PSPICE: device non-uniformity modeling and other examples

Lecture 10

Special Topics:
Device Modeling

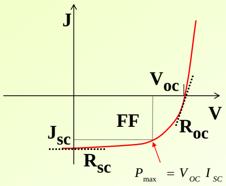
Outline

- PSpice for study of device non-uniformity
- Other applications
  - – Propagation of signal in PV cell
  - – FET system for cancer drug studies
- Hands-on session
  - – Editing PSPICE models
  - – Modeling mini-module example file

Introduction

- Semiconductor device modeling in 2-D and 3-D through equivalent circuits
- Applicable to modeling of any other problems involving electro-magnetic signals
- Basic approach: draw equivalent circuit, vary part models, parameters, etc.

PV device performance



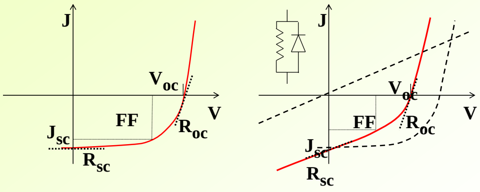
$P_{\max} = V_{OC} I_{SC} FF$

- V_{oc} is the open-circuit voltage
- I_{sc} is the short-circuit current
- *FF* is the fill factor
- $P_{\max}$ is the maximum power
- η is the efficiency

The input power for efficiency calculations is 1 kW/m^2 or 100 mW/cm^2

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

PV device performance



- Example of the shunt (R_{SC}=>0) effect on IV curve and major PV parameters

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Study of PV device non-uniformity

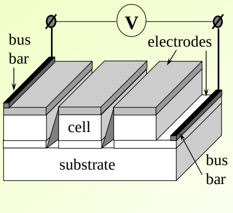
- Device is represented by equivalent circuits for 2D or 3D connections
- Applicable at a cell, cell-on-a-substrate, module, or PV field levels
- Device optimization, influence of component parameters, and various other phenomena can be studied

Study of PV device non-uniformity

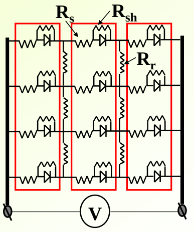
- Introduced distributions of PV parameters (Voc, Jsc, Rser, Rsh), both statistical and spatial
- Calculated resulting device efficiency dependent on changes in:
  - Module size and disorder amplitude
  - Series and interconnect resistances
  - Shunting-like phenomena

Diana Shvydka and V. G. Karpov, Power generation in random diode arrays, Phys. Rev. B 71, 2005, pp. 115314-1-5.
Diana Shvydka and V. G. Karpov, Modeling of nonuniformity losses in integrated large area solar cell modules, *Proc. 31st IEEE PVSC*, Florida, 2005, pp 359-362.

PV non-uniformity: Equivalent circuit for module

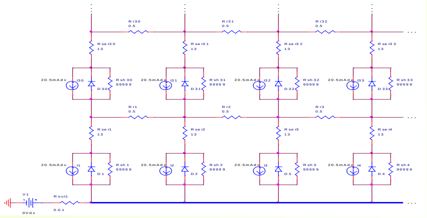


Integrated module –
3 linear cells in-series
through metallized scribes



Equivalent circuit
3 by 4 sub-cells, lump
parameters

PV non-uniformity: PSPICE Schematics



- Represents 2x1 ft module with 1 cm^2 cells
- 58 linear cells in series, 29 sub-cells in parallel, total 1682 sub-cells
- Parameters: Voc, Jsc, Rs, Rsh, Rr (one fluctuating)

PV non-uniformity: Procedure

1. Generate parameter distributions:
statistics – by first three moments (average, SD, and skewness γ);
geometry – assign values to sub-cells

2. Model J-V curve of non-uniform module, calculate relative efficiency:

$$\eta_{rel} = \eta_{non-unif} / \eta_{uniform}$$

or relative mismatch loss:

