# MONO-CRYSTALLINE SILICON SOLAR CELL DEGRADATION ANALYSIS


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University of Fort Hare
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# Outline

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# Background



- P-N junctions are the basic unit of photovoltaic (PV) solar cell, a good understanding of its structure is required to interpret solar cell breakdown mechanism.
- Most of the breakdown mechanism that occurs at room temperature are not destructive, provided there is heat sinking procedure.
- The joining of P and N type Si material establishes equilibrium state by electron holes filling, hence both side is depleted.
- The charge carrier generation depends on the nature of the p-Si layer of the solar cell, but carrier collection occurs at the n-type layer of the solar cell.
- The combination of electron and hole at the p-n junction result to the formation of recombination centre.
- Degradation usually results to morphological change of PV material.

# Aim and Objectives

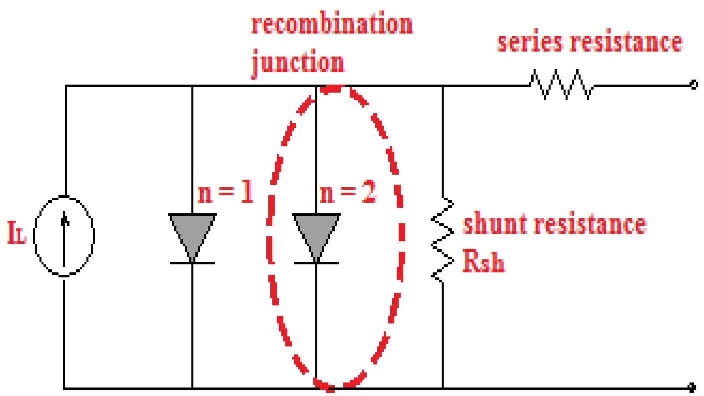


**Aim**

- To investigate the electrical and structural property of intentionally induced degradation in monocrystalline silicon solar cell.

- **Objectives**
- Determine the degradation effect of the induced defect on mono-Si solar cell.
- Potentially Induced degradation on mono-Si through reverse bias.
- Schematically remove predetermine layers through ion milling.
- Determine the electrical properties of degraded mono-Si cell.

# Equivalent circuit model




Double exponential equivalent model of PV

$I_{o,1}$ = the Reverse saturation current representing the diffusion and recombination of electrons and holes at the p- and n- interface

$I_{o,2}$ =The reverse saturation current which represents the generation and recombination of electrons and holes at the depletion region.

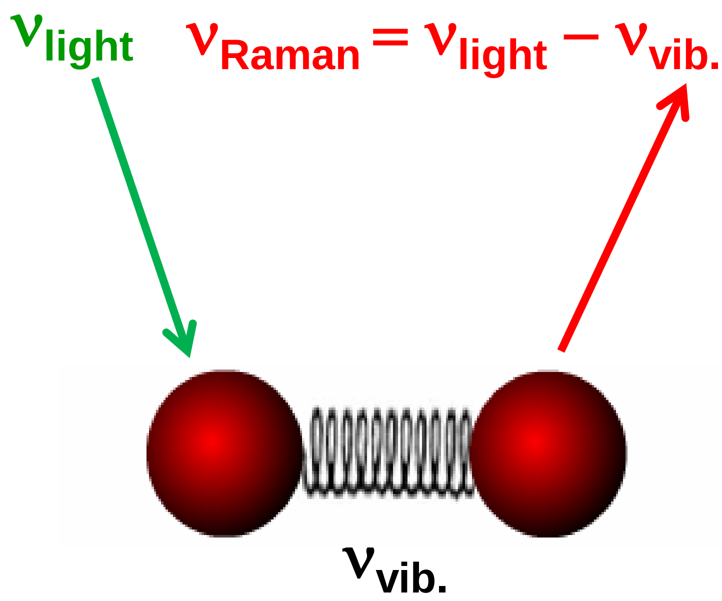
n = Ideality factor, V = The applied voltage

