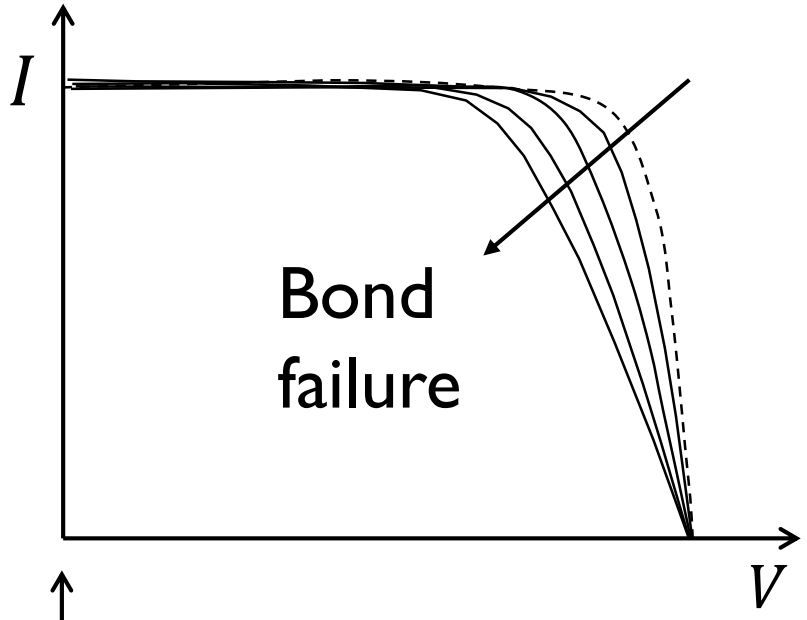
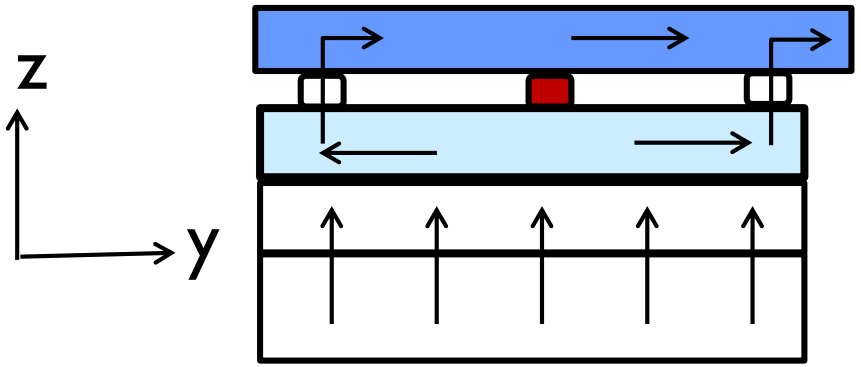
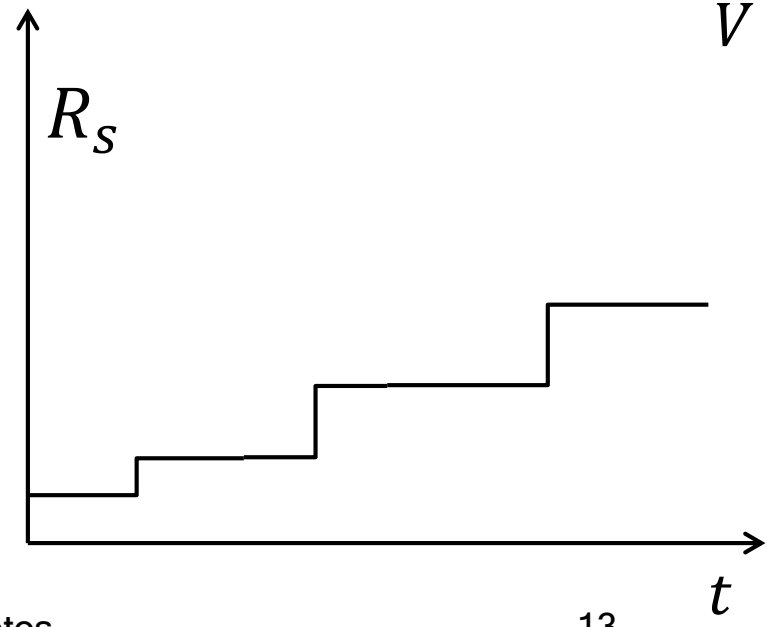
Increased series resistance









Outline

1) Background: Why does reliability matter
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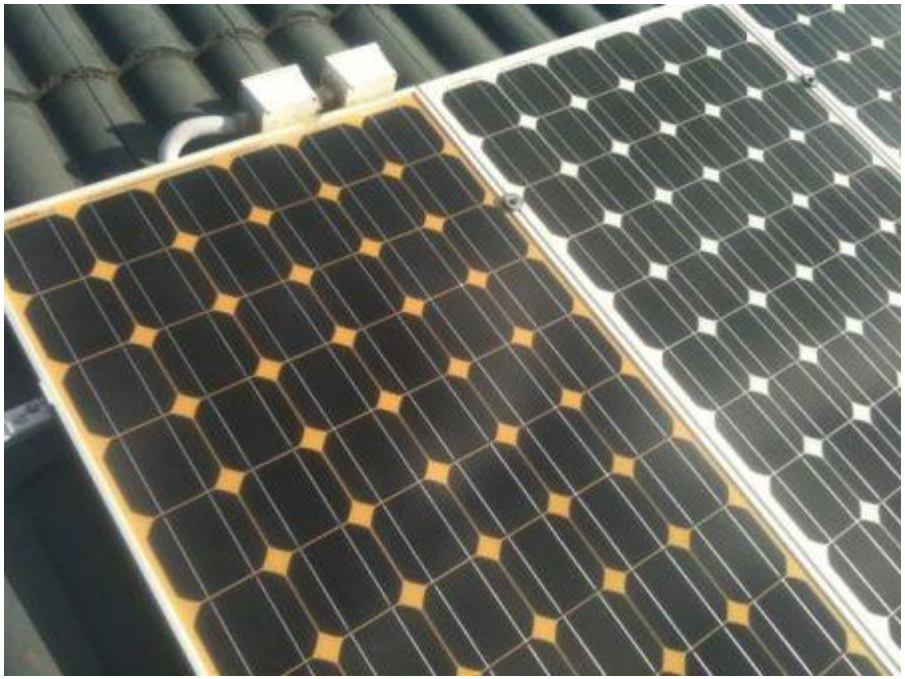
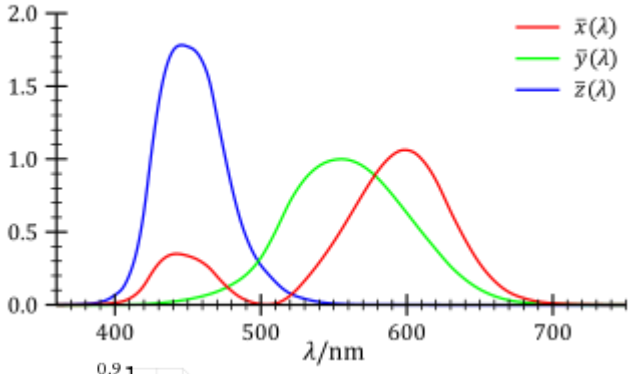
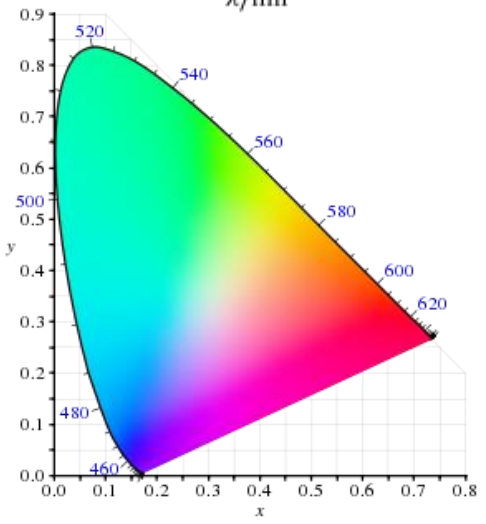
3) Forward and inverse reliability prediction
4) Conclusions