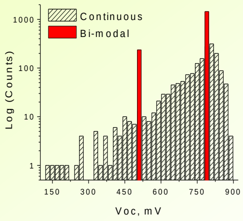
$$m = P_{non-unif} / P_{uniform}$$

3. Study dependence on module size, degree of disorder

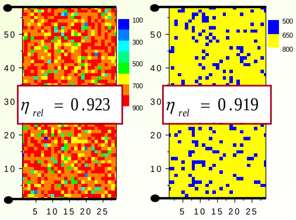
PV non-uniformity: Parameter distributions

Statistics

First three moments: <Voc>=755mV, SD=100mV, γ=-1.3

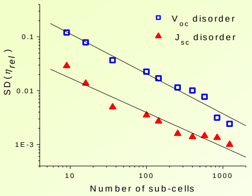


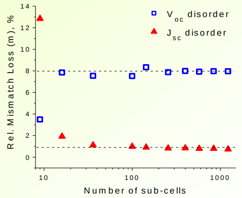
Geometry
(Voc maps)



Continuous Bi-modal

PV non-uniformity: Module size dependence





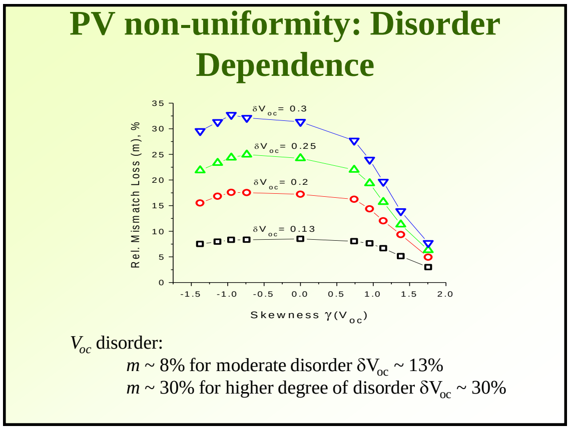
Scaling law:

$SD \propto N^{-\alpha}$

$\alpha_{Voc} \approx 0.74$

$\alpha_{Jsc} \approx 0.64$

- SD of relative efficiency changes by 2 orders
- Module size changes from 3x3 to 35x35 sub-cells
- For large module mismatch loss converges
- Each point obtained on 20 simulations

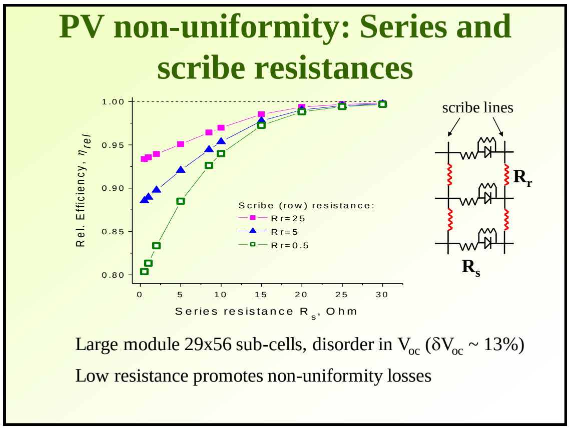


PV non-uniformity: Disorder Dependence

V_{oc} disorder:

m ~ 8% for moderate disorder δV_{oc} ~ 13%

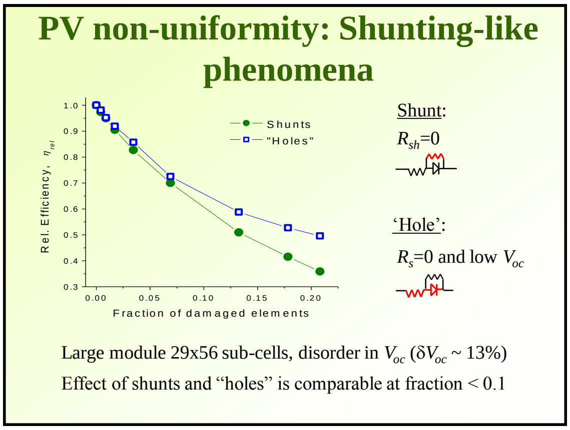
m ~ 30% for higher degree of disorder δV_{oc} ~ 30%



