Printable Organic Solar Cells

Challenges and Opportunities in Technology Transfer from Lab to Market

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KONARKA®
116 John Street,
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“Plastic” Solar Cells


Lightweight, flexible and rugged !
RESERVED
RESERVED
RESERVED
RESERVED

Conversion of Sunlight into Electricity

Three step process

1. **Absorption of photons in a material**

   19th Century Chemistry

2. **Photo-induced charge separation**

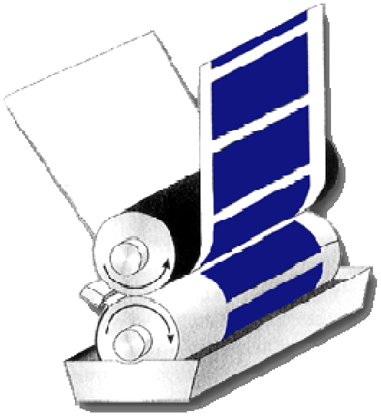
   20th Century Chemistry/Physics

3. **Collection of charges at electrodes**

   21st Century Chemistry, Physics and Materials Science

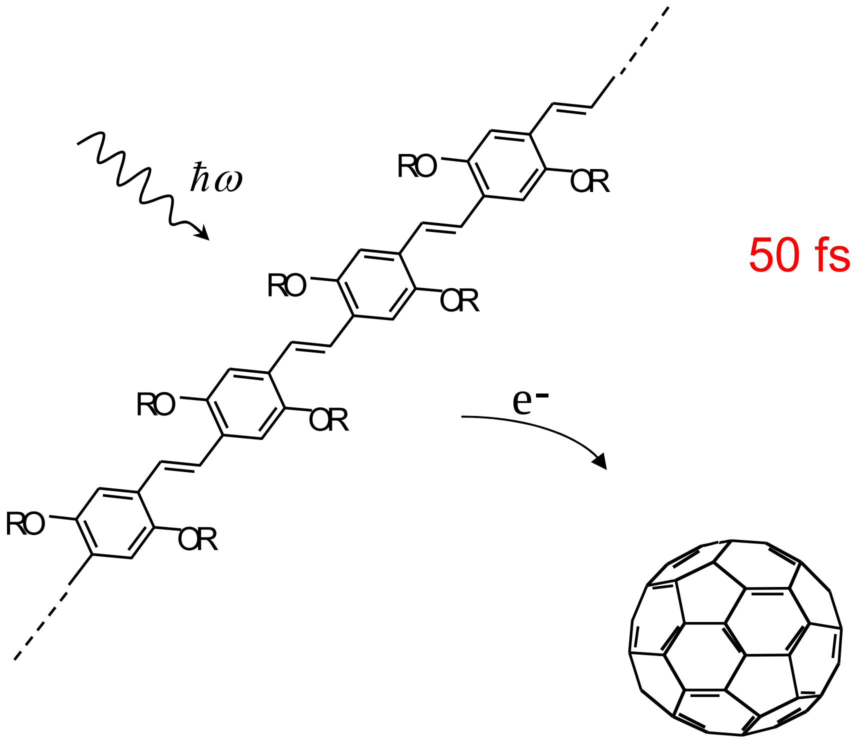
Semiconducting Polymers

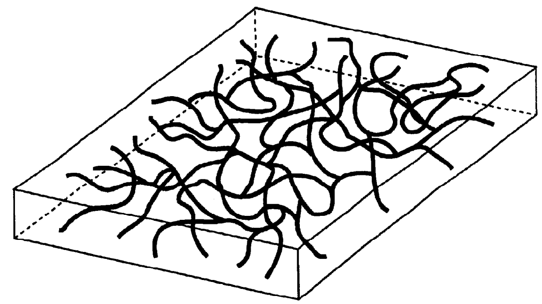
"inks" ----with electronic functionality!



Roll-to-roll manufacturing of plastic solar modules at Konarka facility in New Bedford, MA

The "Idea" ----

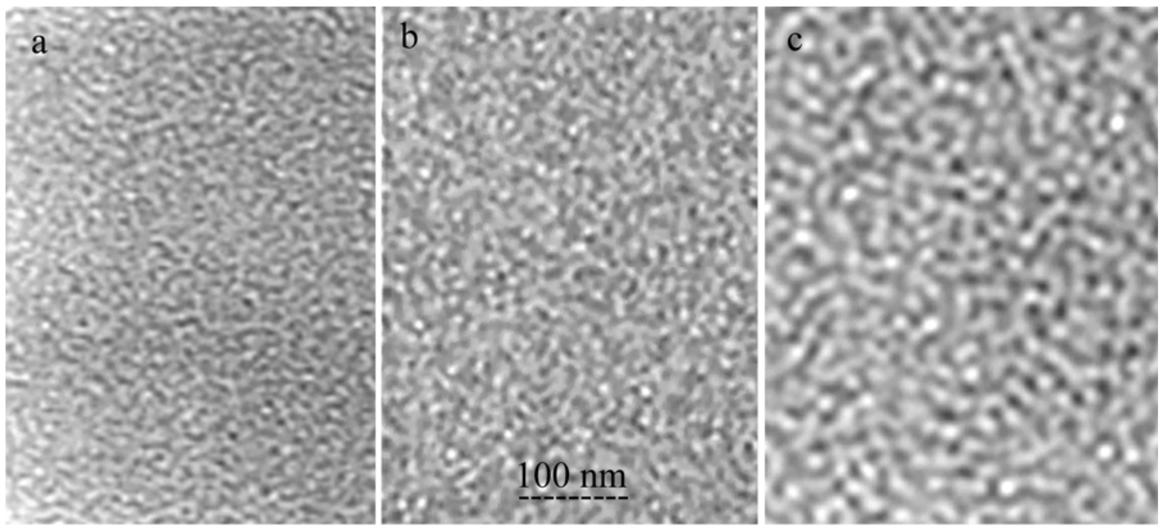


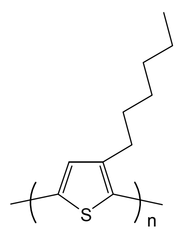


Bulk Heterojunction Material

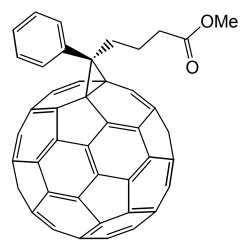
Bulk Heterojunction Morphology
Effect of Heat Treatment

Before 150°C anneal	150°C anneal 30 min	150°C anneal 2 hours





P3HT



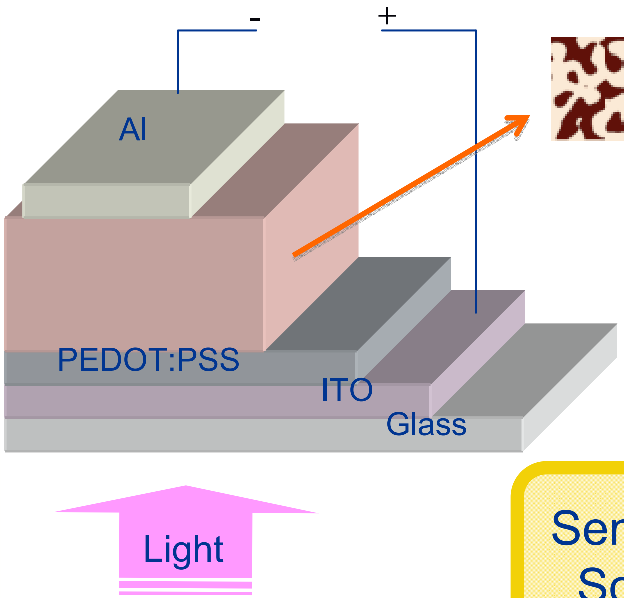
PCBM

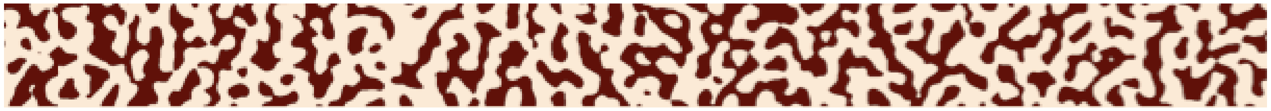
Manufacturing

Technology	Energy for production (MJ.Wp^{-1})	CO_2 footprint (gr.CO_2-eq.Wp^{-1})	Energy payback time (years)
mc-Si	24.9	1293	1.95
CdTe	9.5	542	0.75
CIS	34.6	2231	2.71
Flex OPV	2.4	132	0.19