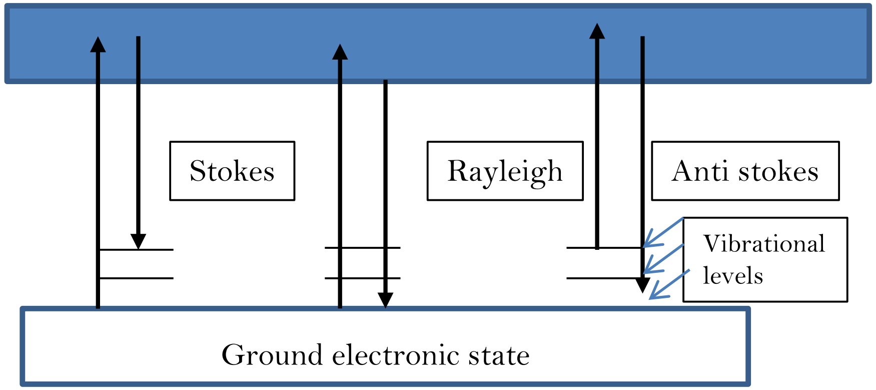
kT/q = The thermal voltage

$$I = I_{o,1}\left[\exp\left(\frac{V - R_S I}{nKT/q}\right) - 1\right] + I_{o,2}\left[\exp\left(\frac{V - R_S I}{2nKT/q}\right) - 1\right] + \left(\frac{V - R_s I}{R_{Sh}}\right)$$

**Raman effect: (electron cloud & bonds)**

- **non-resonant** excitation (Stokes) of vibrational quantum states
- energy shift between the exciting and scattered photon is characteristic for the molecules involved in the scattering process.
- The incident laser photon helps to activate (excite) the ground state molecule, and after relaxation, the excited molecule falls to another energy level (new energy state) which is different quantitatively from the virtual energy state.
- Hence photon is emitted and the molecule returns through a different rotational or vibrational state to its new energy state (interstitial energy state).