PV non-uniformity: Series and scribe resistances

Large module 29x56 sub-cells, disorder in V_{oc} (δV_{oc} ~ 13%)

Low resistance promotes non-uniformity losses



PV non-uniformity: Shunting-like phenomena

Shunt:

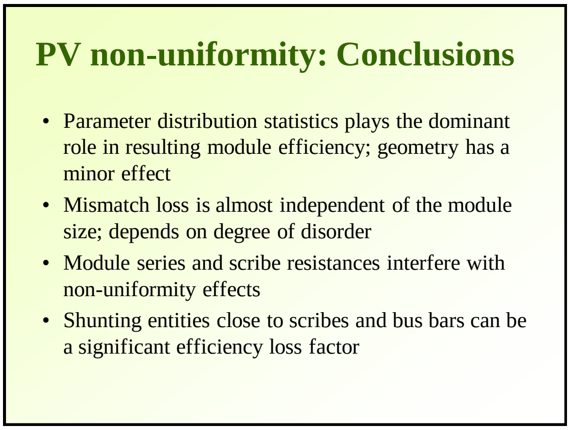
R_{sh}=0

'Hole':

R_s=0 and low V_{oc}

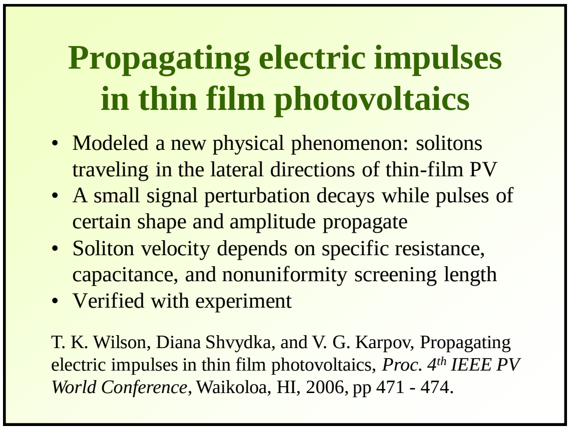
Large module 29x56 sub-cells, disorder in V_{oc} (δV_{oc} ~ 13%)

Effect of shunts and "holes" is comparable at fraction < 0.1



PV non-uniformity: Conclusions

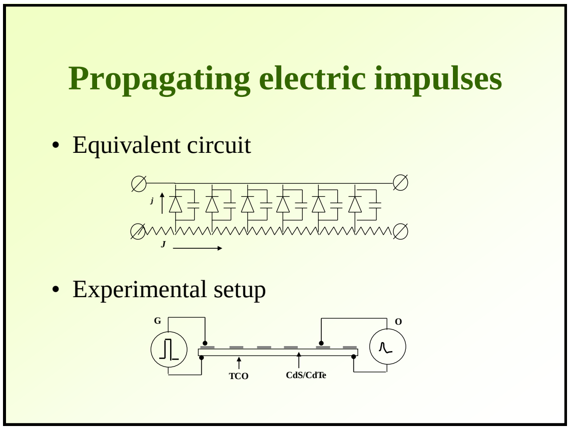
- Parameter distribution statistics plays the dominant role in resulting module efficiency; geometry has a minor effect
- Mismatch loss is almost independent of the module size; depends on degree of disorder
- Module series and scribe resistances interfere with non-uniformity effects
- Shunting entities close to scribes and bus bars can be a significant efficiency loss factor



Propagating electric impulses in thin film photovoltaics

- Modeled a new physical phenomenon: solitons traveling in the lateral directions of thin-film PV
- A small signal perturbation decays while pulses of certain shape and amplitude propagate
- Soliton velocity depends on specific resistance, capacitance, and nonuniformity screening length
- Verified with experiment

T. K. Wilson, Diana Shvydka, and V. G. Karpov, Propagating electric impulses in thin film photovoltaics, *Proc. 4th IEEE PV World Conference*, Waikoloa, HI, 2006, pp 471 - 474.