A. L. Roes *et al*, *Progress in Photovoltaics* 17, 372 (2009)

Bulk-heterojunction Solar Cells





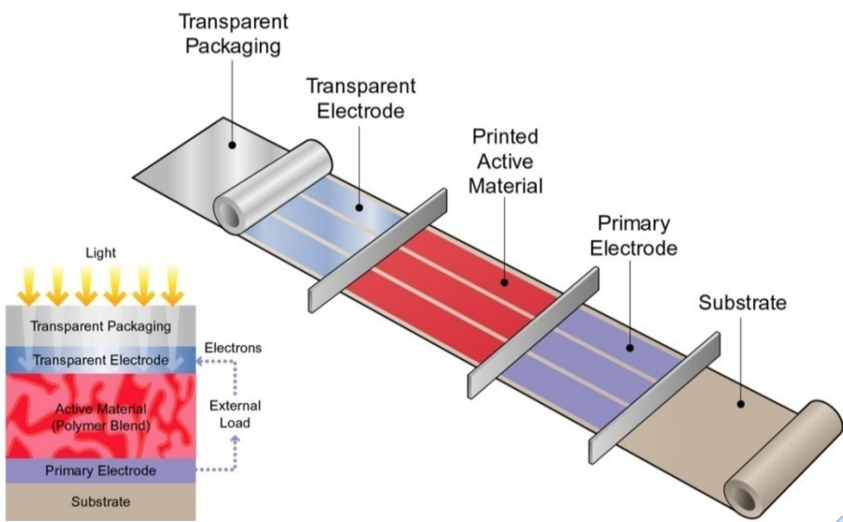
Thin Film of Phase Separated
Bulk Heterojunction Material

Semiconducting polymers
Solution processed

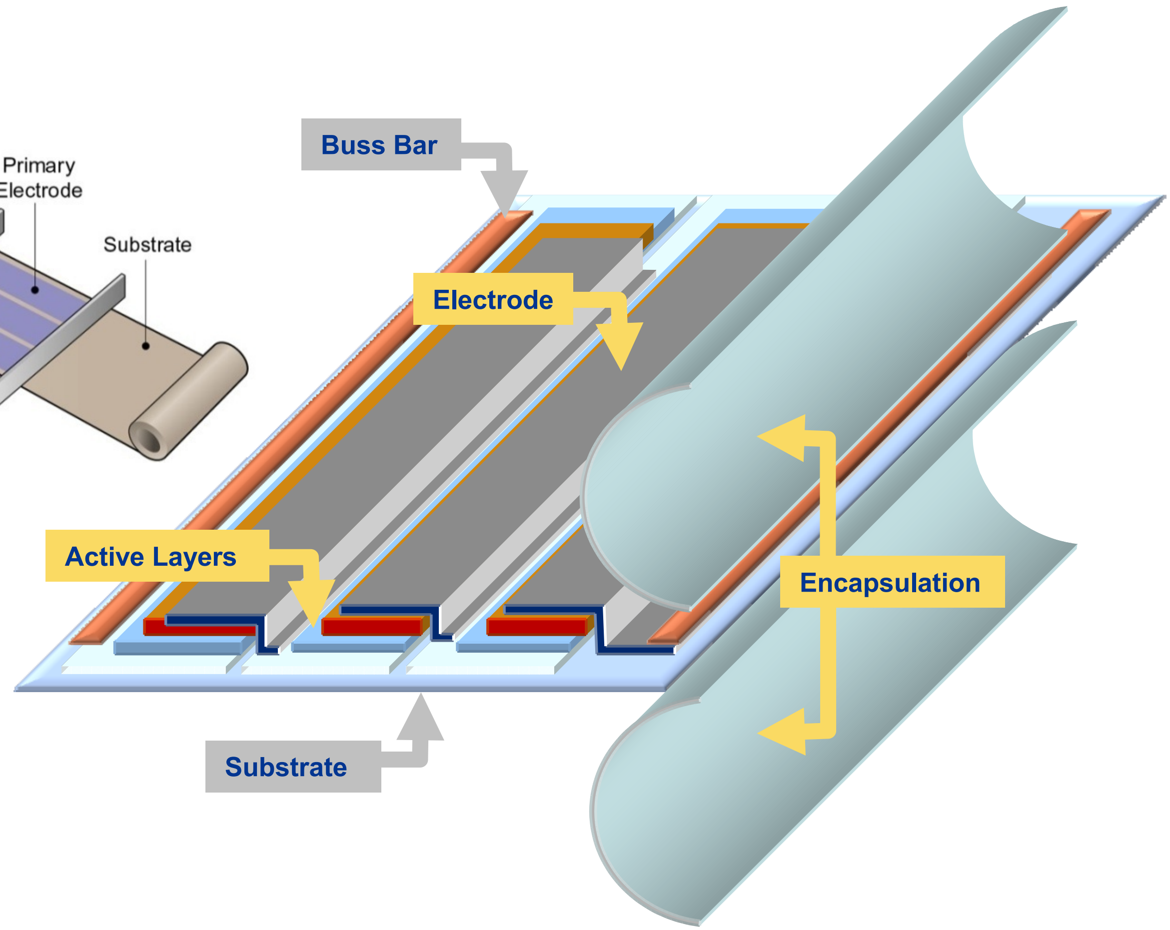
Fullerene derivatives
Solution processed

Nano-structure self-assembles --- Spontaneous Phase Separation

Technology Overview



Printing Techniques +Synthetic Materials = Scalability



Leverage Existing Capacity

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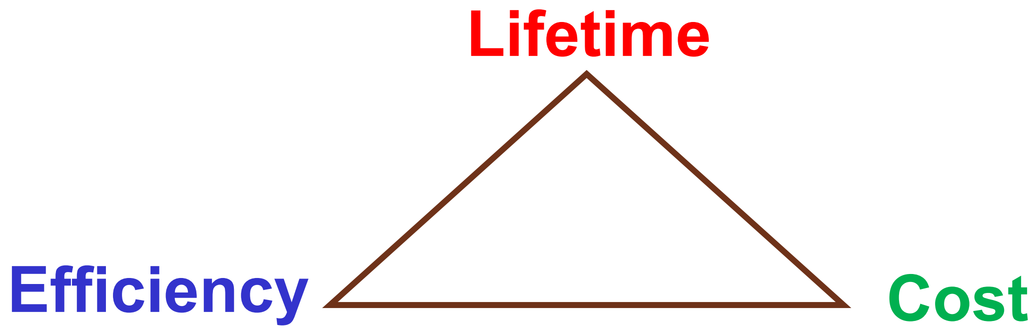
Retrofit existing printing facilities:

- Low CAPEX:
- Fast Ramp-up
- High Yield
- Output Quantity:
  - Web Width: 1.5 meter
  - Speed: 30 feet/min
  - Output equals: 1.0 GW/yr*

* Note: @ 5% module efficiency

200 nm active layer (1:1 D/A)
2,000 Kg of Donor
2,000 Kg of Acceptor
Active material cost of 4 cents/Wp @10$/g

Performance Requirements



Lifetime

3 to 5 years - flex encapsulate / 15 to 20 yrs - glass encapsulate

Cost

<$50/sq.meter

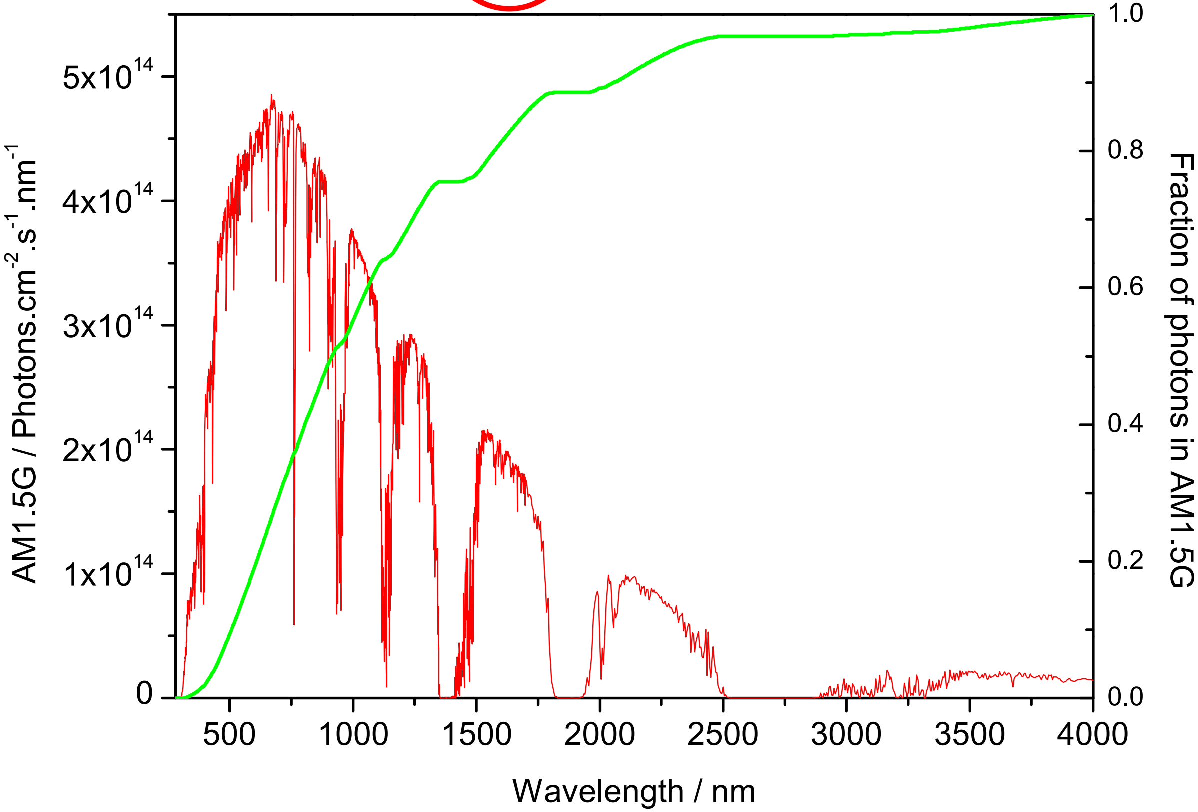
Efficiency

Translates to $1 watt @ 5% eff.

