Solar cells in radiation environments
Application of SPENVIS for solar cell performance prediction

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Contents

• Are radiation studies a worthwhile investment?

• Improving the cost effectiveness of radiation prediction
  – JPL ‘Equivalent fluence model’ (EQFLUX in SPENVIS)
    – many organisations and companies in Europe and elsewhere use this method via SPENVIS
    – it has worked well historically and is available to the whole community
    – Requires lots of reference data for every new cell type
  – NRL Displacement damage dose concept
    – A potential alternative to EQFLUX that requires less test data
    – see presentation by Scott Messenger
  – Theoretical model based on introduction of recombination centers in the solar cell
    – A theoretical model, hence potentially several possible applications inside or outside SPENVIS
    – see presentation by Jacques Bourgoin
Motivation - Economics for a 10kW Solar Array

• **Relative Costs (rough numbers...)**
  • Cost to launch a 10kW solar array based on *mass only*
    – Say €4M (@ €30k/kg)
    – Note that mass is not necessarily critical if the mass of the satellite is compatible with the capacity of a designated launcher, but this is anyway a useful number…
  • Cost of a 5% power margin based on only this number
    – Around €200k
  • Cost of a radiation campaign on a new cell design
    – Potentially several €100k (cost of samples, radiation, measurements…)
    – *This is equivalent to the profit on sales of a lot of solar cells…. !*
    – *Cost of qualification is significant, but still a good investment*

• **Conclusions**
  • *Extra power margin is very expensive !*
  • We would like to reduce the cost of ground testing, but **NOT** at the expense of the accuracy of power prediction
  • A radiation study costing up to several €100k which improves ‘end of life’ power prediction is likely to pay for itself very quickly…. 
Radiation damage to solar cells

- Most solar cell degradation in space is mostly caused by displacement damage
- Atomic displacement introduces ‘recombination centers’ which reduce the probability that an electron will contribute to the solar cell current
- Space solar cells are protected by a coverglass to reduce the radiation dose (mostly by slowing down the whole proton spectrum and cutting out low energy protons)
- For this reason, we tend to perform ground tests on unprotected solar cells with protons and electrons in the range 0.1MeV to 10MeV
Implementation in SPENVIS (using EQFLUX)

SPENVIS is an efficient forum for a new model within the solar power community!

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See also development of NIEL model in MULASSIS.
JPL Equivalent Fluence Method

*Improvement of any step makes a difference to the end result...*

- Measure PV Degradation Curves (~4 electron and ~8 proton energies)
- Determine Damage Coefficients for Uncovered Cells
- Calculate Damage Coefficients for Isotropic Particles w/ Coverglasses of Varied Thickness
- Calculate Equivalent 1 MeV Electron Fluence for Orbit (EQGAFLUX)
- Compare with telemetry data for array power vs measured radiation

*From S.R. Messenger et al, Progress in Photovoltaics 9, 103 (2001)*
• How can we make ‘end of life’ performance prediction more cost effective?
  – Improve knowledge of the environment
  – Understand and model the interactions between the environment and the device
  – Acquire appropriate ground test data
  – Compare predictions with in-flight data from solar arrays and radiation monitors
Establishment of Relative Damage Coefficients

\[ \frac{P}{P_0} = 1 - A \log(1 + \Phi/B) \]: See presentation by Jacques Bourgoin

We define an ‘equivalent fluence’ for a mission

- From S.R. Messenger et al, Progress in Photovoltaics 9, 103 (2001)
JPL Equivalent Fluence Method

From S.R. Messenger et al, Progress in Photovoltaics 9, 103 (2001)
Difficulties with application to Multi-Junction Cells – Example 1.

AR coating | GaInP | GaAs | Ge

50keV protons stop in the top cell

50keV RDC is correct only IF top cell is current limiting
JPL Equivalent Fluence Method

- Measure PV Degradation Curves (~4 electron and ~8 proton energies)
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- Calculate Damage Coefficients for Isotropic Particles w/ Coverglasses of Varied Thickness
- Calculate Equivalent 1 MeV Electron Fluence for Orbit (EQGAFLUX)
- Determine Incident Particle Spectrum (e.g. AP8)
- Read Off EOL Values

*From S.R. Messenger et al, Progress in Photovoltaics 9, 103 (2001)*
Establishment of Relative Damage Coefficients

RDC’s are defined for a given remaining factor.

All curves need to be parallel to give accurate results.

Care needs to be taken for:

1. Triple-junction cells
2. Low energy protons

From S.R. Messenger et al, Progress in Photovoltaics 9, 103 (2001)
Array level considerations

• Cells are electrically connected in series strings
  – How uniform is cell degradation and how does this affect the string performance?

• Array level testing – calibration uncertainties
• How accurate are corrections for albedo, temperature, incidence angle etc?
• How do we combine all this information in a model of the power system?
• What telemetry data is available?

• There are few available published comparisons between cell, ground level array testing and flight data for triple junction cells
NRL Displacement Damage Dose Method

Potentially similar accuracy to EQFLUX from less ground test data

Calculate Nonionizing Energy Loss (NIEL) (Energy Dependence of Damage Coefficients)

Measure Characteristic Degradation Curve vs. $D_d$ ($D_d=NIEL\times\text{Fluence}$) (2 $e^-$ and 1 $p^+$ energy)

Determine Incident Particle Spectrum (e.g. AP8)

Calculate Slowed-Down Spectrum (SDS) (Shielding)

Calculate $D_d$ for Mission (Integrate SDS with NIEL)

Read Off EOL Value

From S.R. Messenger et al, Progress in Photovoltaics 9, 103 (2001)
Fundamental Model – may be complementary to EQFLUX?

- Nature and properties of the recombination centres
- Geometry of the cell
- Nature of the electron and proton spectra

Experimental 1 MeV electron degradation curve

Calculation of the Equivalent 1 MeV electron fluence

Calculate RDCs?

Read EOL Value

Calculation is from first principles for any structure – hence potentially a predictive design tool
Preliminary results generated using ‘MATHCAD’ implementation

From N. de Angelis et al., Proc. IEEE PV specialists conf., 2005
Requirements for solar cell models in SPENVIS

• EQFLUX is the ‘default’ reference
  – *We need to show that any new model can achieve at least an equivalent level of accuracy to EQFLUX*
  – *We need to update the solar cell databases in EQFLUX both to use it accurately and to facilitate comparison*

• Comparison with EQFLUX must be easy

• Validation is a critical step but published flight data for multi-junction cells is scarce

• Making SPENVIS an efficient forum for these models helps to facilitate validation / comparison and reduce duplication of effort within the community
What to discuss at this workshop?

- What does the community want from SPENVIS for solar array calculations?
  - Updated RDC’s for new cells?
  - Implementation of NIEL based model?
  - This will help us to focus resources effectively
- How to validate a new model?
- How to apply a fundamental model?
  - Calculate and upload RDC’s into EQFLUX?
  - A design tool complementary to EQFLUX or a completely new application?
  - How to deal with confidentiality issues concerning cell structure?