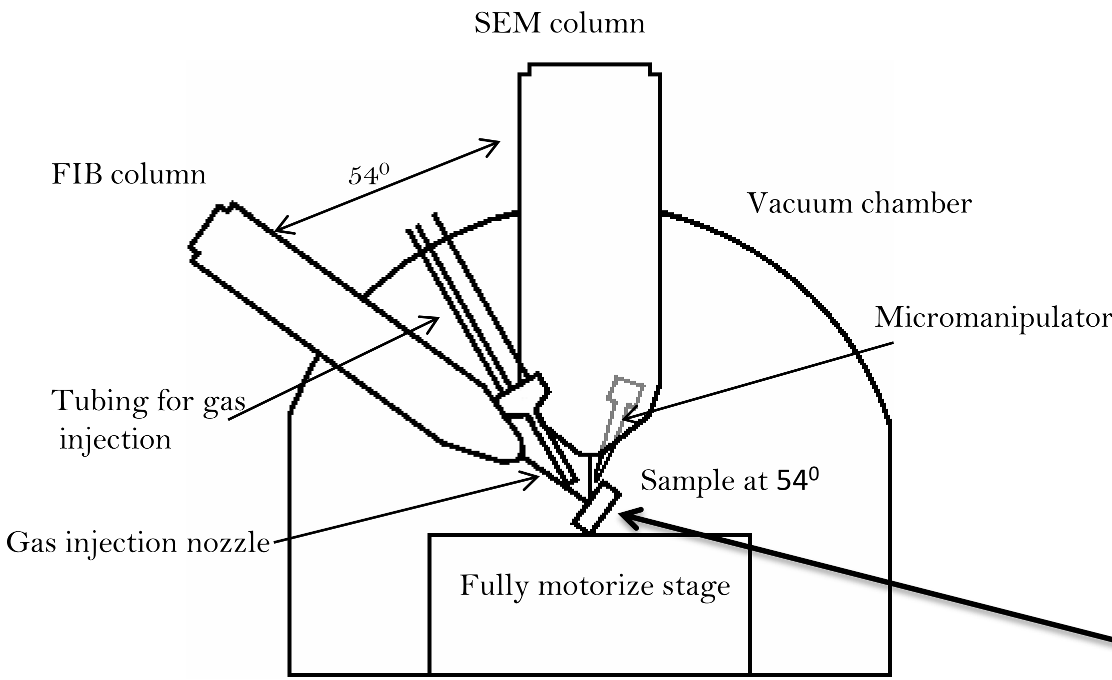


Infrared absorption

# Method:
# FIB Milling



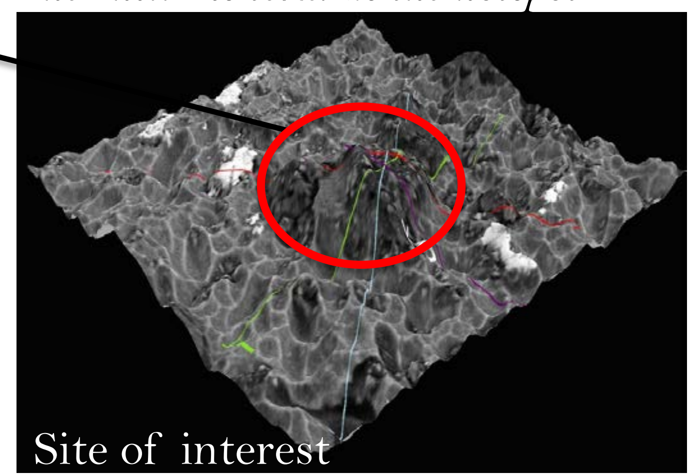



Ga$^+$ source
Liquid metal ion source (LMIS)

Why Ga$^+$

- Narrow energy distribution.
- Melting point at 30 $^0$C (liquid around room temperature).
- Inert at both high and room temperature.

*The "hill" is term as the hotspot*




- Identify site of interest
- Deposit protective carbon layer
- Mill trenches with high current
- Reduce milling current as sample get thinner

# Results:
# LAS and Depth profiling

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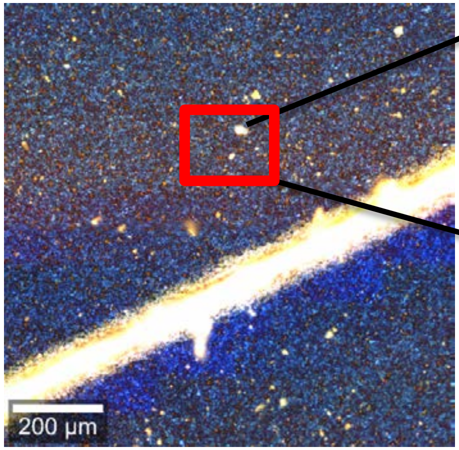
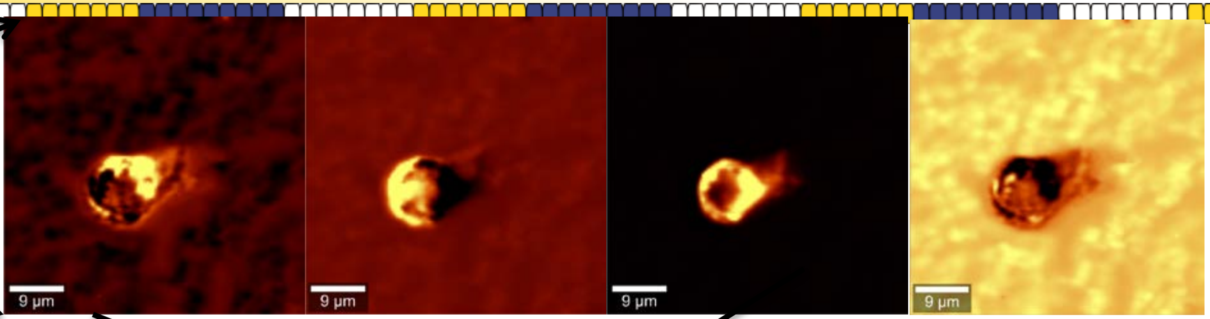
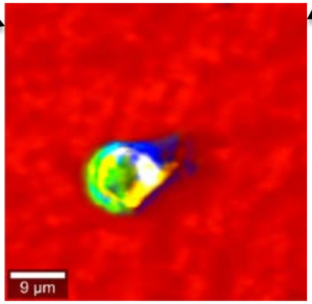
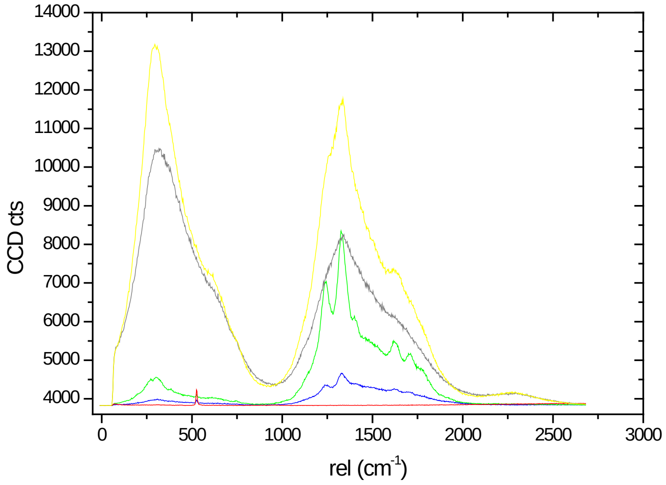