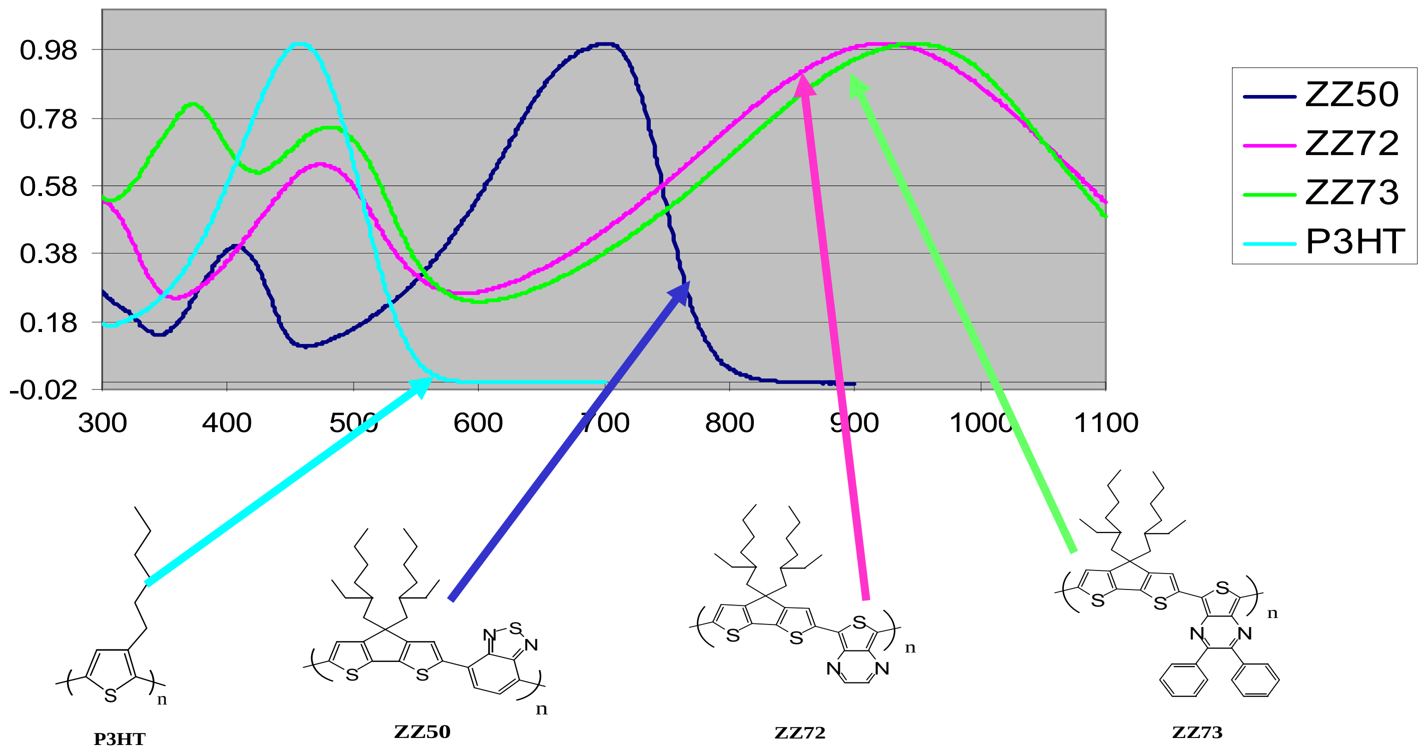
Optimization

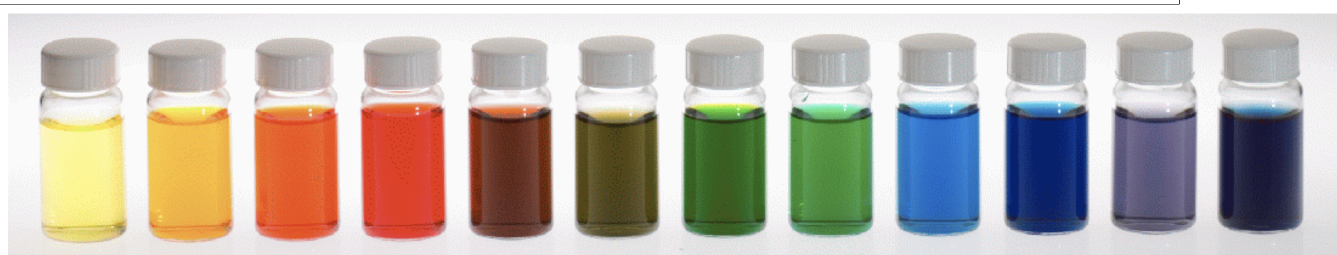
Absorption of the incoming photons

$$\eta_{device} \propto \eta_{abs} \cdot \eta_{CT} \cdot \eta_{collection}$$

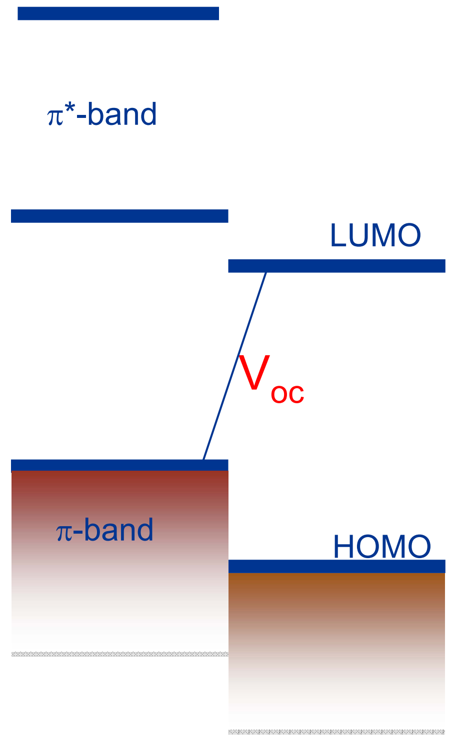


Absorption Spectra of KTI Low-Band-Gap Polymers Compared to That of P3HT





Origin of Voc and the Built-in Potential

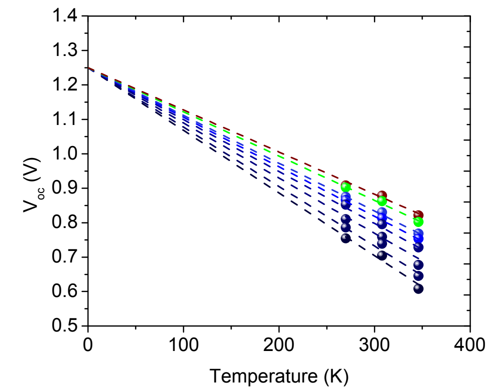


$$V_{OC} \approx E_{fullerene}(LUMO) - E_{polymer}(HOMO)$$

J_{sc} -

- Absorption across solar spectrum (UV – IR)
- Charge transfer and charge separation; mobile carriers
- Competition between carrier sweep-out by internal field and carrier recombination
- Morphology and connectivity of phase separation

$$V_{oc} = \frac{1}{e}\left(E_{LUMO}^{Fullerene} - E_{HOMO}^{Polymer} - \Delta\right) - \frac{k_B T}{e}\ln\left(\frac{n_e n_h}{N_c^2}\right)$$

