



The Solar Cells and Photodiodes Capacitance

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Abstract

- Integrating photodiodes and solar cells in one system can enable the usage of solar cells as a source for powering the photodiodes in an APS active pixel image sensor. The solar cell and photodiode capacitances are one of the most important parameters for designing this system.
- The time domain technique at low frequency is used to measure the solar cells and photodiodes capacitance. The measurements have been carried out on a-Si:H p-i-n cells under forward and reverse bias voltages, in dark and under blue LED light illumination. It is observed, that the deep defect states of i-layer contribute to the capacitance at various bias voltages. Also, the capacitance achieves the upper limit around the built-in potential.
- The proposed method can be used for further development of solar cell and photodiode integrated systems and various sensors.
- **Keywords:** solar cells, photodiode, capacitance, CV time domain technique

Outline

I. INTRODUCTION

- Integrating SC and PD in APS and PV
- achieving good PD capacity and complete charge transfer , with reduced operating voltages and smaller pixel size; decreasing charge transfer times.

II. EXPERIMENTAL DETAILS – fabrication, CV measurements -**The time domain technique at low frequency**

- PD/SC a-Si:H p-i-n voltage pulse response under dark and blue light illumination

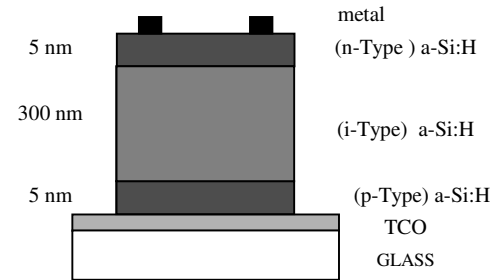
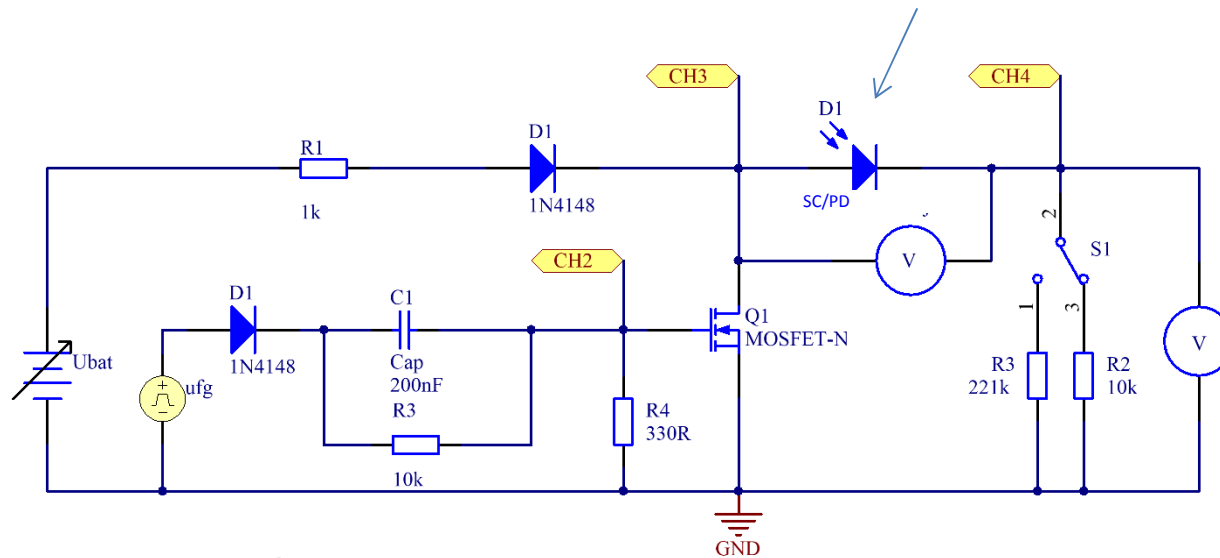
III. RESULTS

- PD/SC I-V characteristic, voltage pulse response under dark and blue light illumination
- a-Si:H p-i-n ideality factor, activation energy, capacitance, charge

IV. CONCLUSIONS

The time domain technique at low frequency

LED $\lambda = 455 \text{ nm}$, $I_{\text{LED}} = 20 \text{ mA}$
 $f = 333 \text{ Hz}$



The capacitance measurement set-up

R.A. Kumar et al. [doi: 10.1063/1.1582391]