Yellowing Index of a degraded polymer

1980s: Carrisa Planes PV

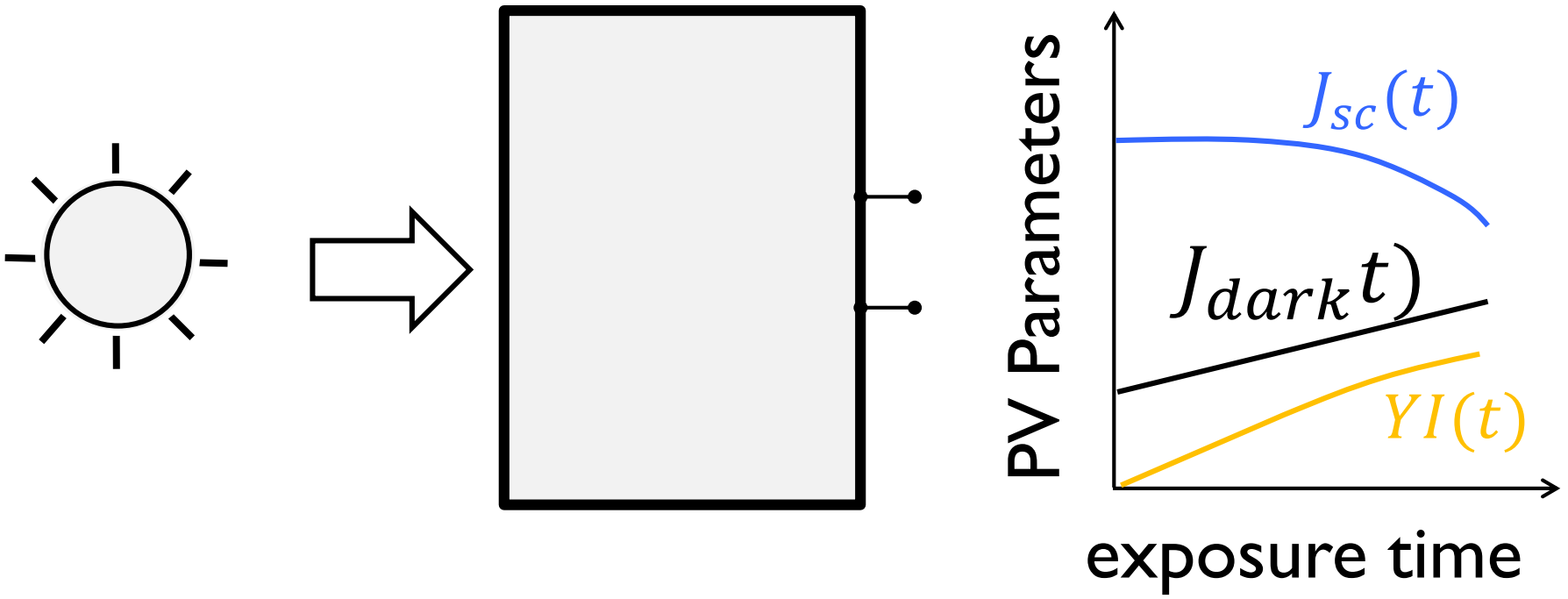




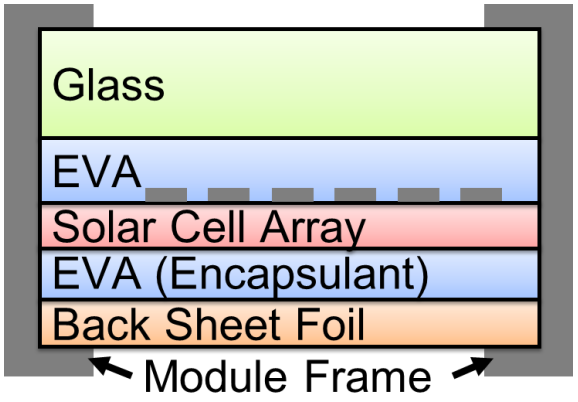


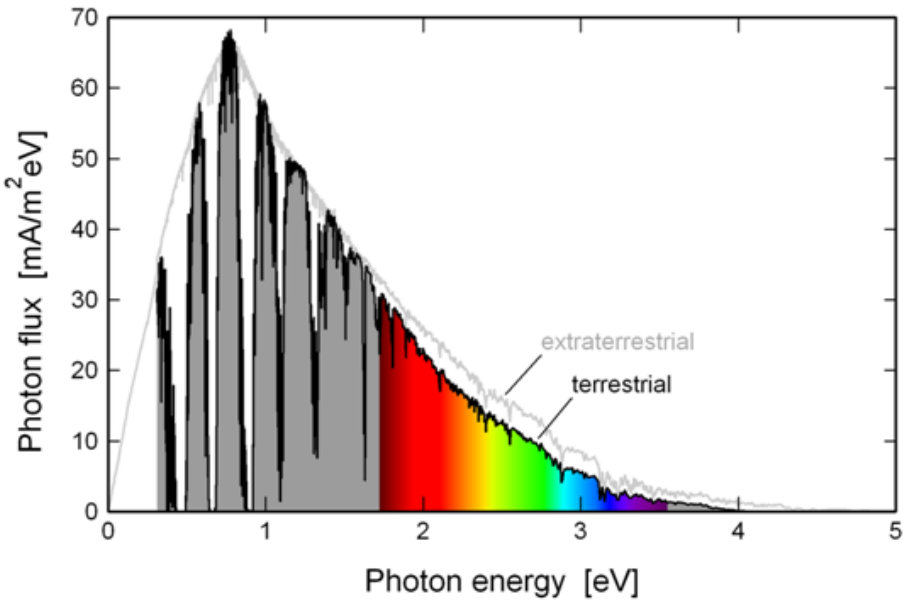
$$YI = (100/Y) * (1.274641506\,X - 1.057434092\,Z)$$

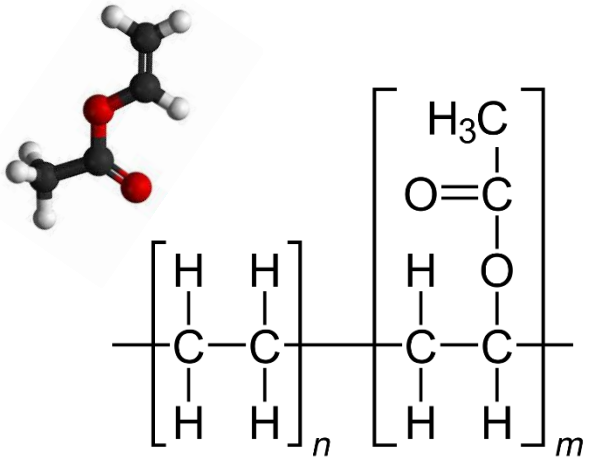
Effect on cell performance



EVA Exposed to Sunlight





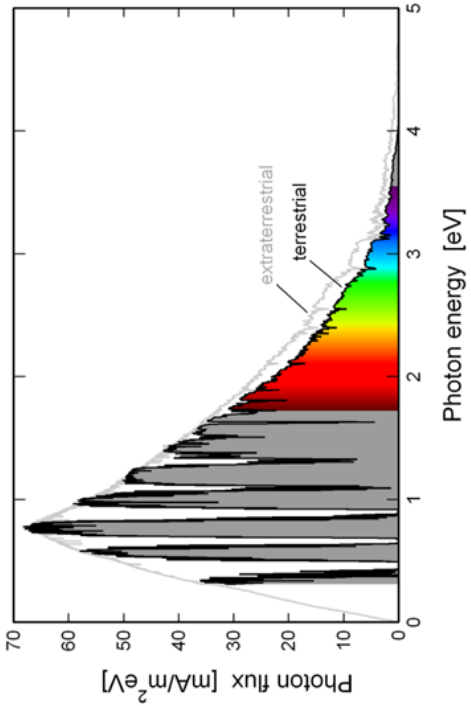


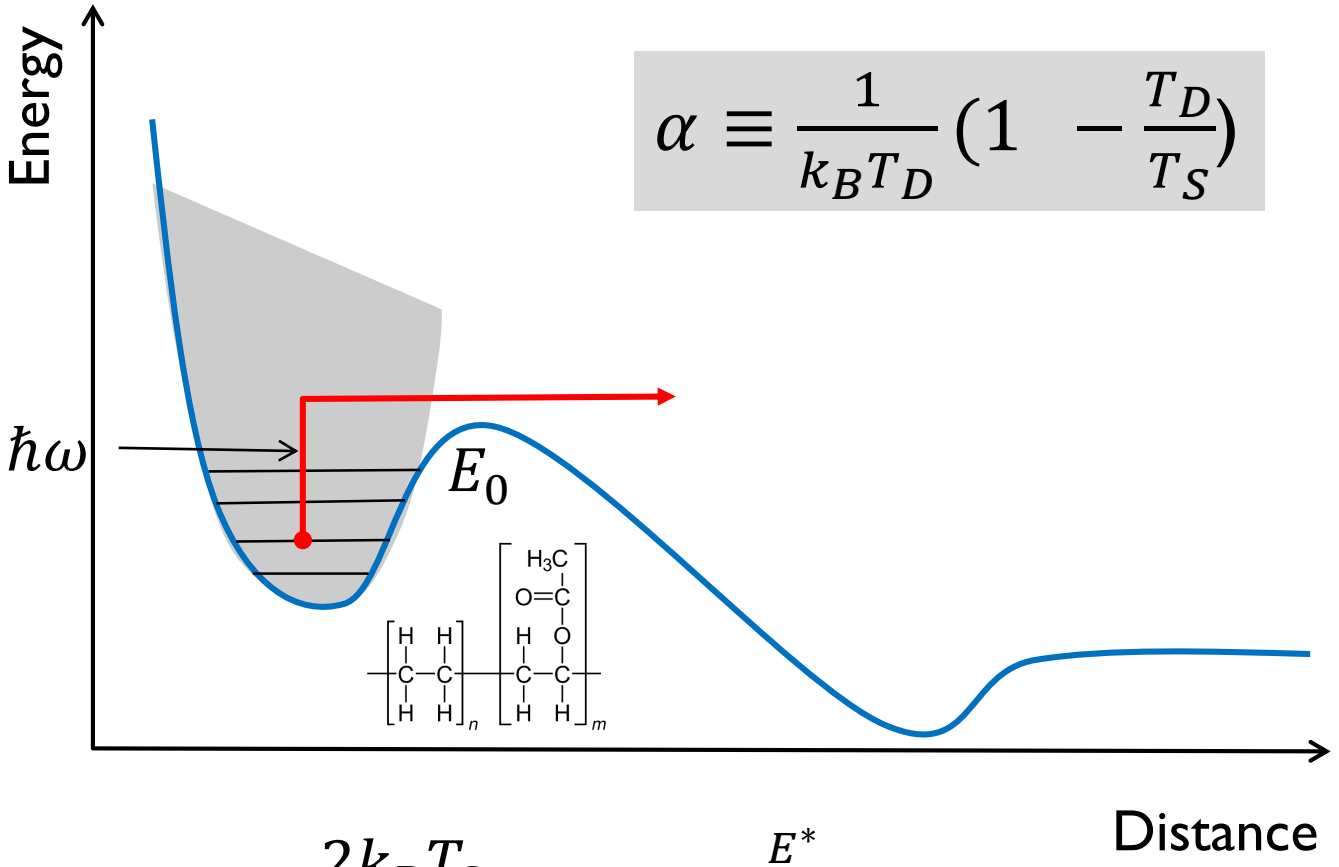
Ethylene-Vinyl-Acetate

Dissociation of Si-H or Si-O bonds

$$R_s = \frac{2N_0 k_B T_S}{h^3 c^2 k_B T_D} \times e^{-\frac{E_0}{k_B T_S}} \times \left[\frac{E_0^2}{\alpha} - \frac{2E_0}{\alpha^2} + \frac{2}{\alpha^3}\right]$$