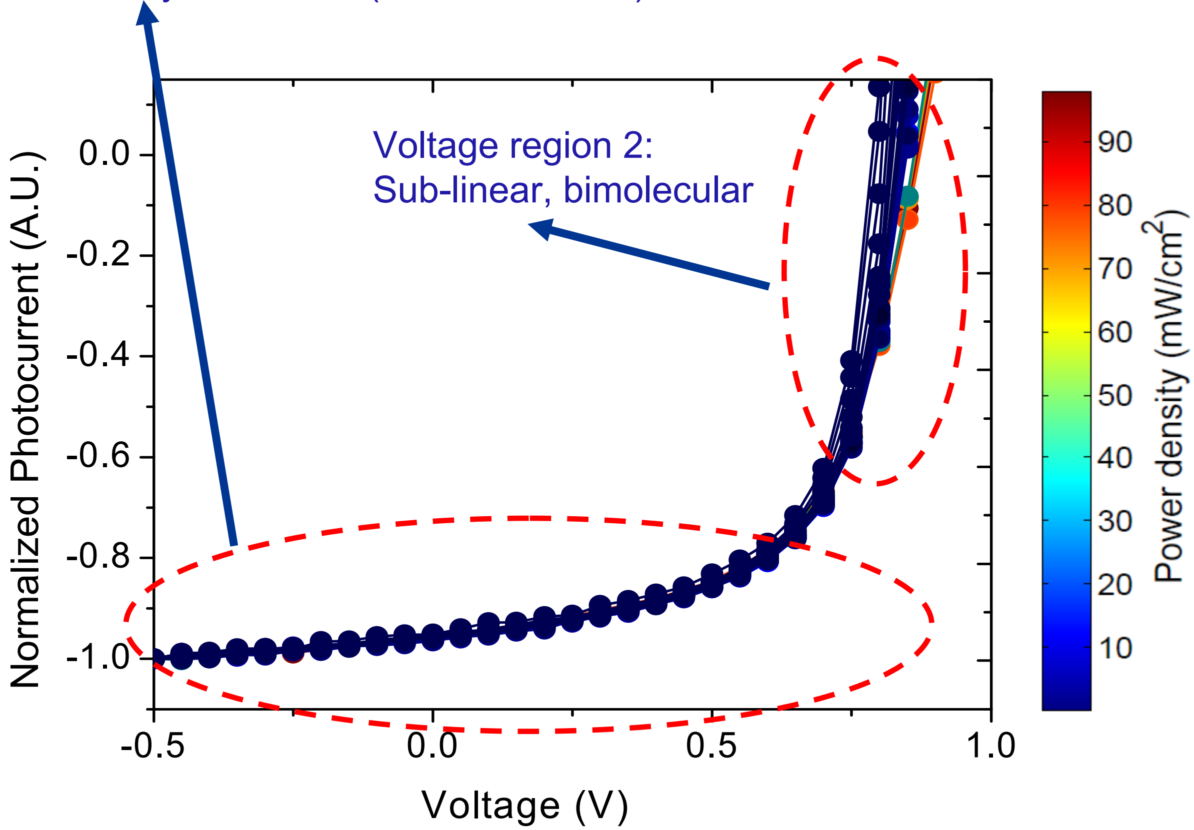


FF -

- Recombination (hole in polymer, electron in fullerene)

Physics of carrier recombination:

Voltage region 1:
Independent of Intensity, first order (monomolecular)



Physics of carrier recombination:

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where Nc= density of states in the band tails

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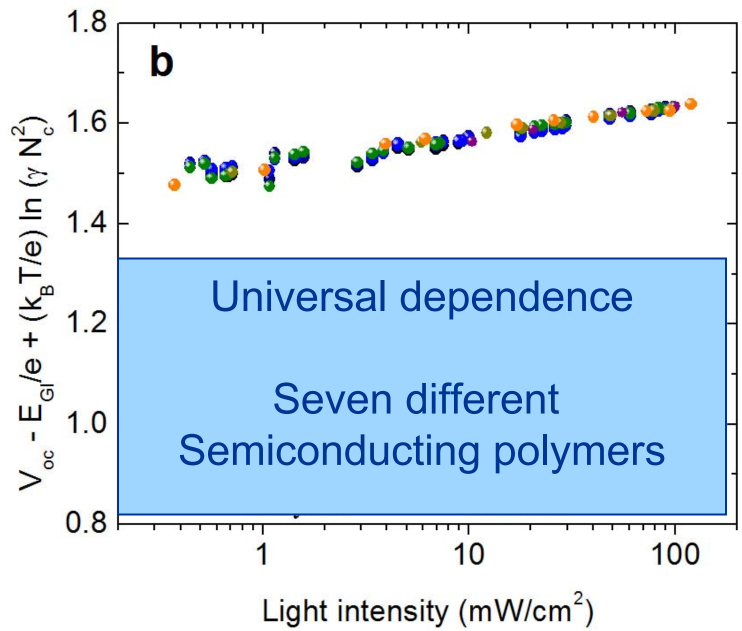
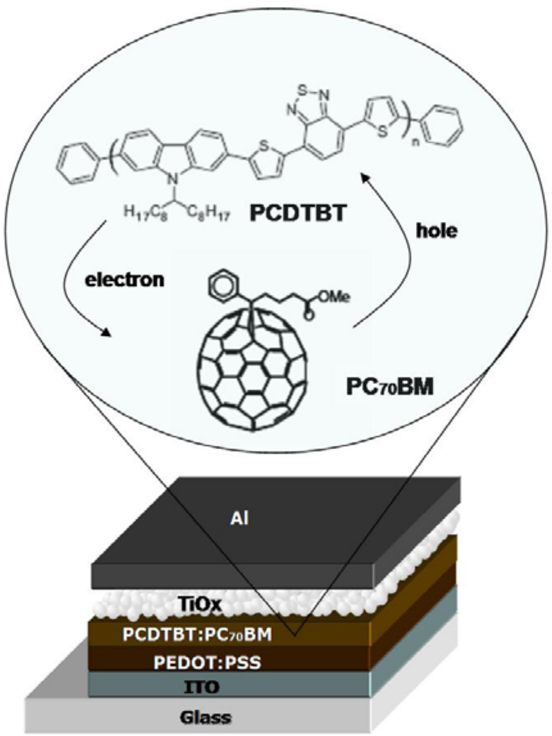
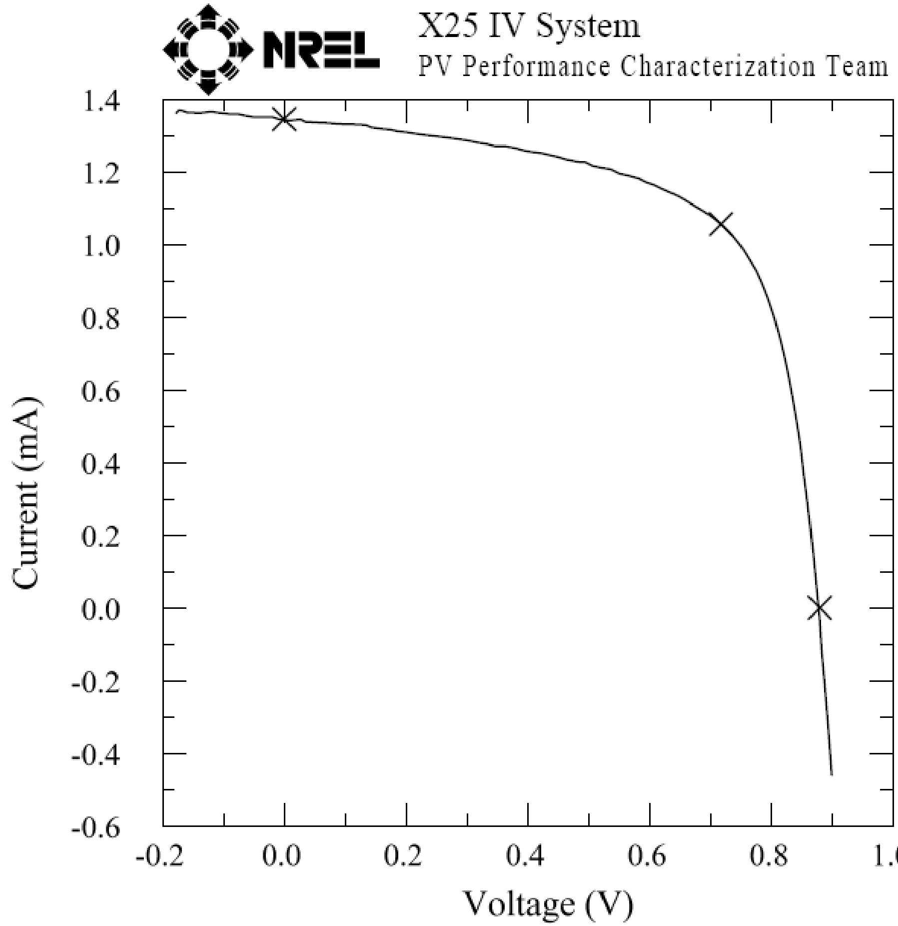