- Total charge stored in nonlinear capacitor

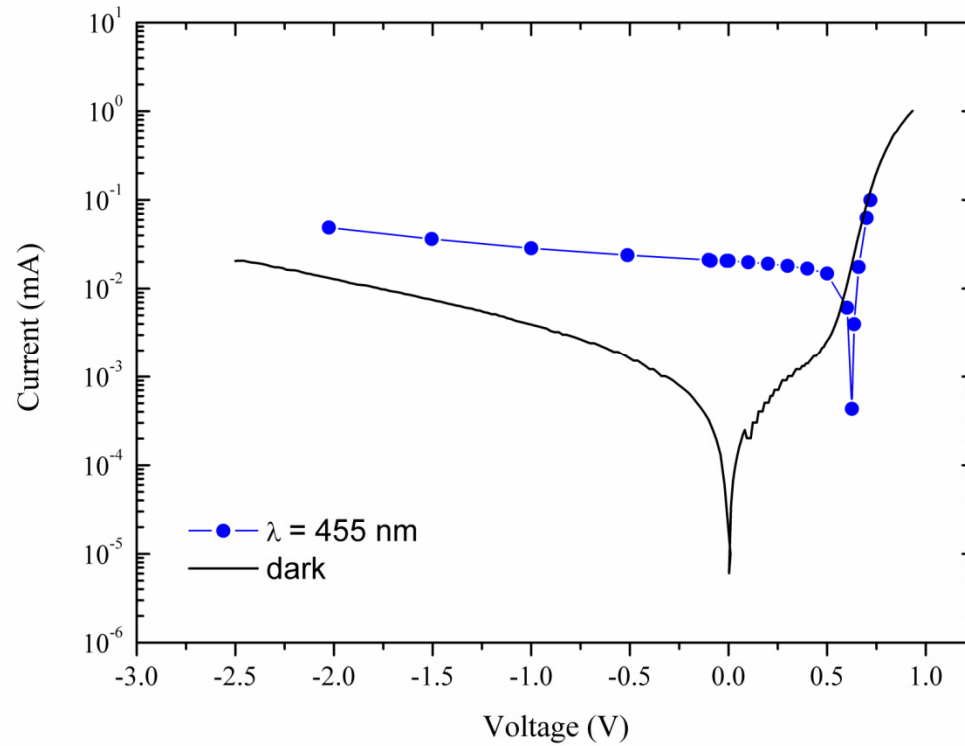
$$Q = \int_0^V C dv$$

- The current due to stored charge is

$$i = \frac{dQ}{dt}$$

The total charge [D.S.Shen and S. Wagner doi: 10.1063/1.360827]

$$Q = Q_0 \left[\frac{(\mu\tau)V_R}{L^2} \right] \left(1 - e^{-\frac{L^2}{(\mu\tau)V_R}} \right)$$