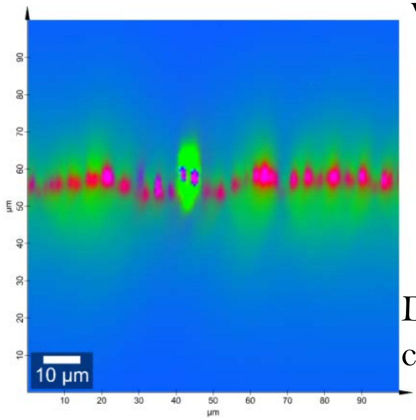




The Raman band in the range of 120-350cm-1, corresponds to coherent vibration of carbon atoms in the direction of the defect cluster.




The spectra, reveals a second order peak excitation of wavelength 1210 cm-1.




Depth profile of the defected cluster region.

# Stress analysis (FWHM)

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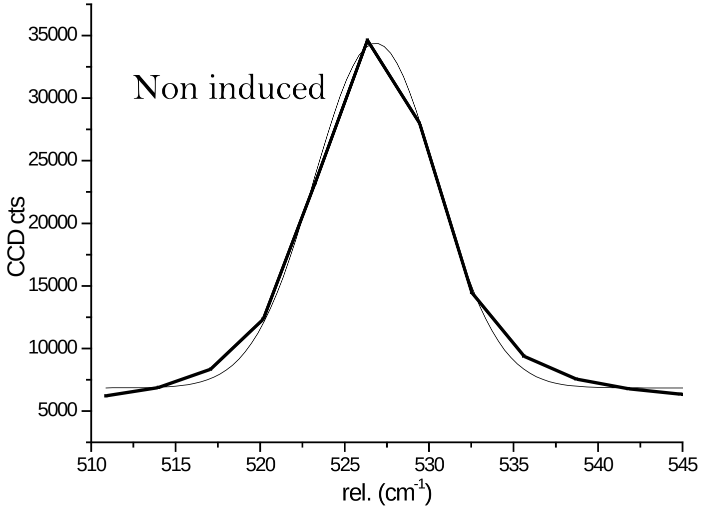
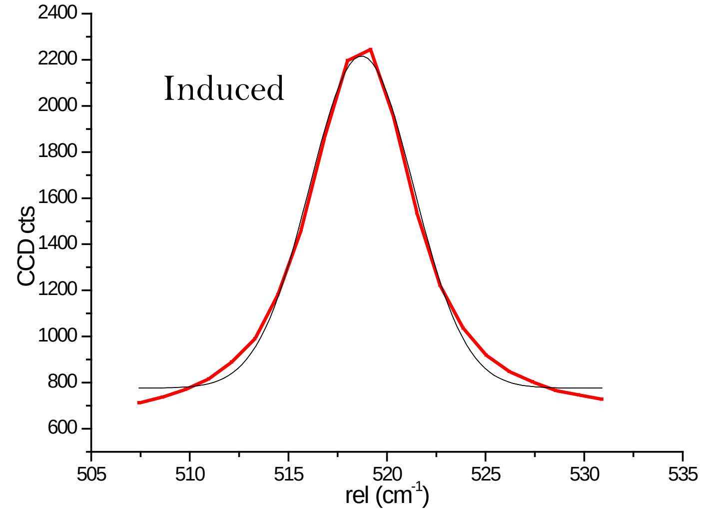
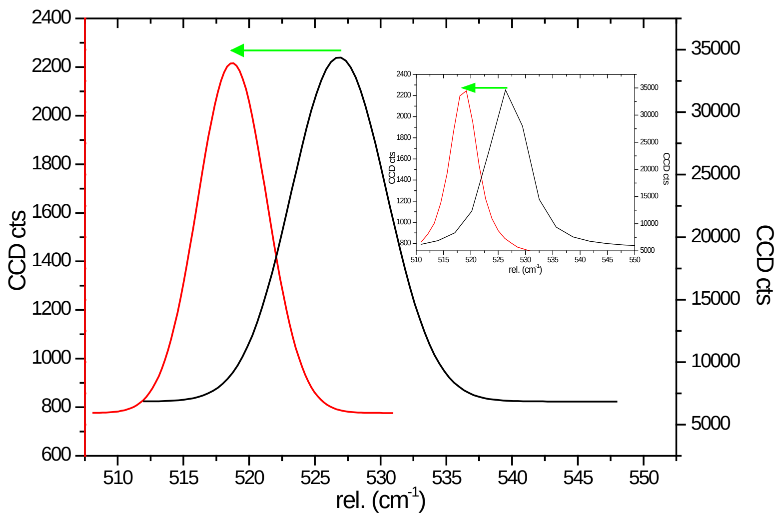