$$\delta V_{oc} \propto \frac{kT}{e}\ln(I)$$

np ~ I

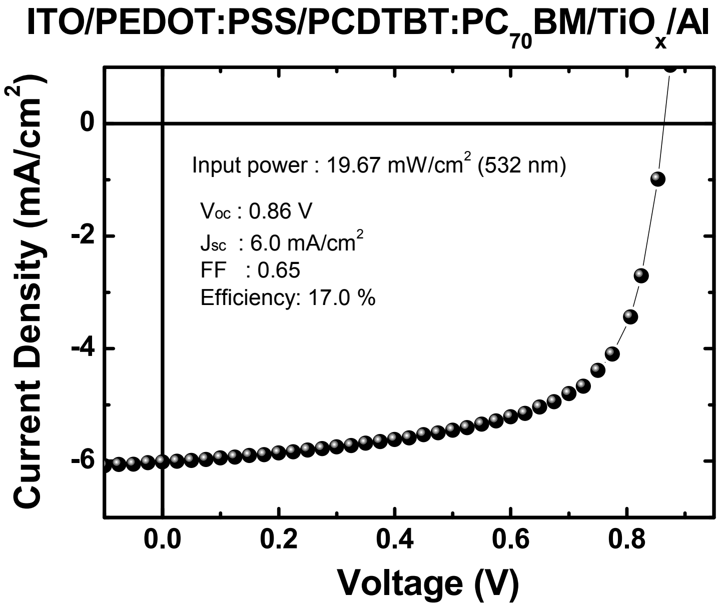
Bimolecular --- slope 1 --- not 2





V_{OC} = 0.88V
FF = 64%
Power Conversion Efficiency = 6 %

17% Power Conversion Efficiency for wavelengths within the absorption band



High efficiencies are possible ---

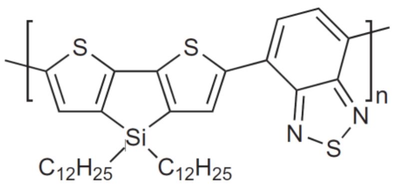
But:
Absorption spectrum is not well matched to the solar spectrum
--- no absorption beyond 650 nm.

Improve the performance by reducing the band-gap and improving the morphology.

Importance of the nano-morphology

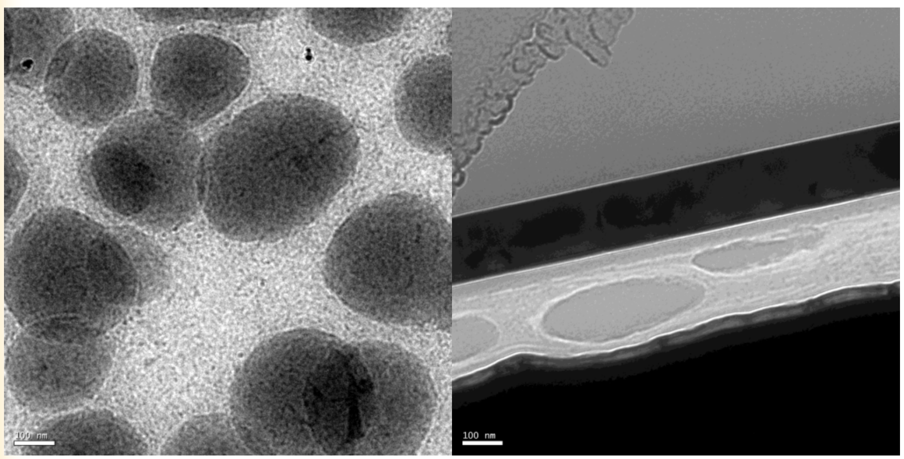
$$I_{SC} \propto \eta_{abs} . \eta_{CT} . \eta_{collection}$$

Example:
Si-PDTBT:PC70BM 1:1



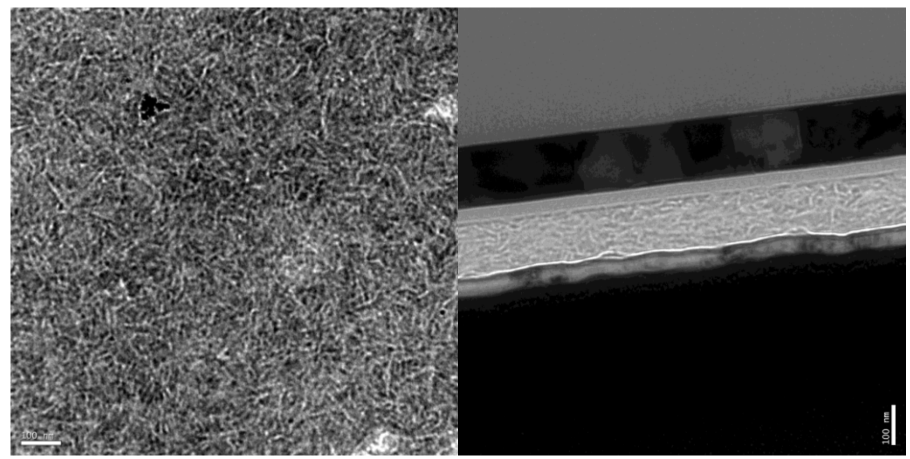
with Chloro-napthalene as processing additive

Without processing additive



Top down | Cross section

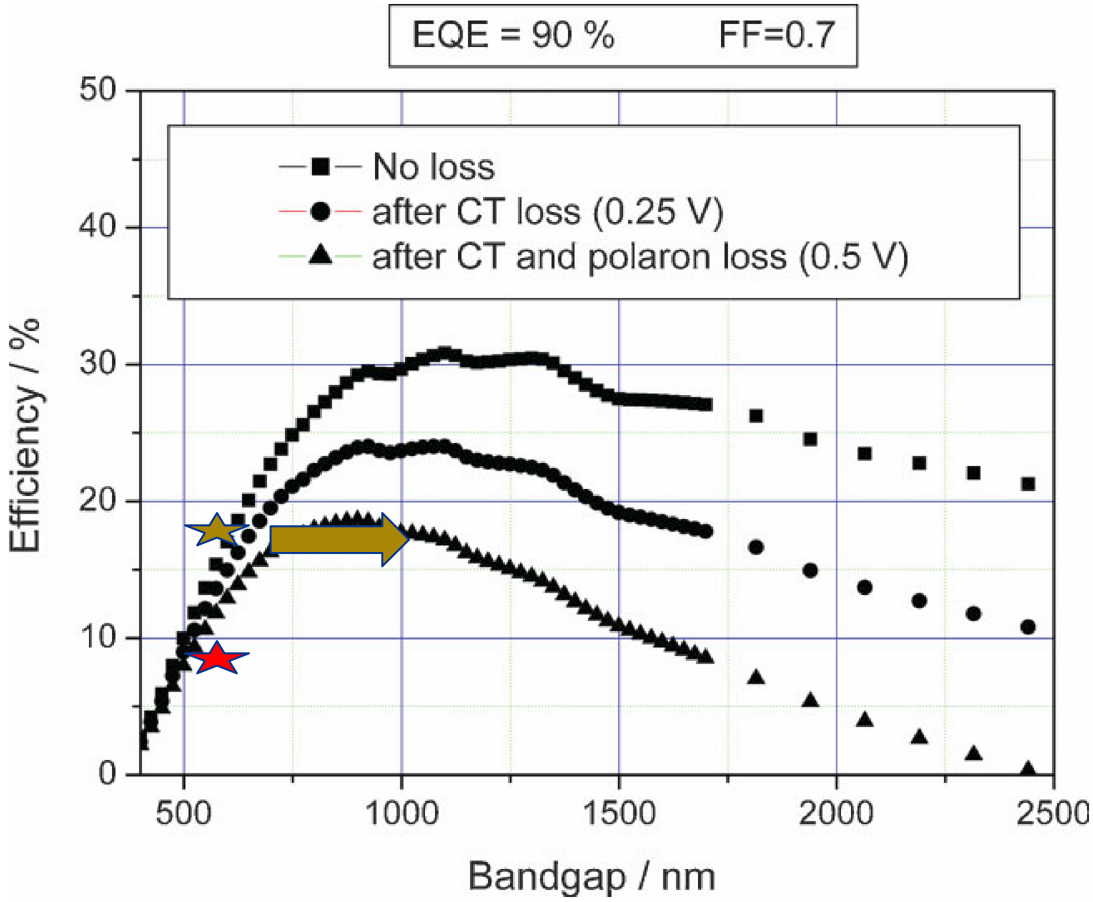
With Processing additive



Top down | Cross section

Double the Efficiency!