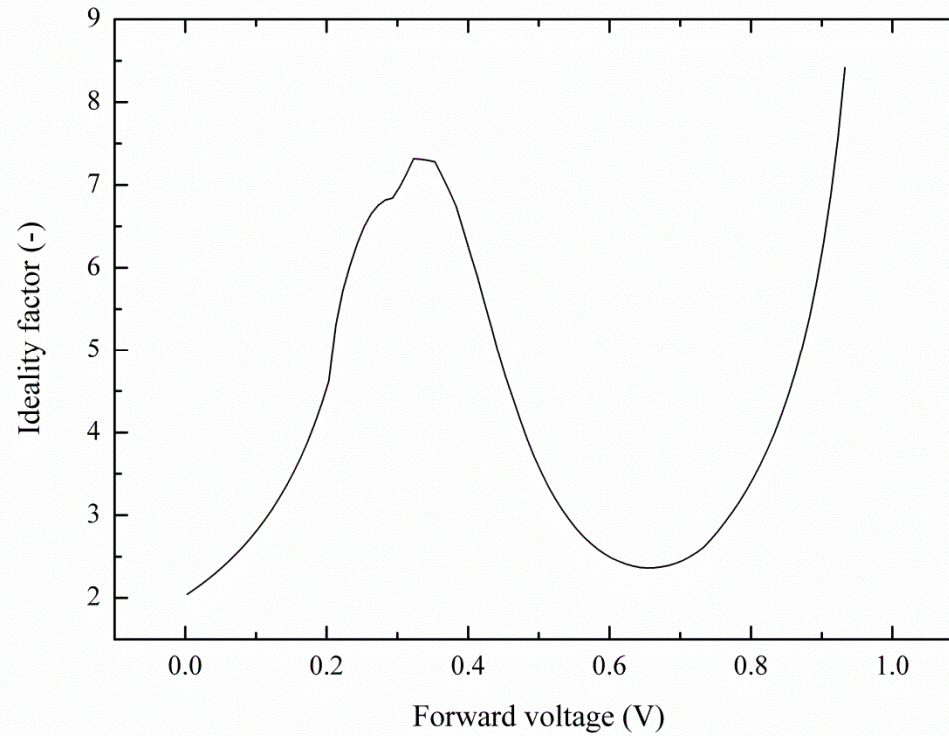


a-Si:H solar cell and photodiode I-V characteristics

The cell current–voltage, I-V, characteristics measured under the dark and blue LED light illumination, $\lambda = 455$ nm condition.

Reverse dark current model is [doi: 10.1016/j.jnoncrysol.2008.03.041]

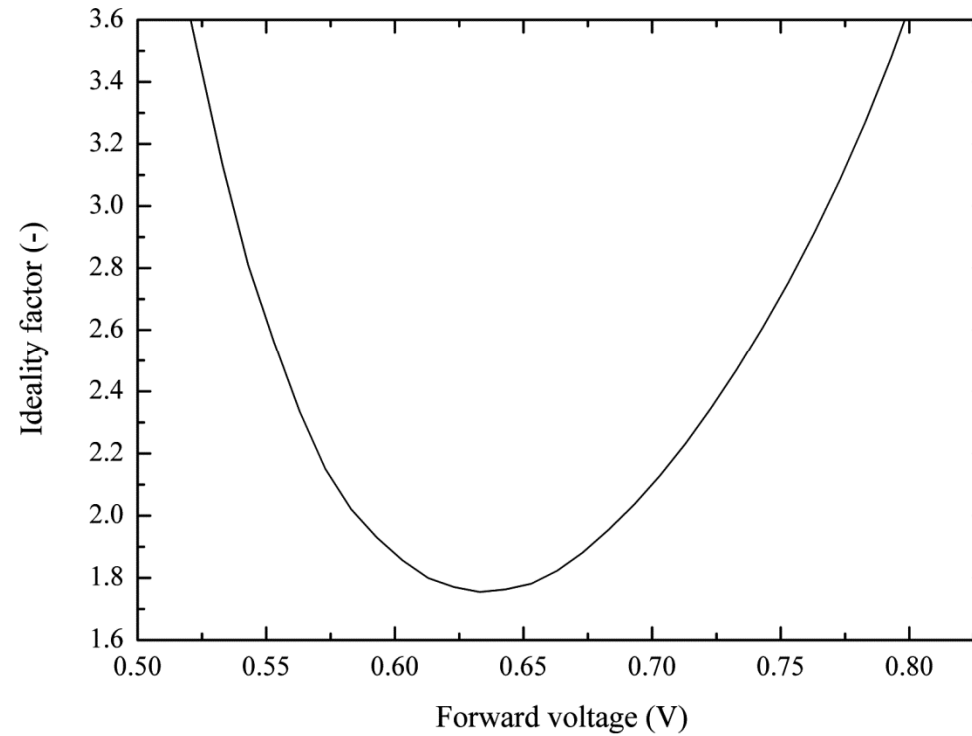
$$J_{th} = k_{th0} |V_R|^{\frac{1}{2}} + \left(\frac{g_{th02}}{a} \right) \exp[a(|V_R - V_0|)] - \exp(a|V_0|)]$$