$$\alpha \equiv \frac{1}{k_B T_D}\left(1 - \frac{T_D}{T_S}\right)$$

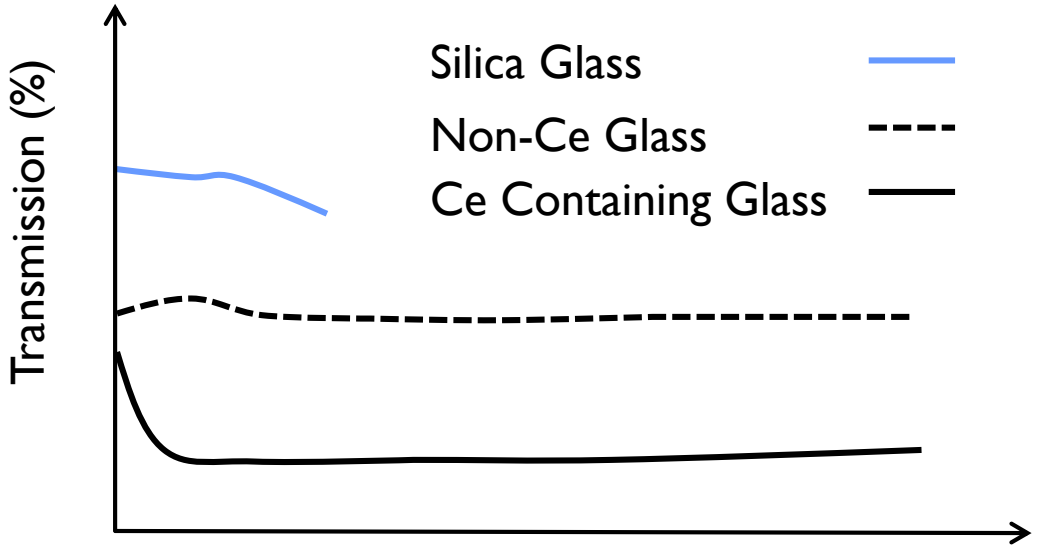




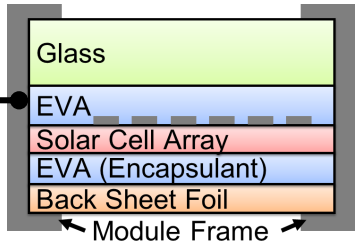
$$N_{ph}(E > E^*) = \frac{2k_B T_S}{h^3 c^2} \times E^{*2}\, e^{-\frac{E^*}{k_B T_S}}$$

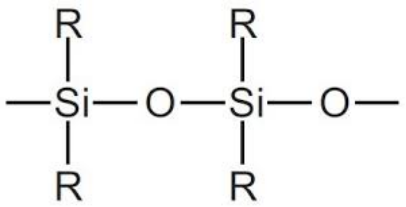
Reducing Yellowing: Use different type of glass

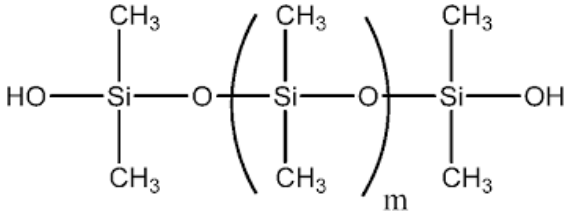
Kempe, 2009.

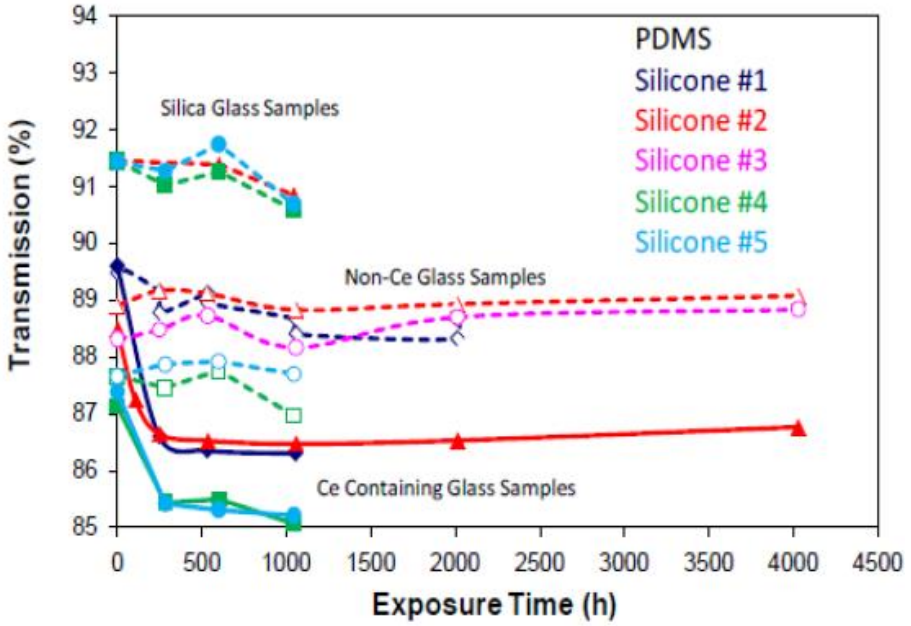


Reducing Yellowing: Use New Additives or Silicone polymer









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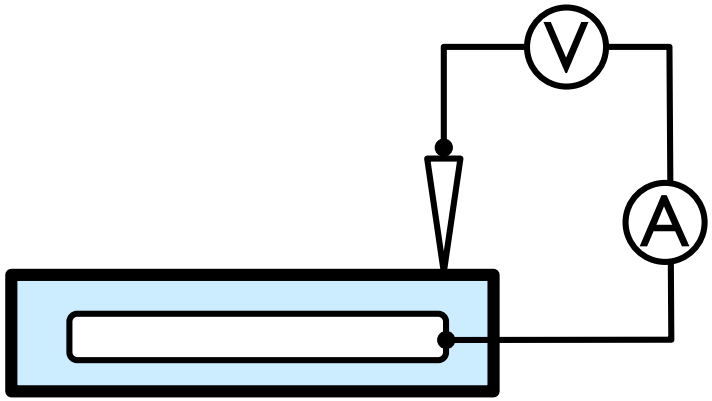
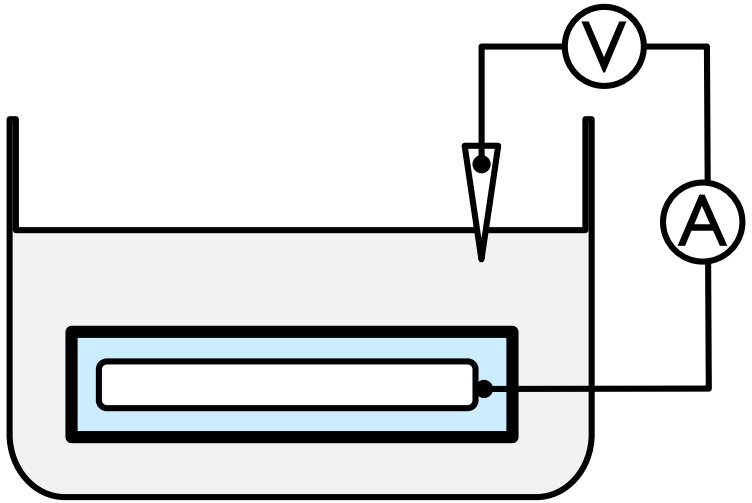
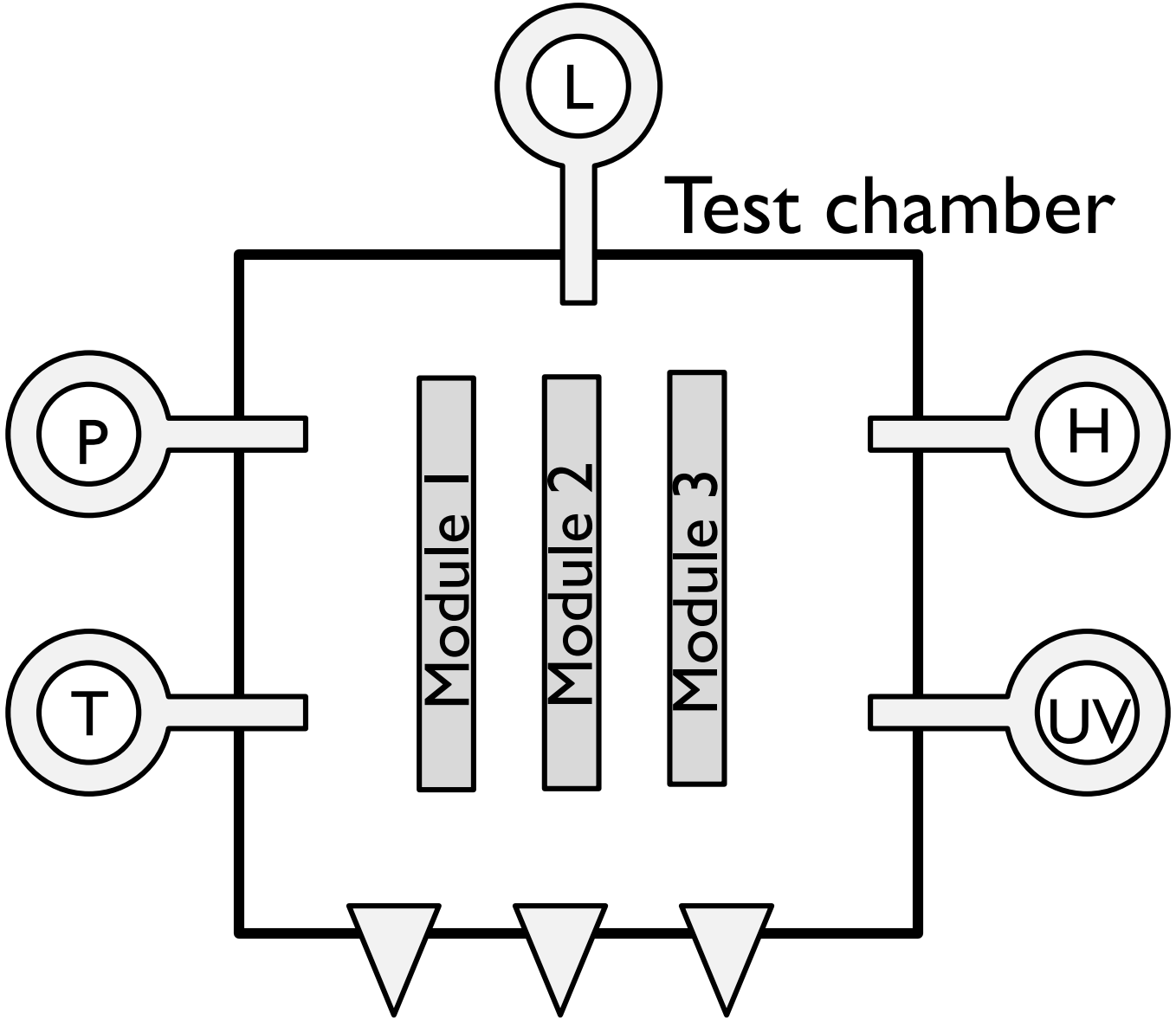
Measuring insulation resistance