Plastic BHJ solar cells can be a 20% technology



Efficiency Outlook

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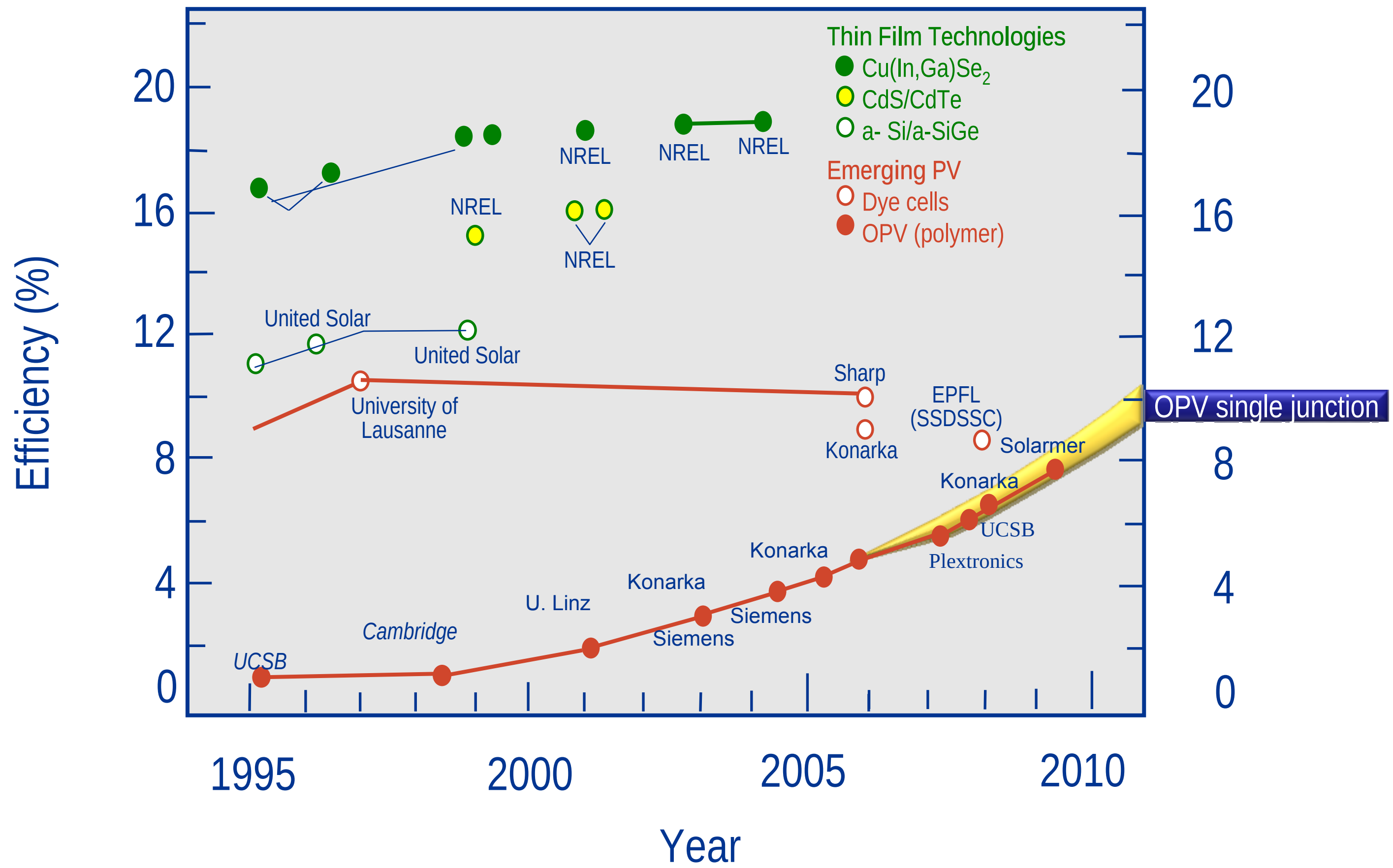
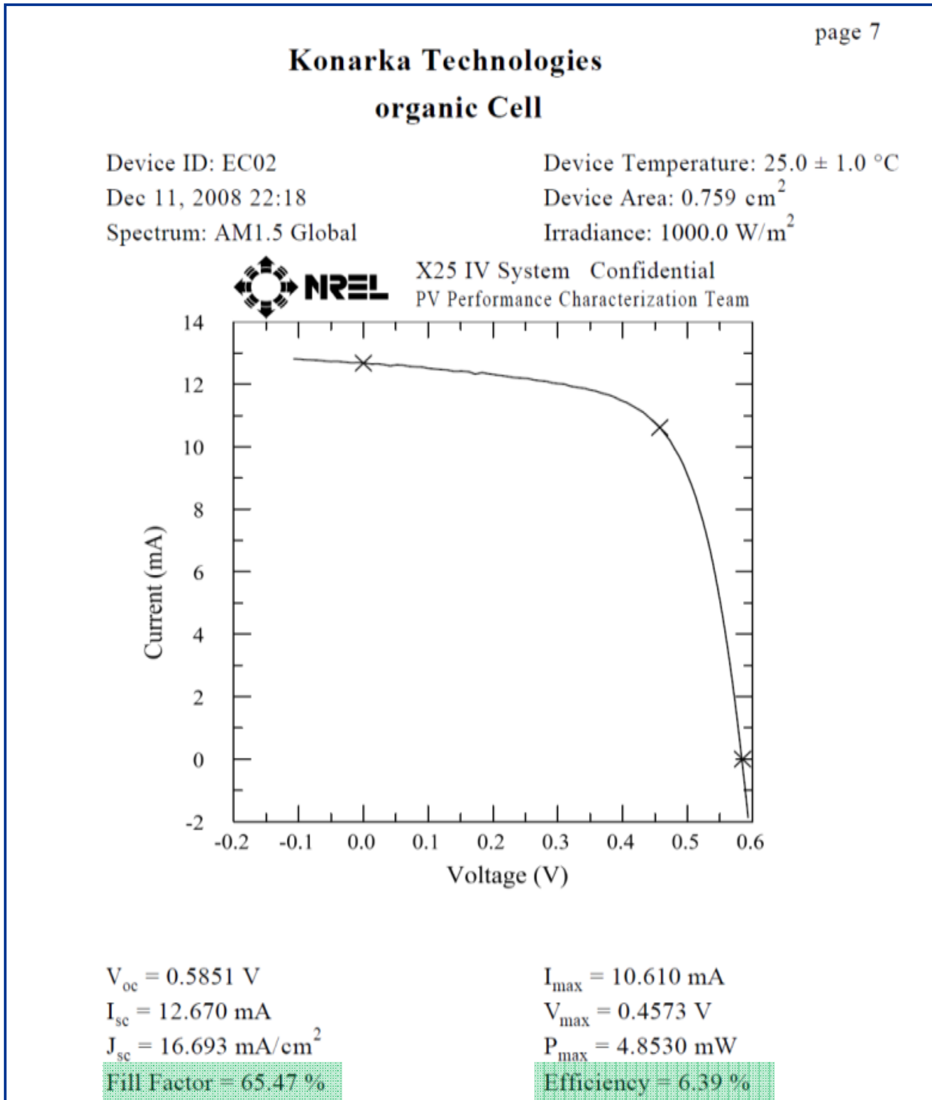


- Single junctions to break 10% by 2011-2015
- Multijunctions technology to drive efficiencies beyond

Converting Light to Energy — Anywhere

Industrial potential- Green Polymer



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Konarka Technologies

organic Cell

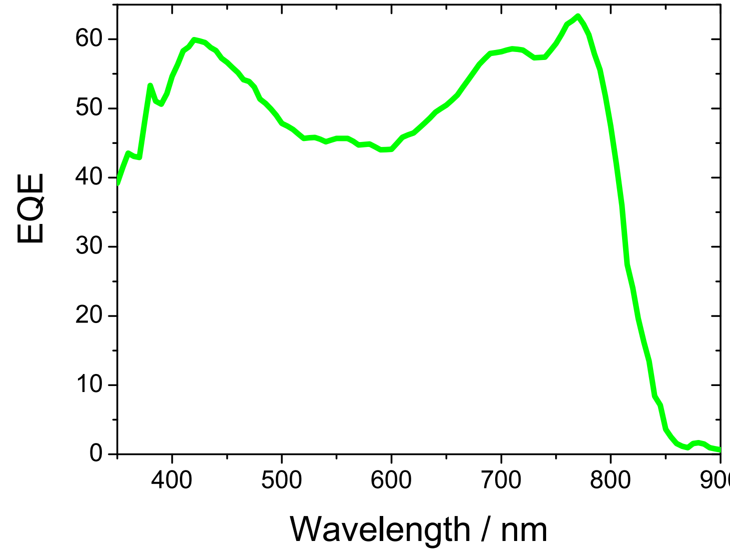
Device ID: EC02
Dec 11, 2008 22:18
Spectrum: AM1.5 Global

Device Temperature: 25.0 ± 1.0 °C
Device Area: 0.759 cm^2
Irradiance: 1000.0 W/m^2

NREL X25 IV System Confidential
PV Performance Characterization Team

V_{oc} = 0.5851 V
I_{sc} = 12.670 mA
J_{sc} = 16.693 mA/cm^2
Fill Factor = 65.47 %

I_{max} = 10.610 mA
V_{max} = 0.4573 V
P_{max} = 4.8530 mW
Efficiency = 6.39 %



Active Layer ≈ 200 nm

Green appearance (T)