a-Si:H solar cell ideality factor

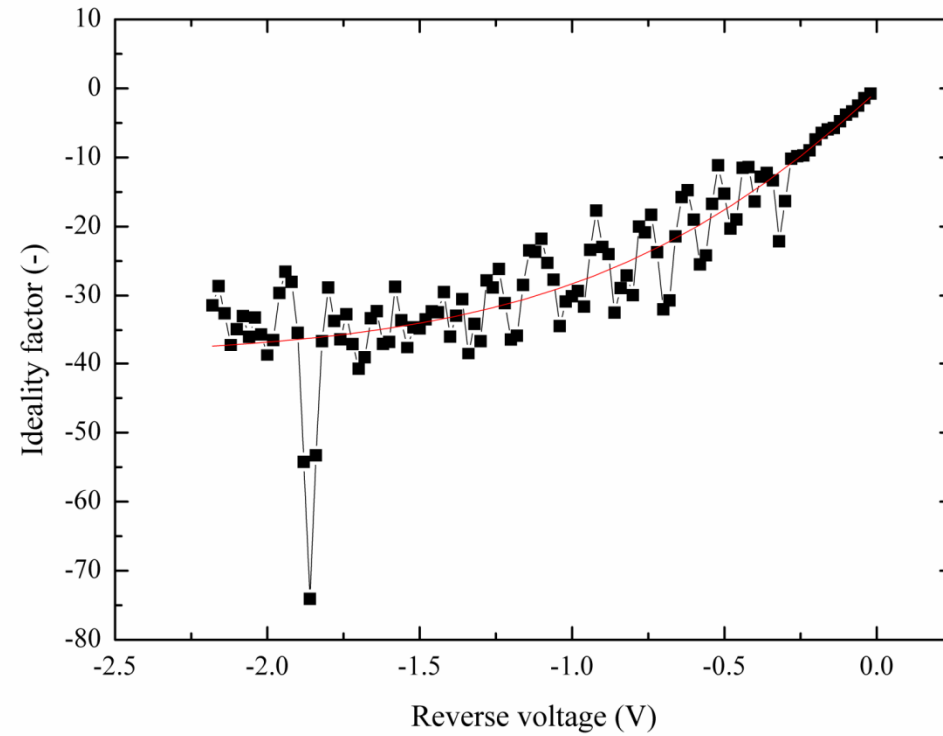
Calculated using *Savitzky-Golay method*. Deng and Wronski definition of voltage –dependent ideality factor [doi: 10.1063/1.1990267]

$$m(V) = \left[\frac{kT}{q} \frac{d \ln I_D}{dV} \right]^{-1}$$



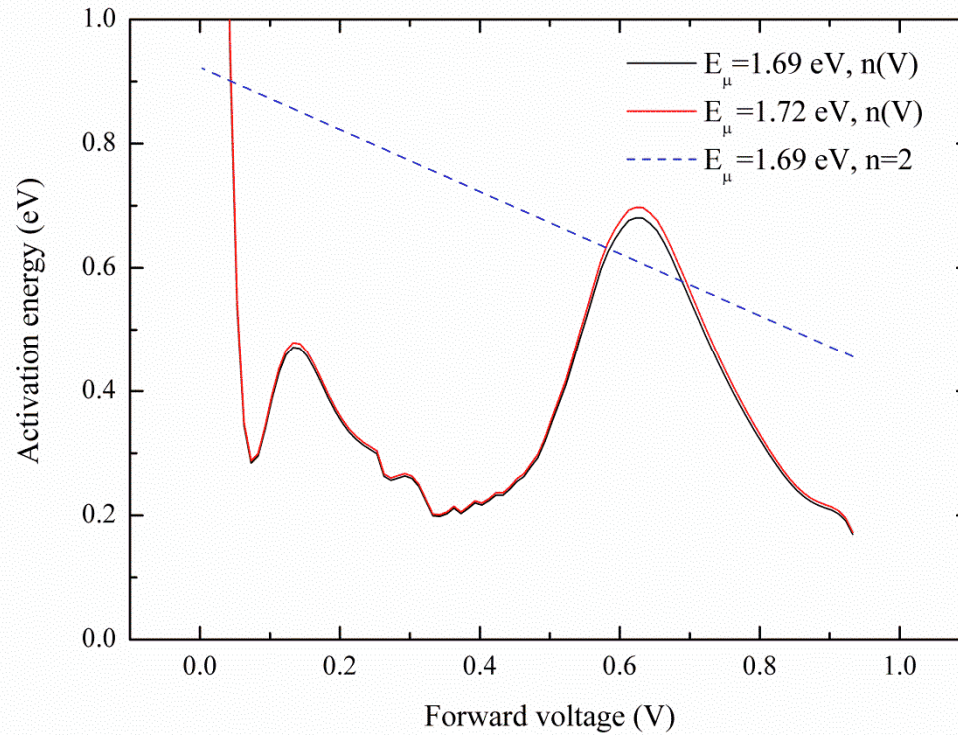
a-Si:H solar cell ideality factor

The ideality factor as a function of voltage for a solar cell with an i-layer thickness of 300 nm, at 30 °C. Calculation is done using the Deng and Wronski definition of voltage –dependent ideality factor .