(a) Dry measurement



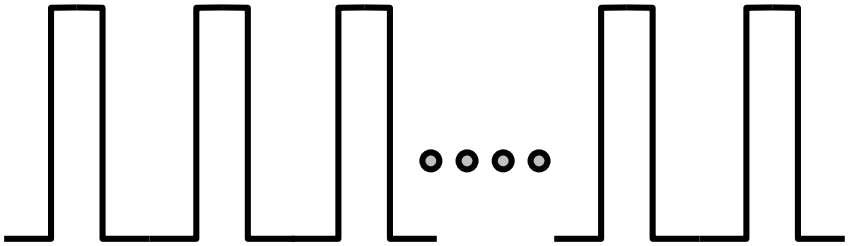
(b) Wet measurement





(Tests: LIV, Dark IV, EL, IR, Resistance, NCOT)

Variety of test sequence



TC: -40 to 85C(10min), 200-600 cycles (Delamination)

DH: 0 to 85%RH/65-85C, 1000hrs (Corrosion, Leak)

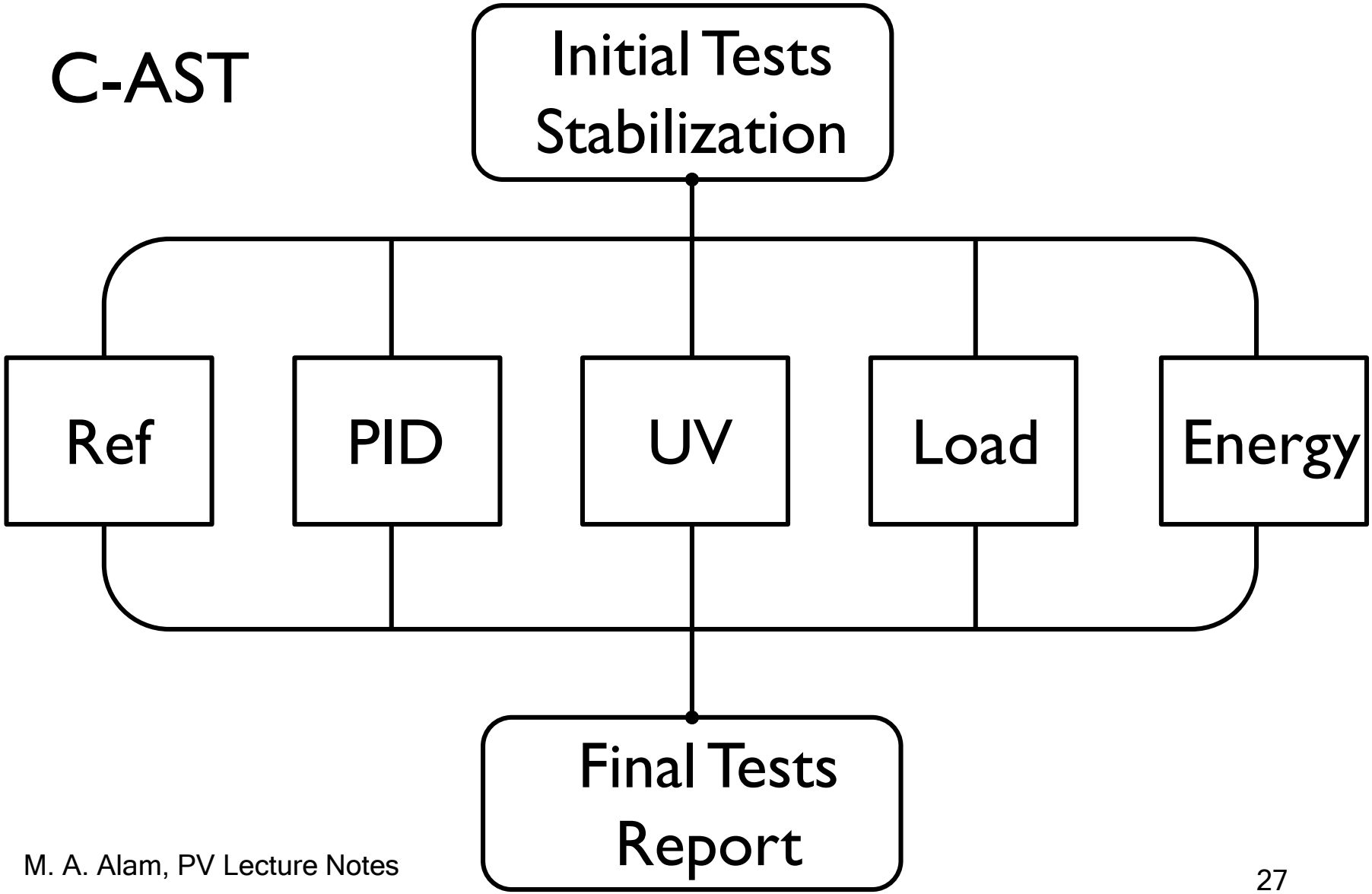
H-F: -40C to 85C @85RH, 10 cycles (Stress/corrosion)

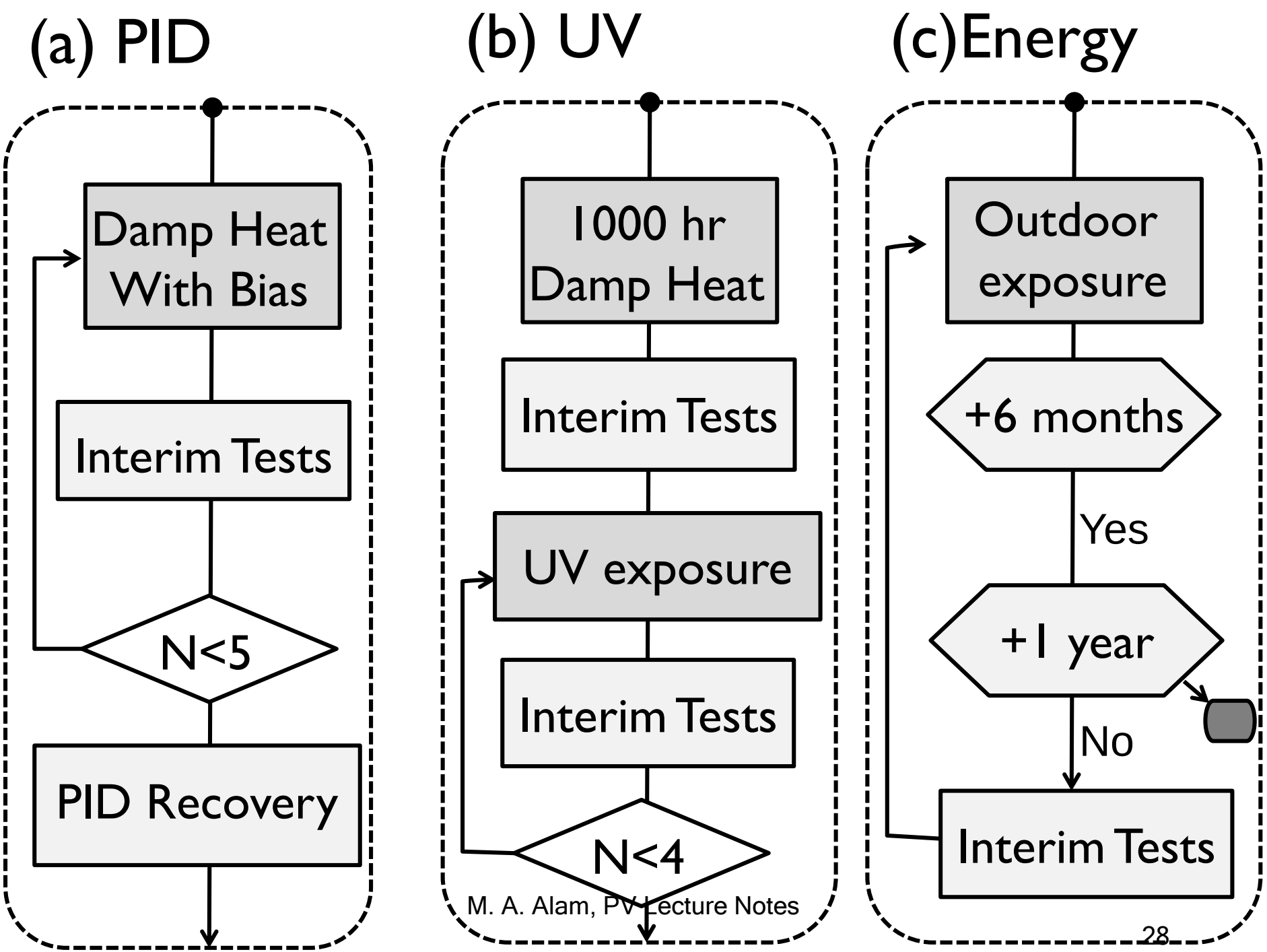
UV: 0 to 25kWh/m^2, 4-5 cycles (Yellowing)