Propagating electric impulses

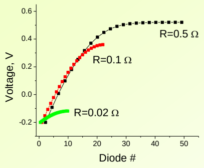
- Equivalent circuit

- Experimental setup

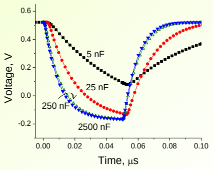
Propagating electric impulses: Parameters

- Considered circuits of 20 – 100 diodes with the parameters chosen to allow for pulse propagation trough the entire system
- Typical parameters: Voc = 520 mV, j0 =0.15-15mA, R=0.01 – 10 Ohm, C=5-2500 nF
- Rectangular pulses with varying amplitudes in the range of +/- 700 mV and durations 10-1000 ms

Propagating electric impulses: Edge effect



Voltage on different diodes rescaled according to y=(Diode #)/L with L inversely proportional to the lateral resistance R. Higher resistances show good scaling, since L is considerably shorter than the system dimension. For low R=0.05 Ohm, L becomes comparable to the system dimension thus violating the scaling



Pulse shape on a given diode for systems with different capacitors measured at different instances and scaled as Θ=t/τ. The scaling fails for small C when velocity v becomes large enough for the pulse to span across the entire system and experience edge effects

Propagating electric impulses

- The predicted phenomenon of soliton propagation could develop into a future non-destructive diagnostic technique sensitive to device imperfections
- Applicable to the problem of electric pulse propagation in living tissues, particularly, nerves (axon of a giant squid system)
  - Ion channels of biological membranes typically exhibit the diode-like IV characteristics

Impedance spectroscopy with field-effect transistor arrays for the analysis of anti-cancer drug action on individual cells

A. Susloparova, D. Koppenhofer, X.T. Vu, M. Weil, S. Ingebrandt

- Impedance spectroscopy measurements of silicon-based open-gate field-effect transistor (FET) devices were utilized to study the adhesion status of cancer cells at a single cell level
- A well-known chemotherapeutic drug, topotecan hydrochloride, was used to investigate the effect of this drug to tumor cells cultured on the FET devices
- Real-time impedance measurements were performed to verify the design

Analysis of anti-cancer drug action

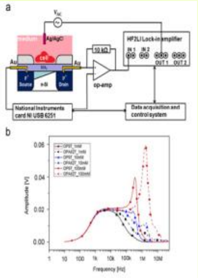


Fig. 1. (a) Experimental setup for cell measurements at higher frequencies (up to 50 MHz). (b) Comparison of measured impedance spectra using two different op-amps, namely the OP97 and OPA 627, in an electrolyte solution with different conductivity in the culture chamber of the FET chip.

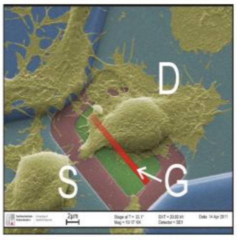
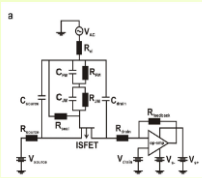


Fig. 2. Scanning Electron Microscopic image of a HEK293 cell, which is attached to an open-gate transistor structure. Source (*S*) and drain (*D*) contacts are indicated in the figure. The electrically sensitive part of the FET is marked (*G*) and in this case measures 16 × 1.5 μm².

Analysis of anti-cancer drug action



- The developed method could be applied for the analysis of the specificity and efficacy of novel anti-cancer drugs in cancer therapy research on a single cell level in parallelized measurements

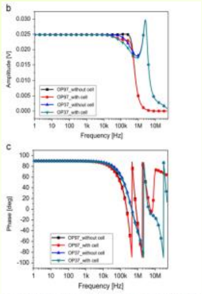


Fig. 6. (a) Equivalent electrical circuit for an adherent cell to an FET device. All elements of the circuit are explained in the text. Bode plot with (b) amplitude and (c) phase of the transfer functions simulated with PSpice for a FET device without and with a single cell on top of the gate.

Summary

- Semiconductor device modeling in 2-D and 3-D through equivalent circuits
- Basic approach: draw equivalent circuit, vary part models, parameters, etc.
- Applicable to modeling of any other problems involving electro-magnetic signals

References

- OrCAD Capture user manual
- OrCAD PSpice user manual
- Additional references are given within slides