a-Si:H photodiode ideality factor

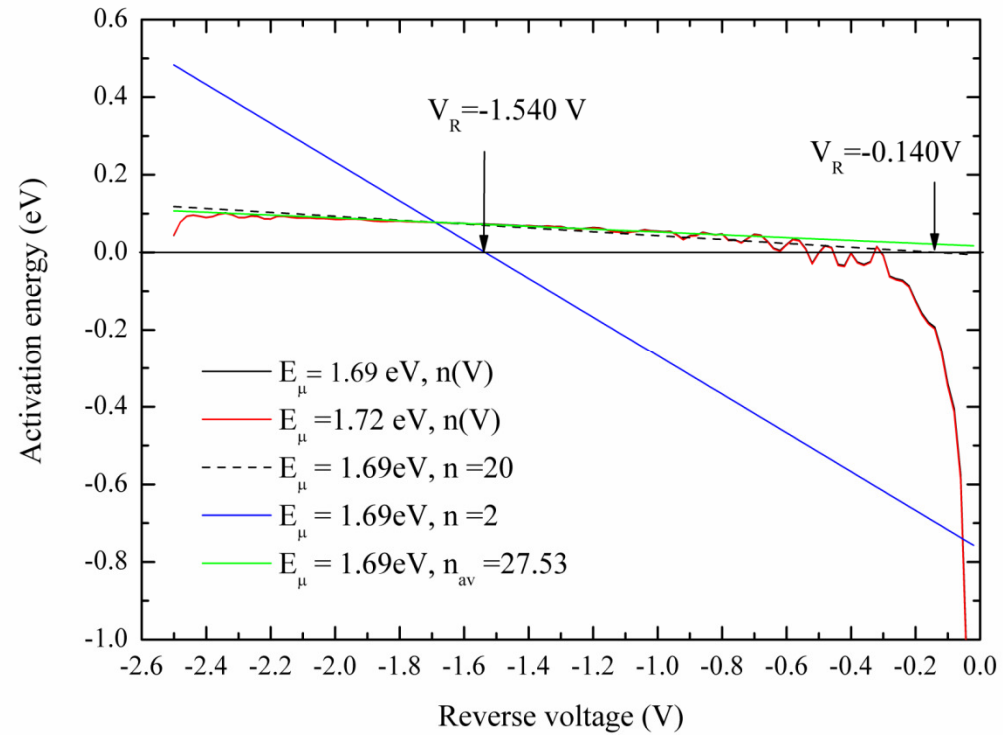
The ideality factor as a function of voltage for a photodiode with an i-layer thickness of 300 nm, at 30 °C. Calculation is done using the Deng and Wronski definition of voltage –dependent ideality factor .



a-Si:H solar cell activation energy

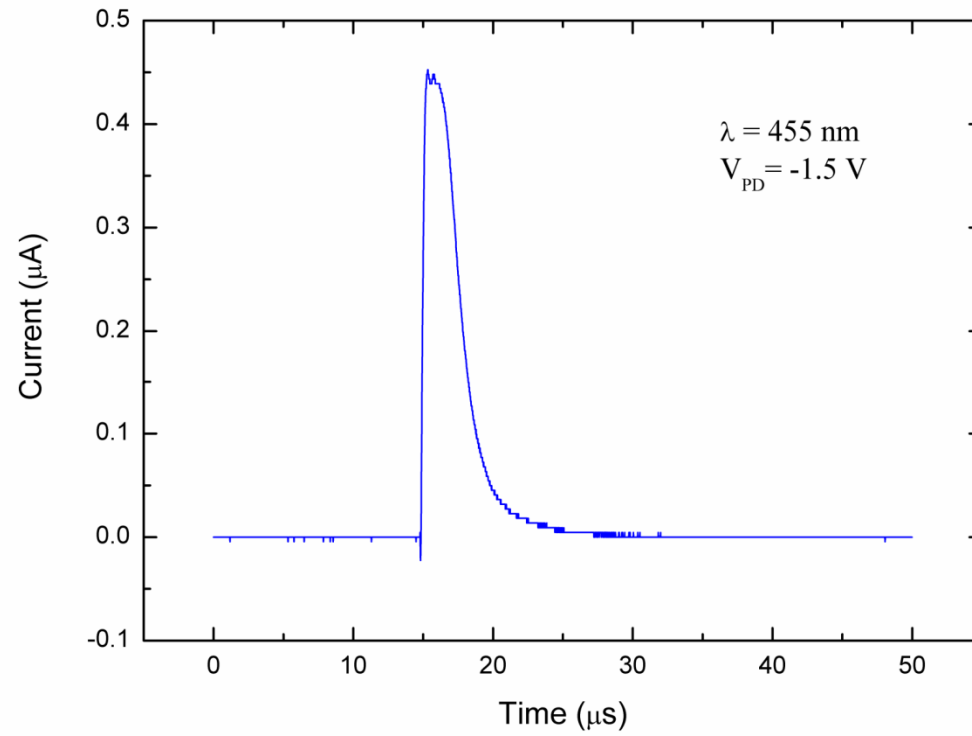
The activation energy as a function of voltage for a solar cell with an i-layer thickness of 300 nm, at 30 °C. Calculation is done following the Kind et al. [doi: 10.1063/1.3662924] expression for the voltage-dependent activation energy of the total recombination:

$$E_a(V) = \frac{E_\mu - V}{2} + 3kT \rightarrow E_a(V) = \frac{E_\mu - V}{n(V)} + 3kT$$

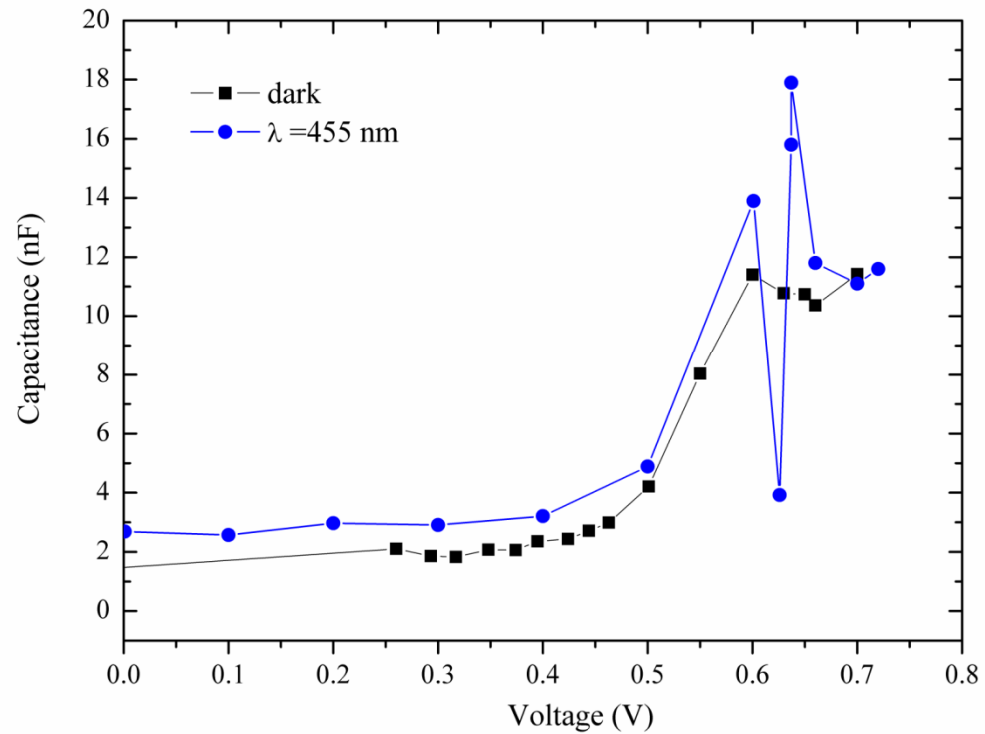


a-Si:H photodiode activation enegery

The activation energy as a function of voltage for a photodiode with an i-layer thickness of 300 nm, at 30 °C. Calculation is done following the Kind et al. expression for the voltage-dependent activation energy of the total recombination.