Load: 0 to 2.4/5.6 kPa, -40C, 2-5 cycles (Wind/Snow)

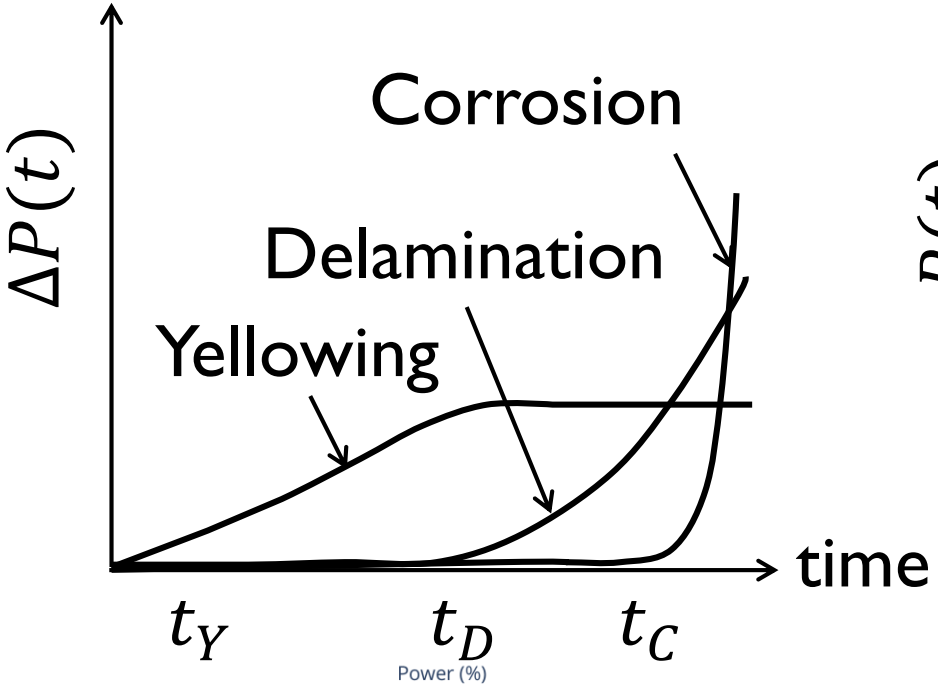
LID: 60 kWh/m^2, 1-10 cycles (EVA, Cells)

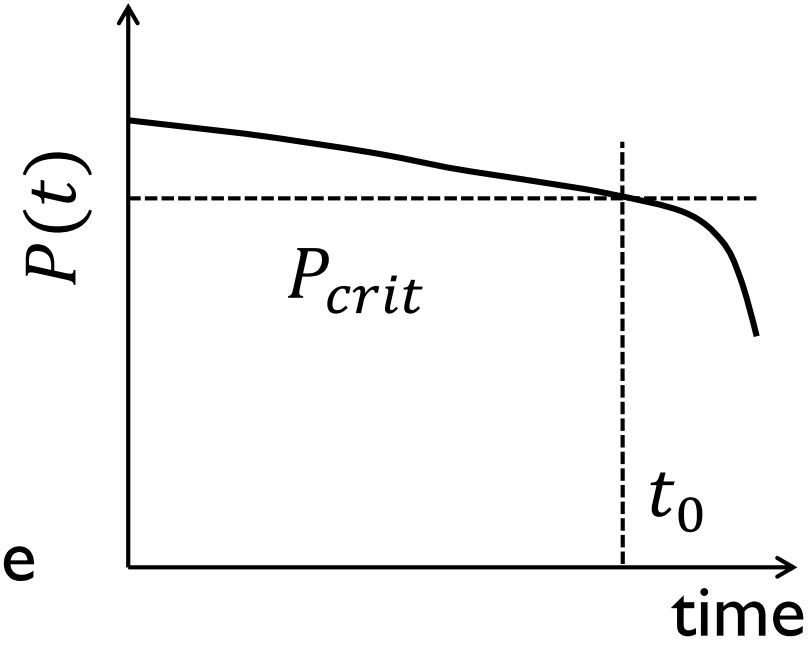
Combined Accelerated Stress Test

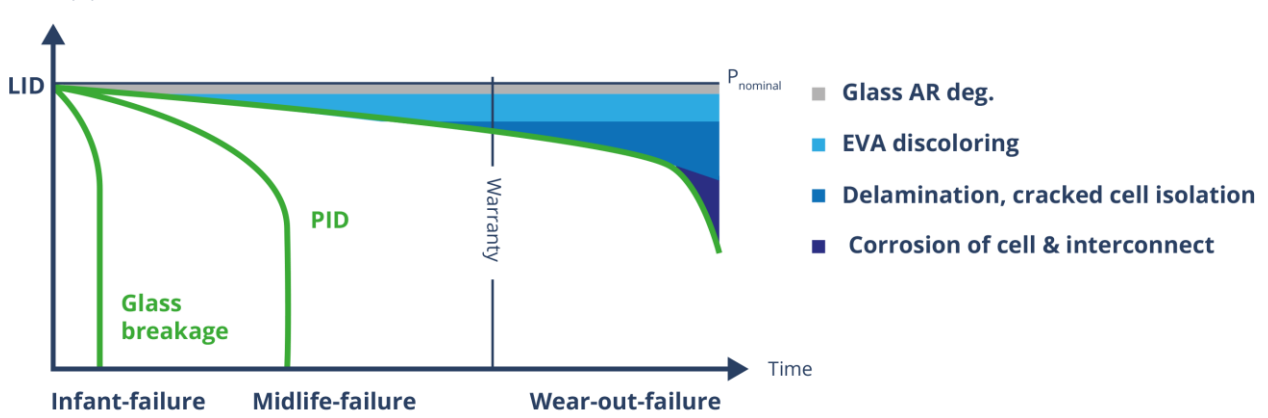



(a) PID
Damp Heat With Bias
Interim Tests
N<5
PID Recovery
(b) UV
1000 hr Damp Heat
Interim Tests
UV exposure
Interim Tests
N<4
(c)Energy
Outdoor exposure
+6 months
Yes
+1 year
No
Interim Tests