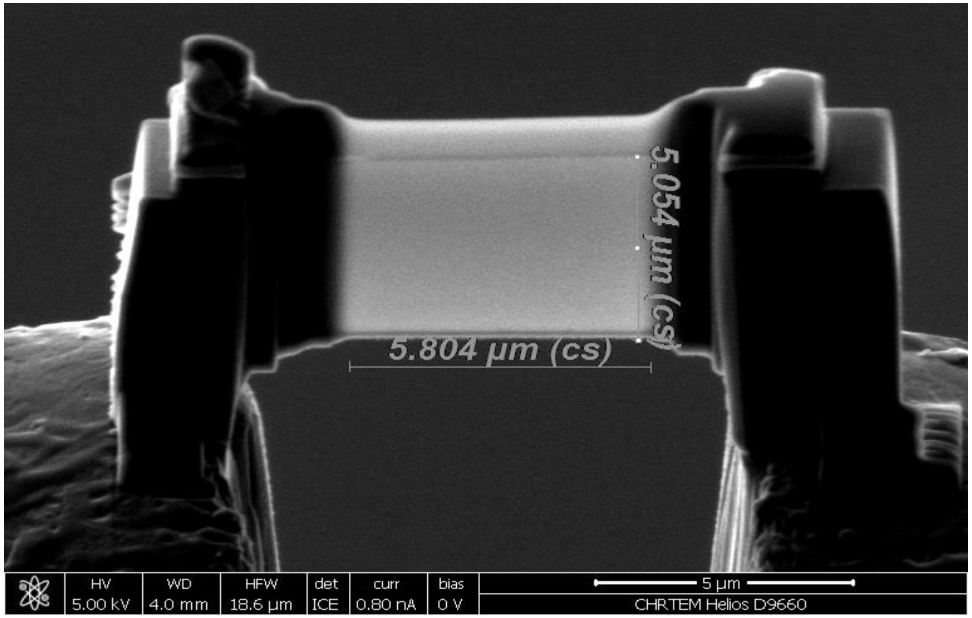




| | Non affected region | Affected region | % change |
|---|---|---|---|
| Si peak | 526.8365 | 518.71753 | – |
| Si shift | - | 8.1189 | 1.54 |
| FWHM:R | 1 | 7 | 85 |
| Intensity | 27549 | 1513 | |