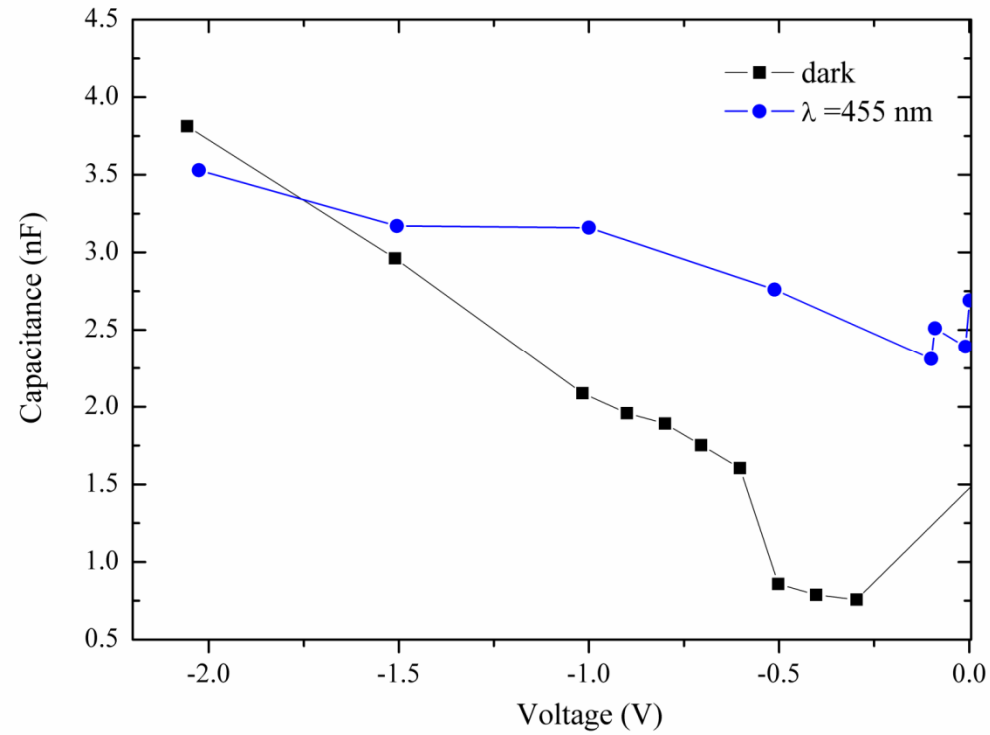
a-Si:H photodiode voltage pulse response at blue light illumination and reverse voltage bias $V_{PD} = -1.5 \text{ V}$



a-Si:H solar cell capacitance at different cell voltages

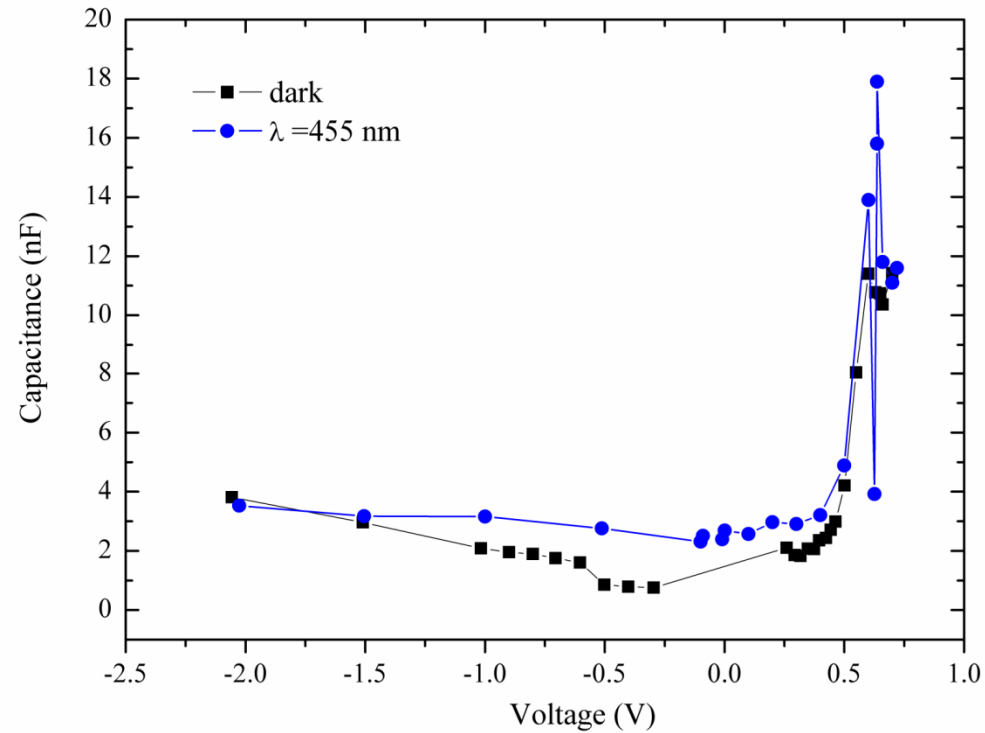
Cell capacitance measured under the dark and blue LED light illumination, $\lambda = 455$ nm condition.