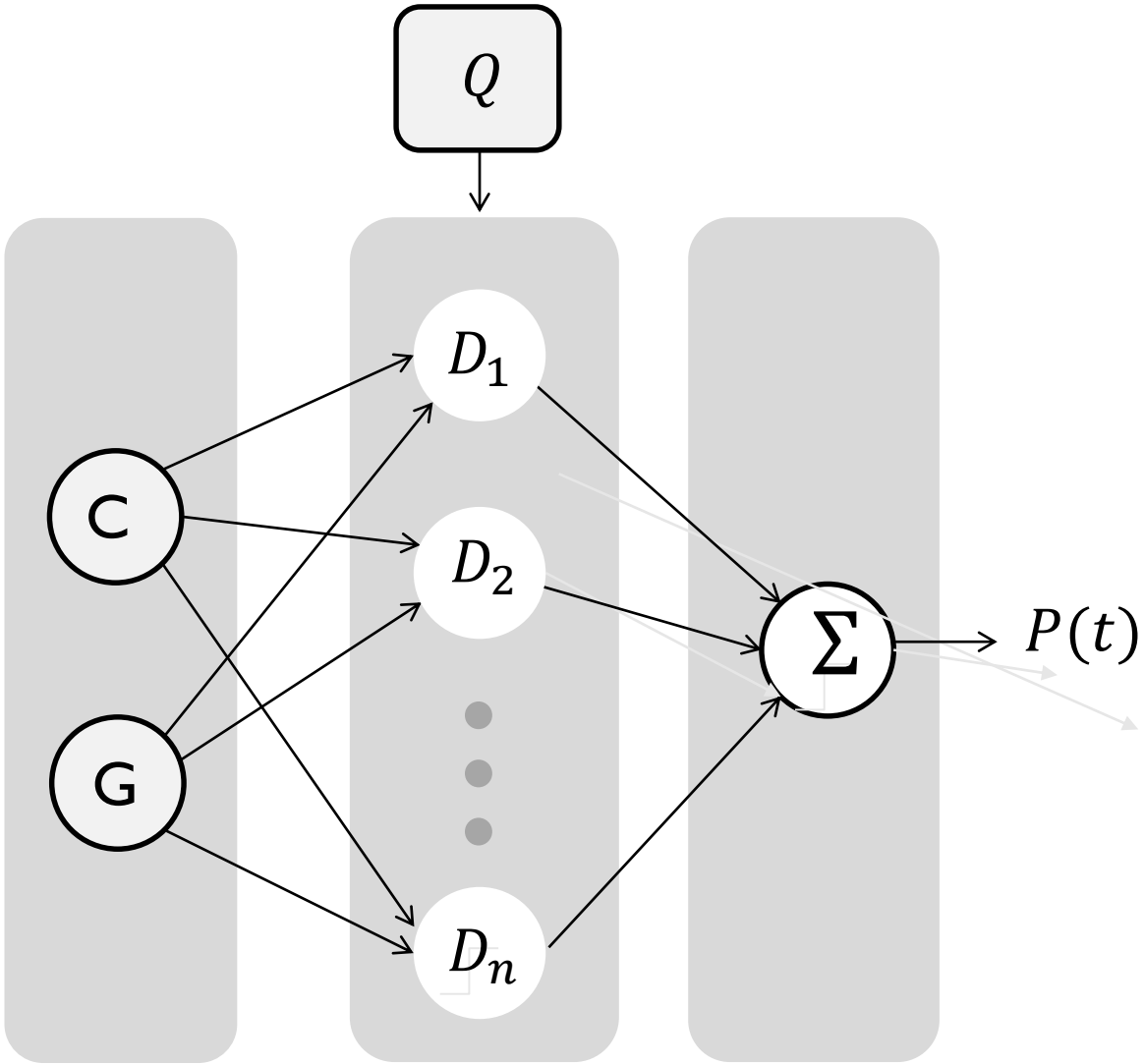
Degradations occur in parallel



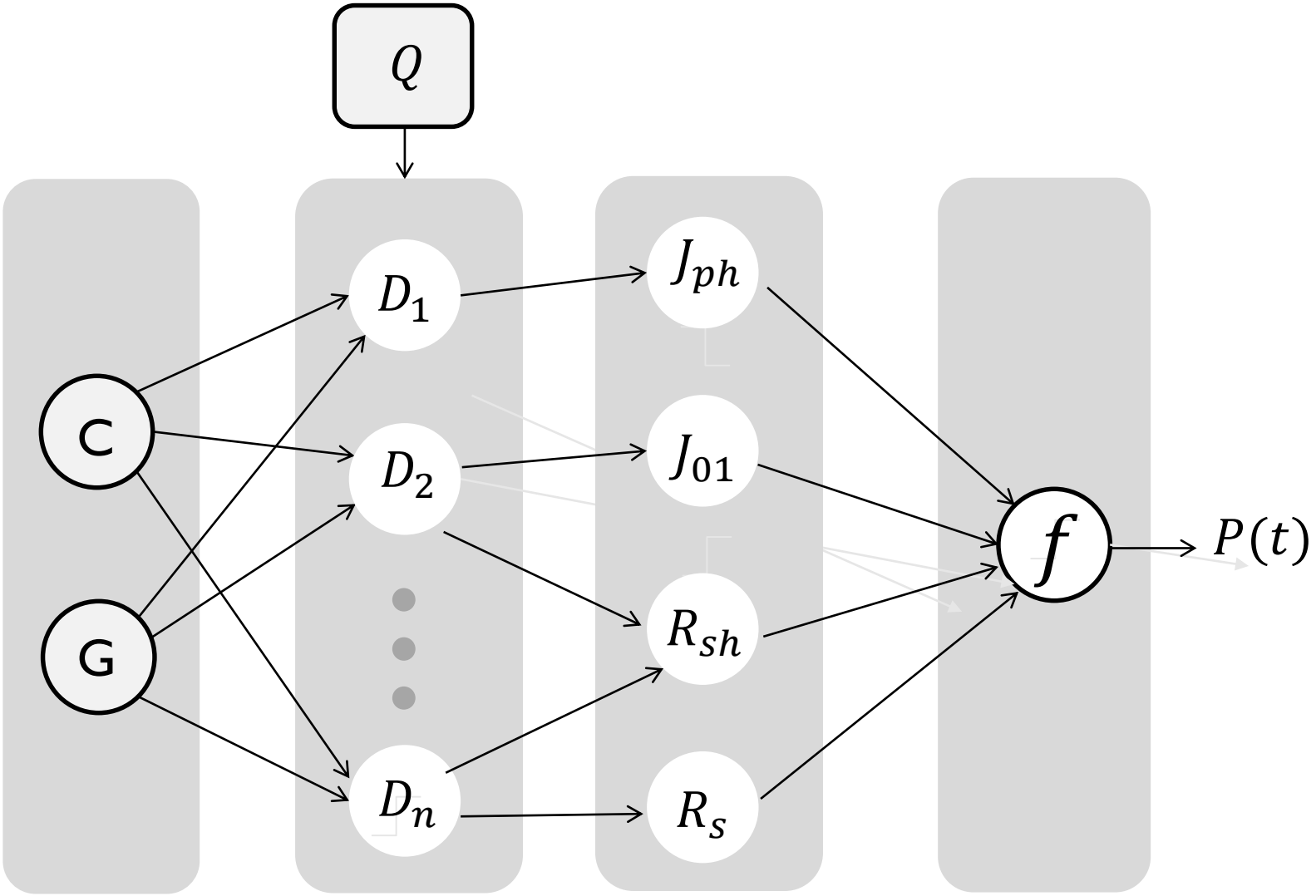




Additive power degradation model

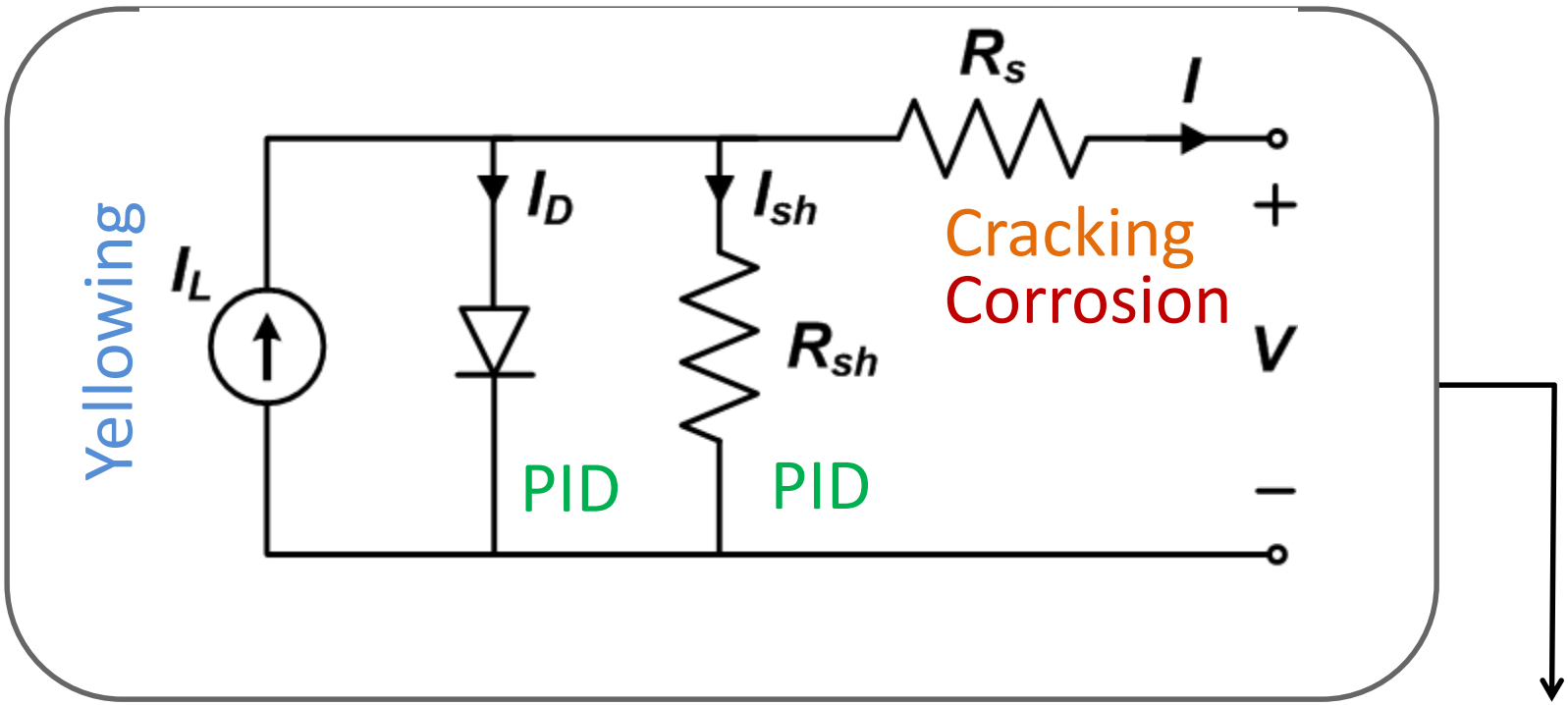


Compact model-based model



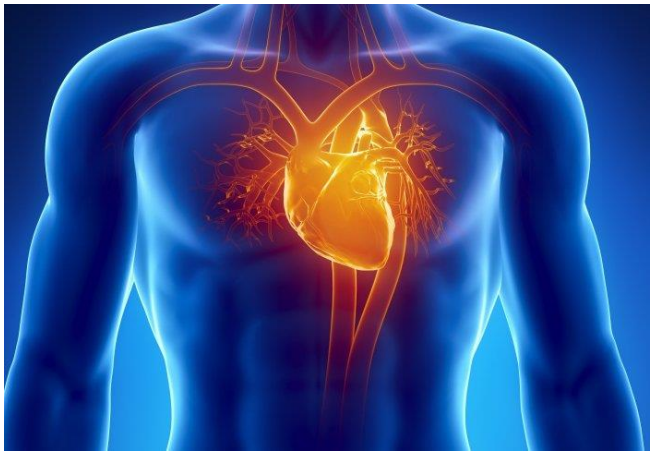
Compact model based approach

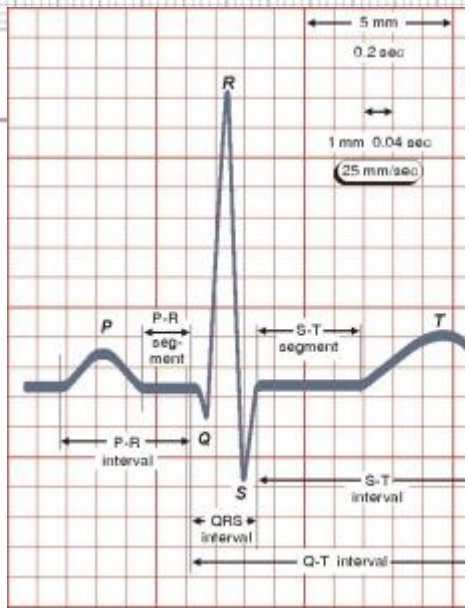
Weather & cell/module/farm configuration

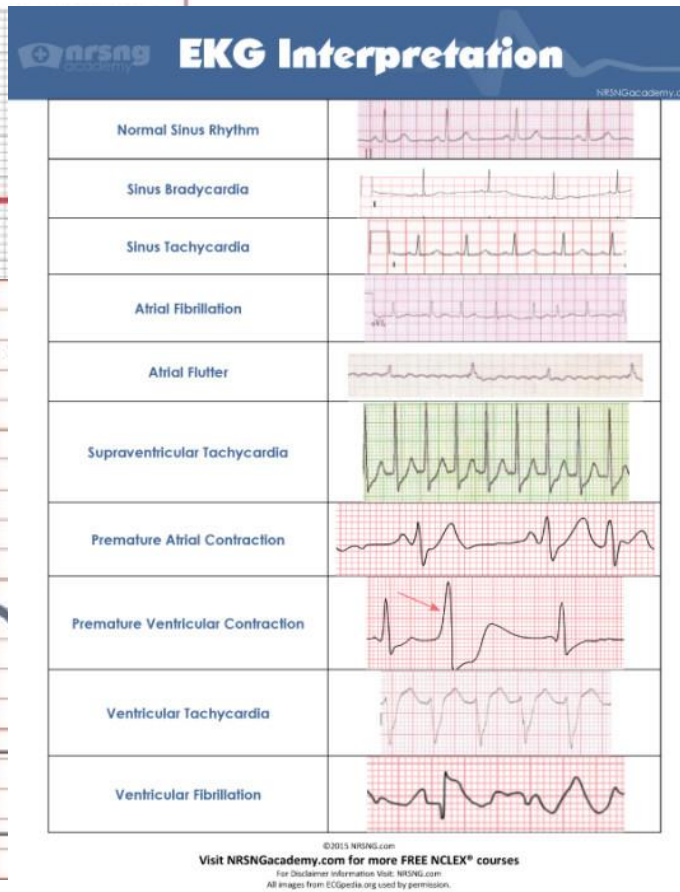