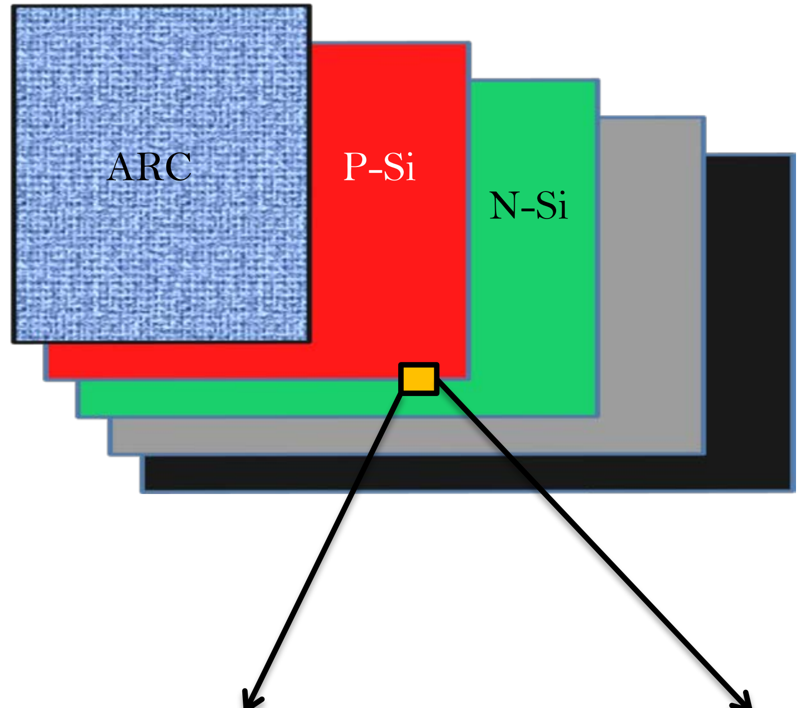
These images show variations in the intensity of Si signal as well as a decrease in the Si intensity in spot high defect density.