The *degradation effect* - the diode injection capacitance becomes more dominant and the device responds to the voltage as a resistor.



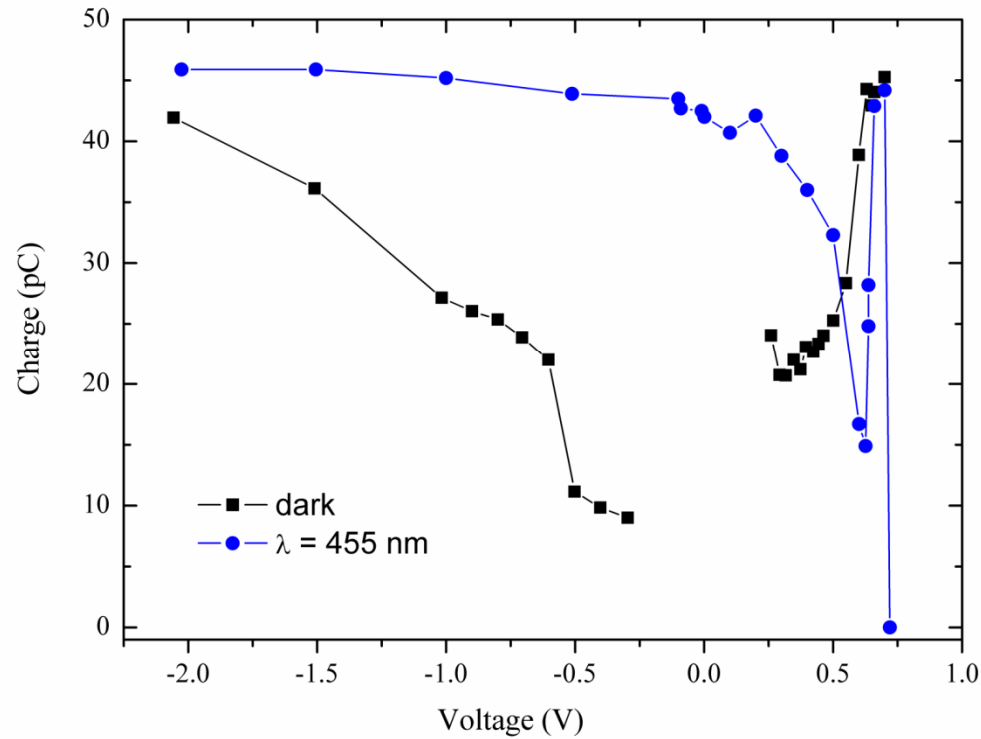
a-Si:H photodiode capacitance at different cell voltages

Cell capacitance measured in dark and under blue LED light illumination, $\lambda = 455$ nm due mainly the transition capacitance.



a-Si:H solar cell and photodiode capacitance at different device voltages

Capacitance degradation effect at sufficiently high forward voltage (V_{bi}) the diode injection capacitance becomes more dominant and the device responds to the voltage as a resistor.



a-Si:H solar cell and photodiode total accumulated charge at different device voltages.

The area under the current response curve give the total charge accumulated in cells follows D.S.Shen and S.Wagner equation [doi: 10.1063/1.360827]

$$Q_{dark} = Q_0 \left[\frac{(\mu\tau)V_R}{L^2} \right] \left(1 - e^{-\frac{L^2}{(\mu\tau)V_R}} \right) \rightarrow (\mu\tau) = 1,15 \cdot 10^{-9} \text{ cm}^2/\text{V}$$

CONCLUSIONS

- **The time domain technique at LF** used for a-Si:H p-i-n SC/PD C-V measurement
- *from* a-Si:H p-i-n PD/SC
 - I-V characteristic
 - calculated *ideality factor, activation energy*
 - voltage pulse response
 - *capacitance, charge*
 - *Capacitance degradation effect* at sufficiently high forward voltage (V_{bi})
- *applications:*
 - method for determination of the DOS and defects activation energies
 - new method to characterize SC/PD
 - image sensor at low bias voltages - integrated SC and PD -APS, PV



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