Time-dependent power output

Approach: An EKG for solar







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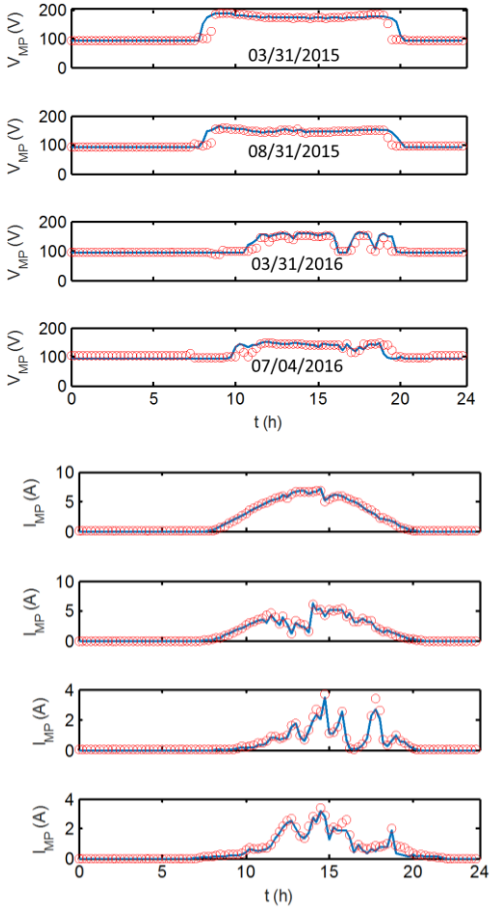
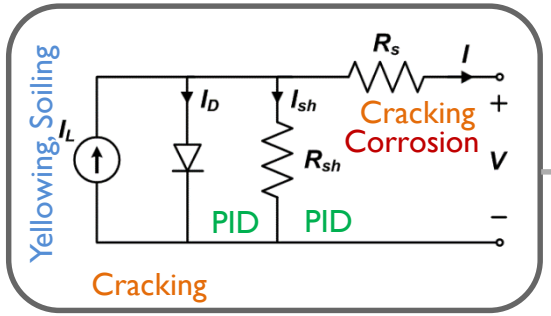
Approach: PV 'Heartbeat' Interpreted

- 24 Solar Panels installed at Purdue
- Archived field data every 15 mins for 3 years



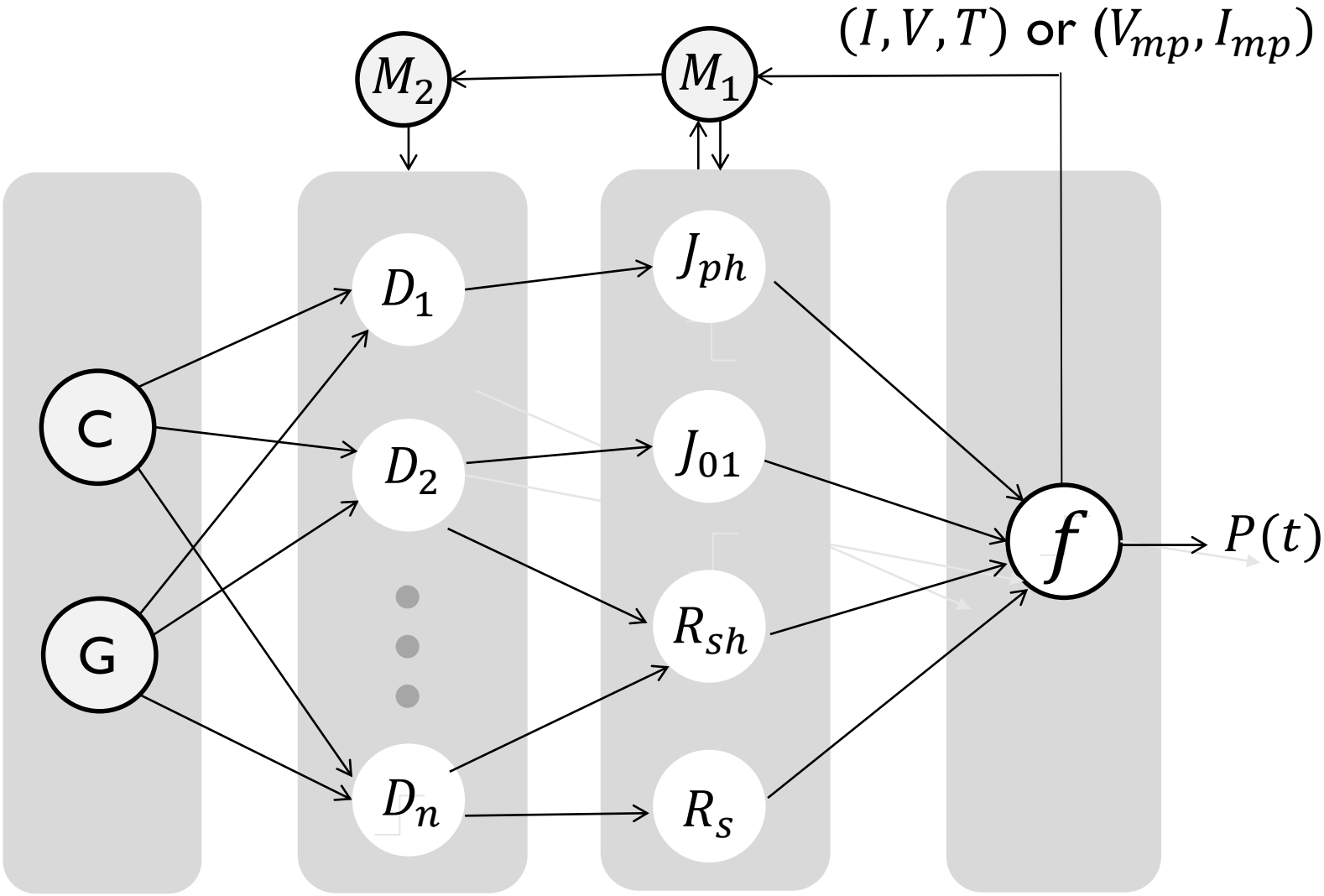
Temperature, RH, technology, module configuration