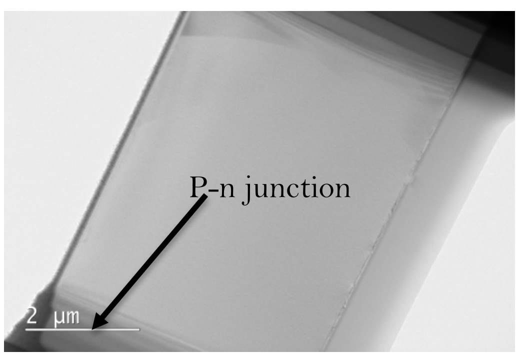
# FIB Milling





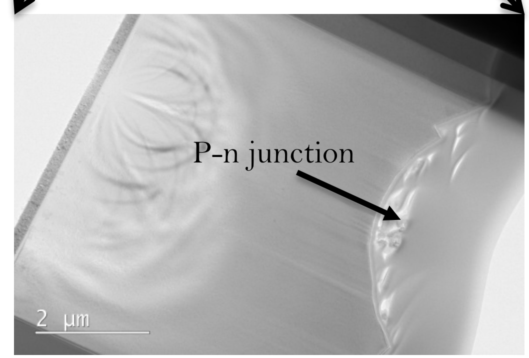

5 micron deep x 6 microns wide, 187micron thick



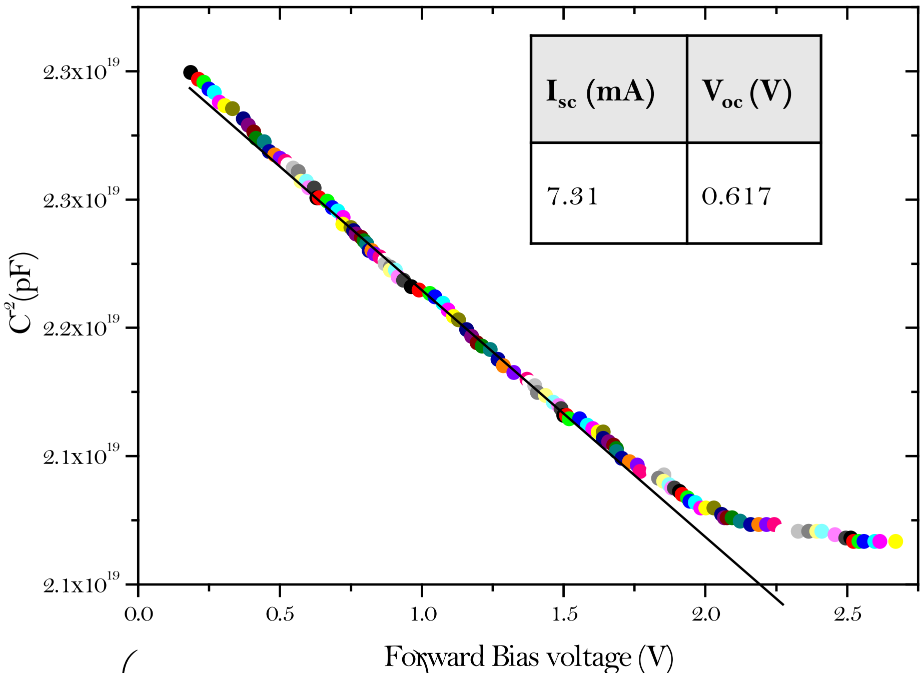



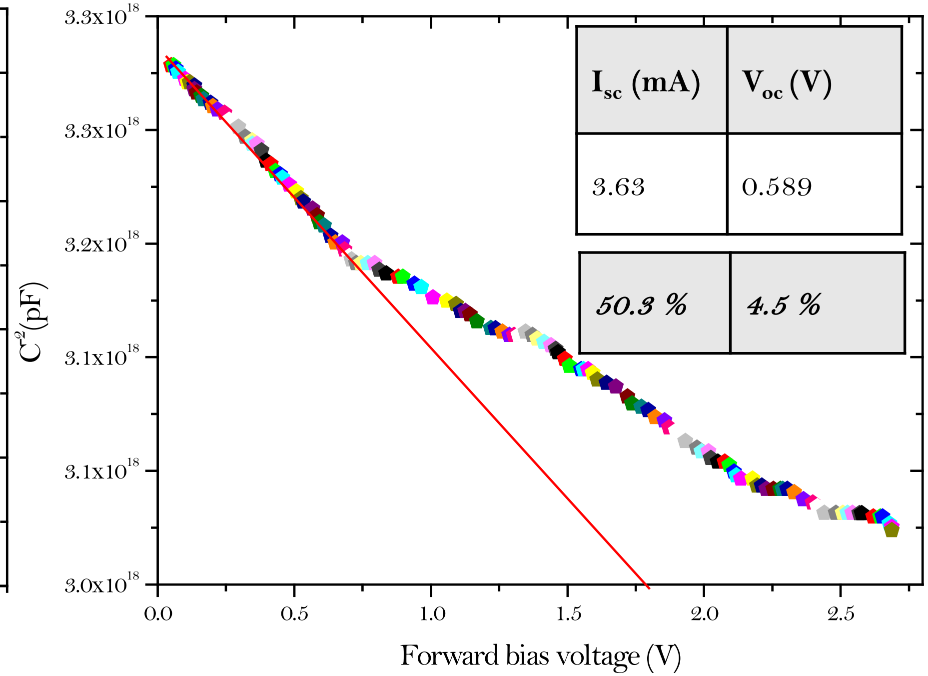

By systematic removal of layers of pre-determined thickness a distortion around the p-n structure was observed for the induced cell within the defective regions.

This results show catastrophic changes in both the morphology and crystallography of the cell.



# C-V measurements




$$N = -\left( \frac{2}{\left( q\varepsilon_s A^2 \frac{d(1/C^2)}{dV_{DC}} \right)} \right)$$

N = A(2/Q/ES/A² /DIFF(INV_C2, DCV_AC))

$N = 96.532 \times 10^{9}\ (cm^{-3})$

$N = 16.024 \times 10^{8}\ (cm^{-3})$

The built in potential across PN junction rises as carrier concentration increases.

$$|E_{bi}| = \frac{4\times10^5}{1-\frac{1}{3}\log(N/10^{16})}$$

$E = 1.2 \times 10^{6}$ V/cm

$E = 1.9 \times 10^{5}$ V/cm

The electric field set up by the space charge prevents further holes filling by electrons, hence increased carrier concentration.

# Conclusions



- Investigations show that induced degradation causes destructive changes on the topography, crystallography and as well as distortion on the p-n junction.

- For a degraded p-n junction, breakdown can occur at much lower temperature according to the empirical equation for electric field at breakdown.

- Results show low carrier concentration on the p-Si for the induced cell due to electron holes filling.

- The degradation experienced by the induced cell resulted to a decrease in the built–in voltage.

# Acknowledgements

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