OPV in Windows: Building Integrated Applications

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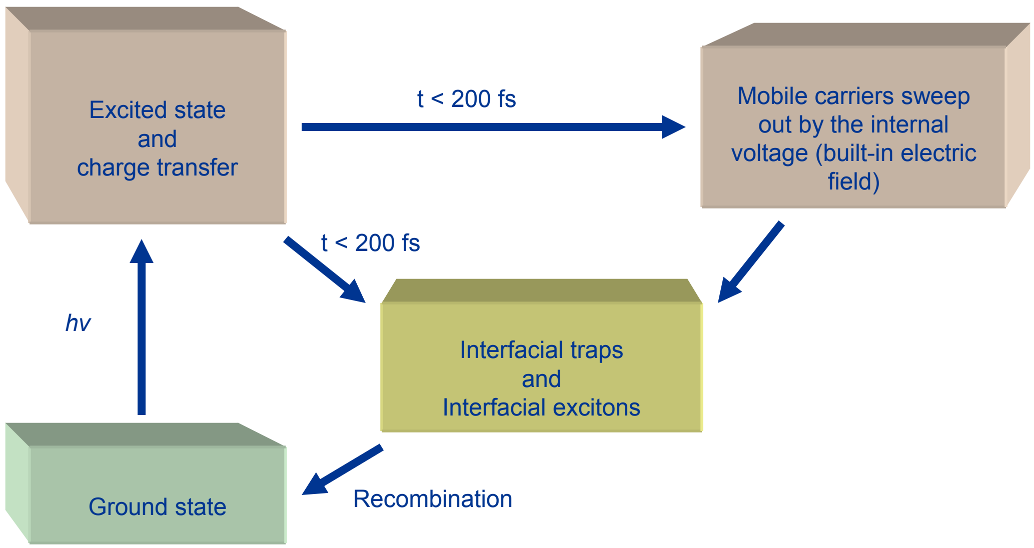
Converting Light to Energy — Anywhere



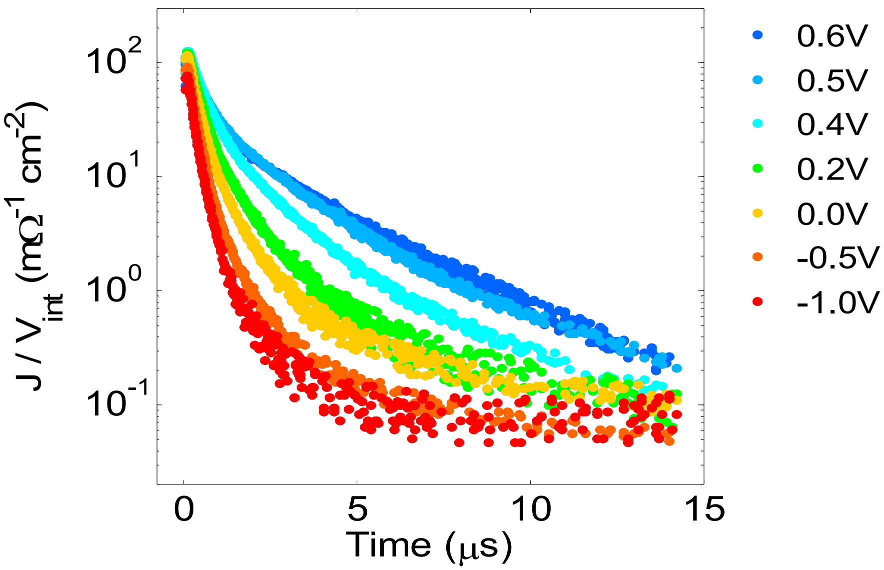
Necessary for high efficiency:

1. Ultrafast charge transfer
   and generation of mobile carriers

2. Sweep-out by internal field prior to recombination

Transient photocurrent in operating solar cell

P3HT:PCBM

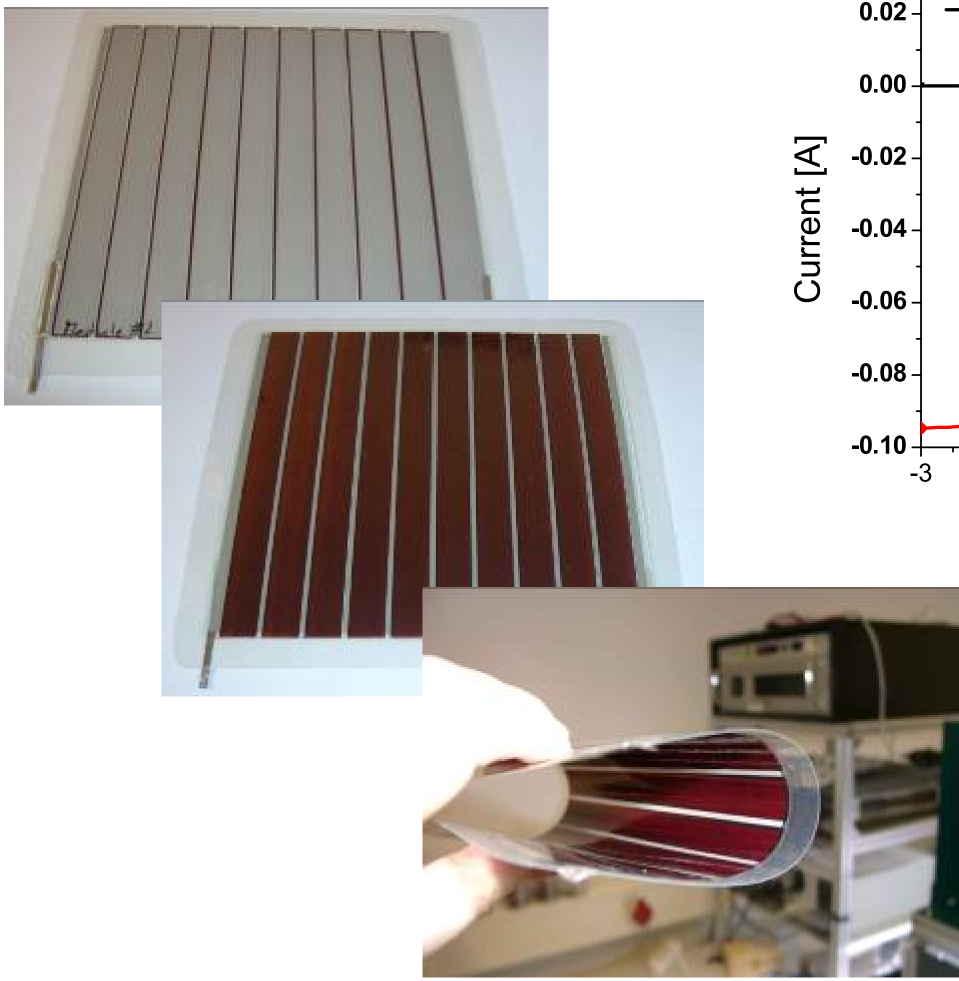


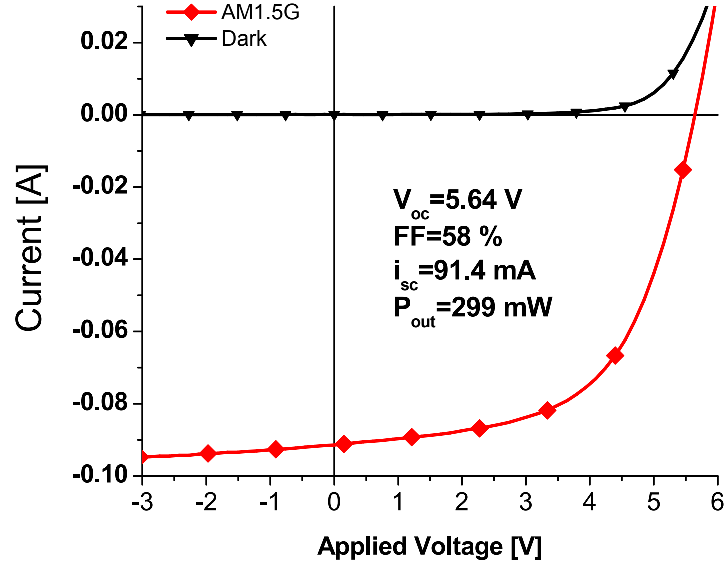
$\tau_{sw} \approx 0.1\ \mu s$

$\tau_R \approx 5\ \mu s$

Sweep-out is faster than recombination
and therefore --- high efficiency

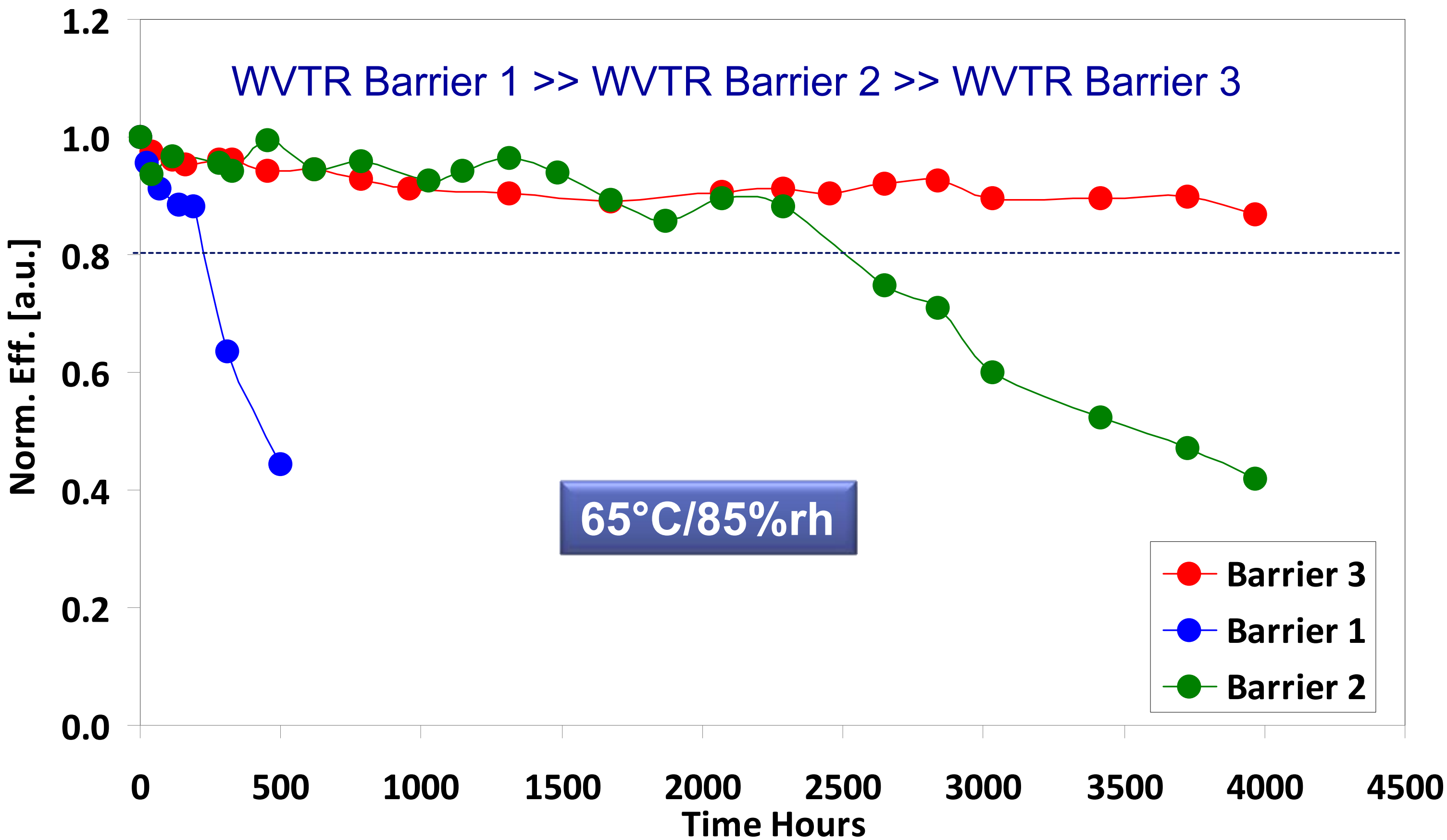
R2R Manufactured Module Performance





- 10 stripe modules. monolithic interconnection
- AM1.5
  - 3 % from high band gap polymer
  - 4 % from low band gap polymer
- Indoor efficiency at >5 %

Lifetime of Production Modules



Depending upon the adhesive/barrier used the lifetime of the modules can be impacted profoundly.

Outdoor Testing - Konarka

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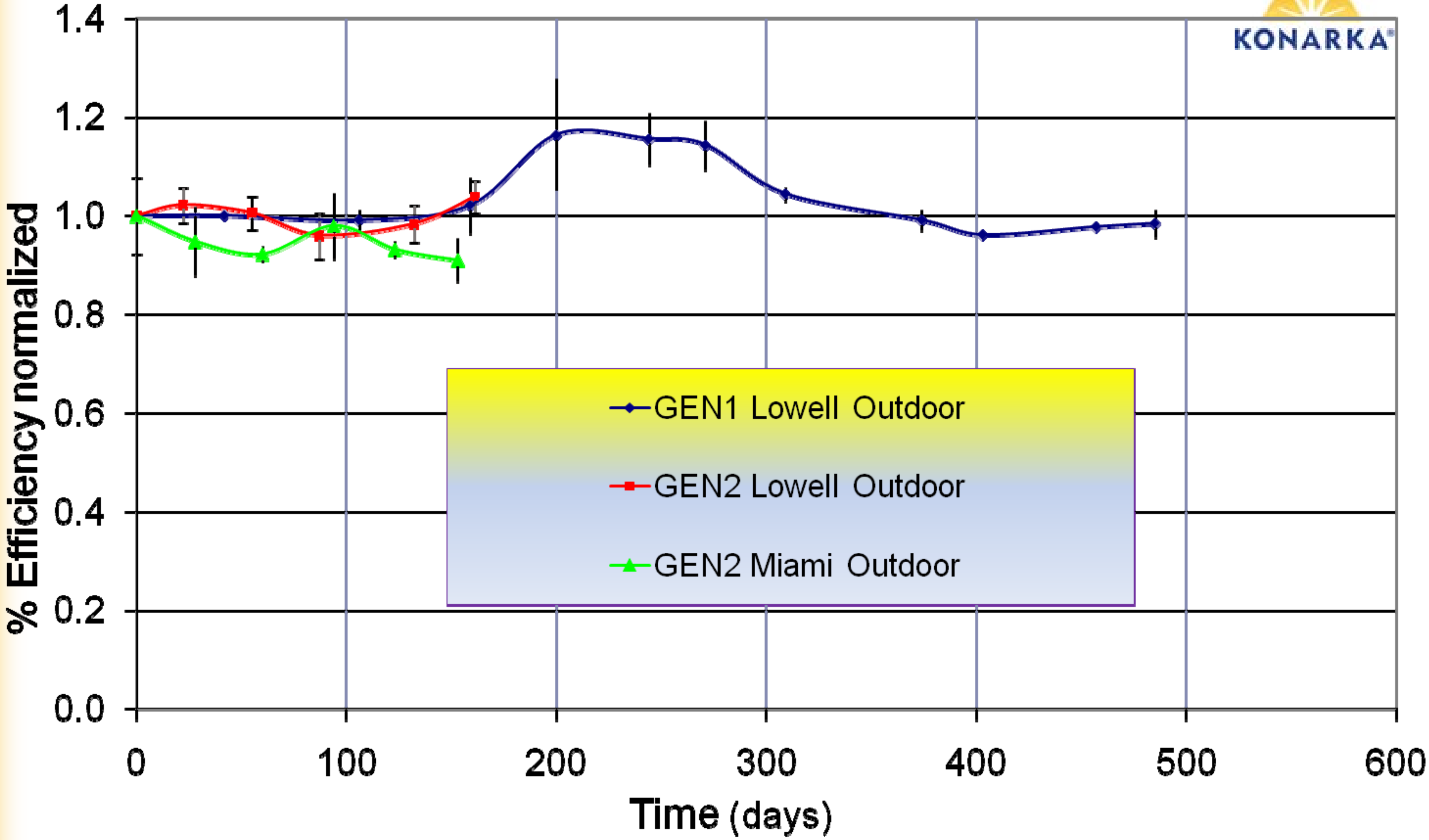
Location Lowell, MA.
Facing solar south at 42° ≈1600 kWh / m^2

Two measurement modes

- **a) Outdoor jV in 4th quadrant with modulated load and wireless data read out**
- **b) Periodic characterization under standard solar simulator**

Outdoor Performance



Key Technology Features

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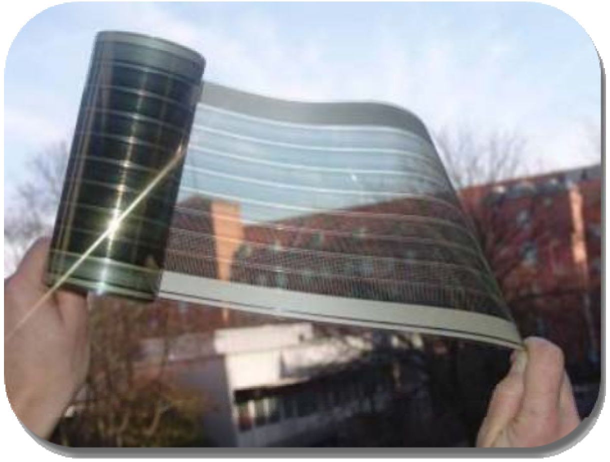
Advantages of OPV flexible thin-film solar technologies:

- Tunable cell chemistry can absorb specific wavelengths of light – as well as broad spectrum
- Less sensitive to angle of solar incidence
- Positive thermal efficiency coefficient
- Flexible, thin, light-weight
- Printable in various widths-Roll-to-roll
- Low light sensitivity (indoor/outdoor)
- Semi-transparent for window applications




Lightweight, flexible and rugged !
RESERVED
RESERVED
RESERVED
RESERVED

Thank you for listening

Questions?