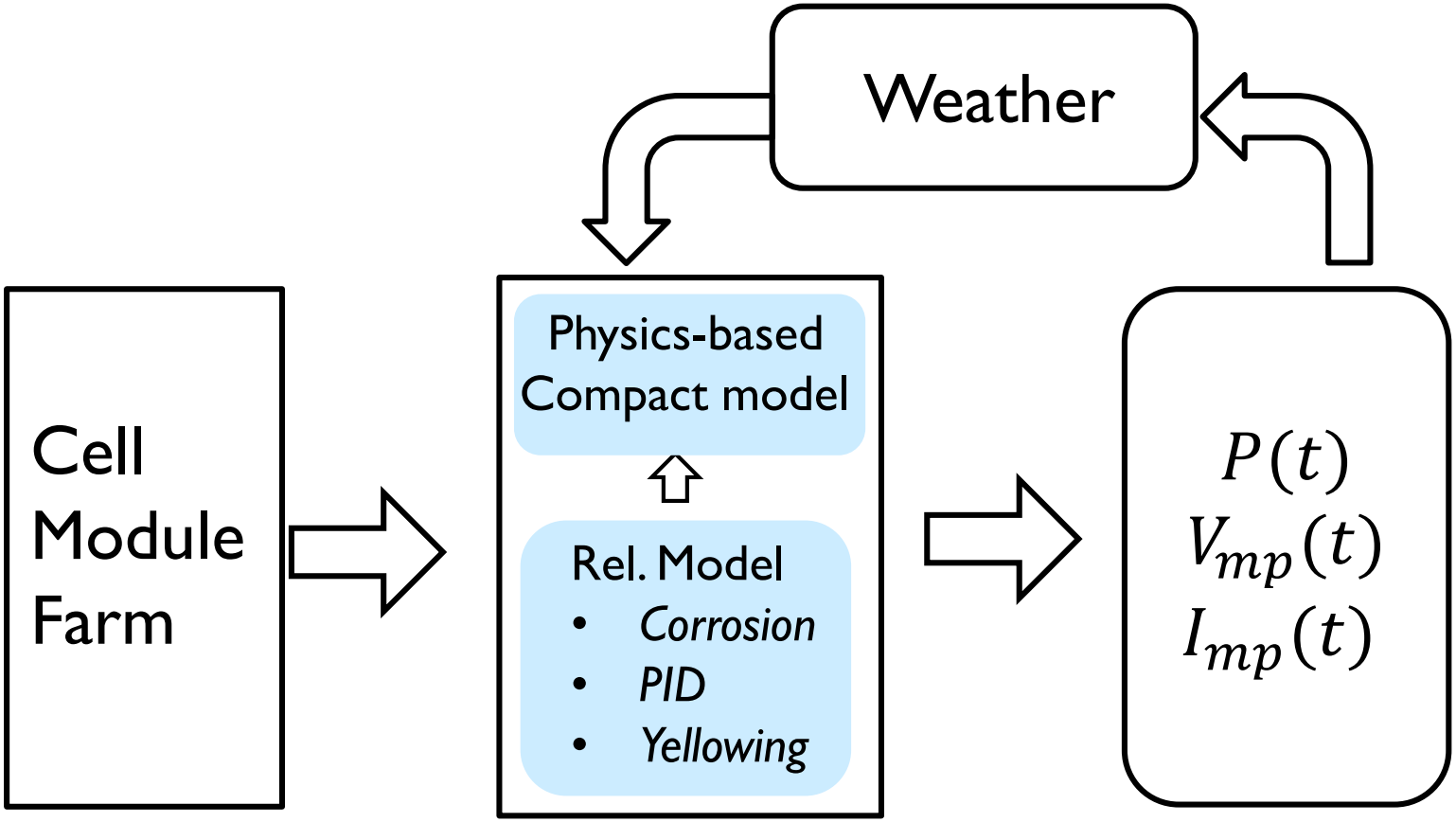
Time-dependent power output

Combining environmental and module data, we can match experiments

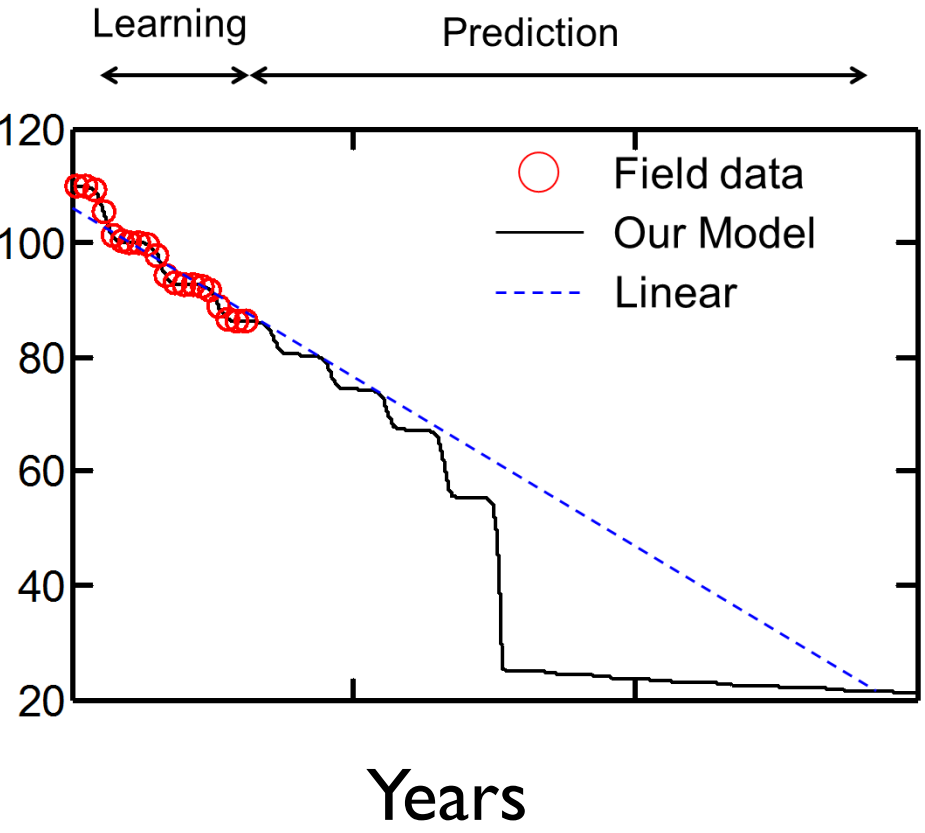
Physics-based machine learning approach

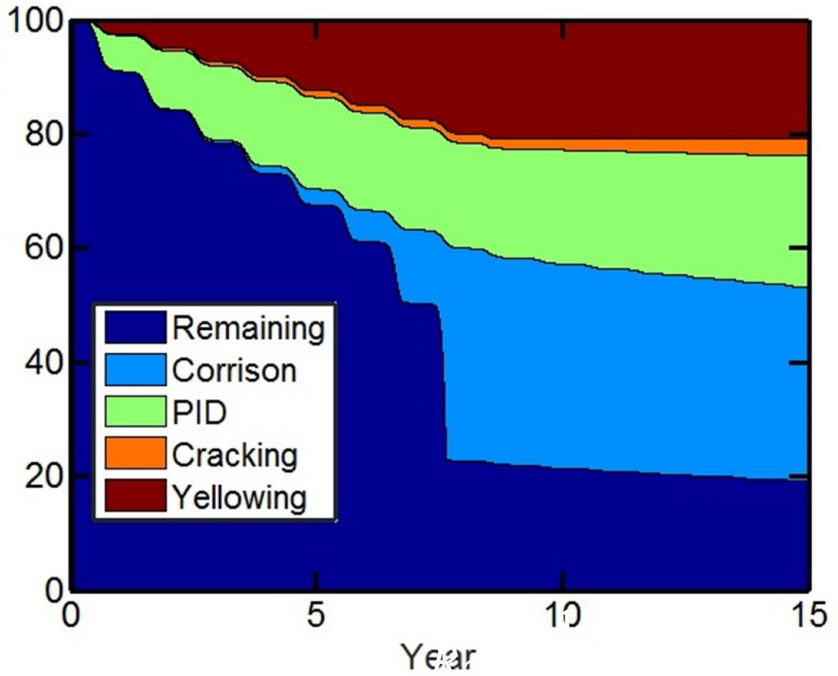


Physics-based lifetime prediction



Approach: Degradation deconvolution and lifetime prediction





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Conclusions

1) Reliability is a crucial element regarding economic viability of solar energy

2) The basic physics of each reliability mechanism can be described by simple physical models. The models are predictive.

3) A high quality qualification program is essential to ensure reliable field operation.

4) The field data contains a lot of information that can be used for lifetime prediction.

Self-assessment Quiz

1. How does moisture accelerate interfacial delamination. What is the difference between dark and light corrosion?
2. Among finger, busbar, and ribbon corrosion, which one has the highest effect of series resistance?
3. Name the degradation mode suppressed by Silicone.
4. Is it correct that UV degradation dramatically reduces the Fill-factor of a cell?
5. What type of temperature acceleration do you expect for yellowing.
6. Define the stress conditions associated with damp-heat test?
7. What is C-AST? What is the purpose of this qualification test?
8. What is the difference between empirical vs. model-based PV degradation models?
9. How does physics-based machine learning can interpret field-degradation data?