ORGANIC PHOTOVOLTAICS AND CONCENTRATED SUNLIGHT?

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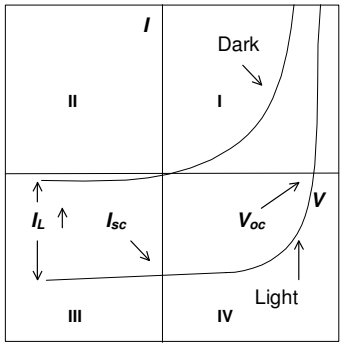
Outline:

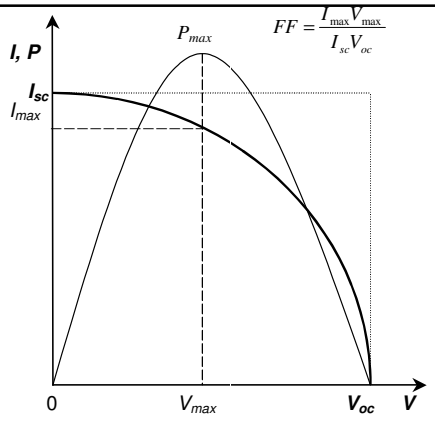
1. Origin of size effect on efficiency of organic photovoltaics
2. Highly concentrated sunlight for accelerated tests of the OPV operational life-time

Scalability Stability

Efficiency

Funding: European Commission's Seventh Framework Programe (FP7/2007-2013, "Largecells" project) http://largecells.eu/





$$I_d = I_0\left[\exp\left(\frac{q(V+IRs)}{nkT}\right)-1\right]+\frac{V+IRs}{R_{sh}}$$

$$I_L = I_0\left[\exp\left(\frac{q(V+IRs)}{nkT}\right)-1\right]+\frac{V+IRs}{R_{sh}}-I_p$$

$$FF = \frac{I_{max}\times V_{max}}{V_{oc}\times I_{sc}}$$

$$\eta = \frac{I_{max}\times V_{max}}{P_{in}} = FF\,\frac{V_{oc}\times I_{sc}}{P_{in}}$$

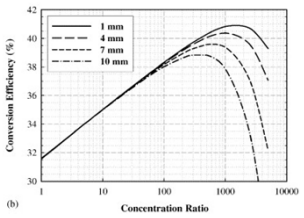
$$V_{oc} = \frac{n\kappa T}{q}\ln\left(\frac{I_{sc}}{I_o}+1\right)$$

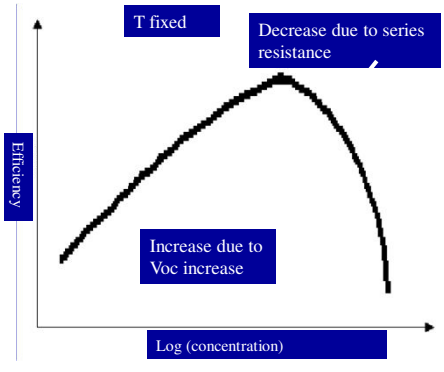
$$I_o = qN_vN_c\left[\exp\left(-E_g/\kappa T\right)\right]\cdot\left(\frac{L_n}{n_n\tau_n}+\frac{L_p}{p_p\tau_p}\right)$$

$$I_L = I_0\left[\exp\left(\frac{q(V+IRs)}{nkT}\right)-1\right]+\frac{V+IRs}{R_{sh}}-I_p$$

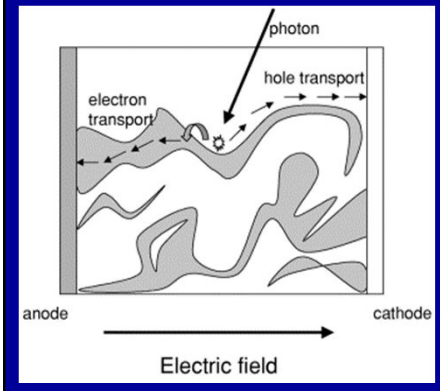
$$FF = \frac{I_{max}\times V_{max}}{V_{oc}\times I_{sc}}$$

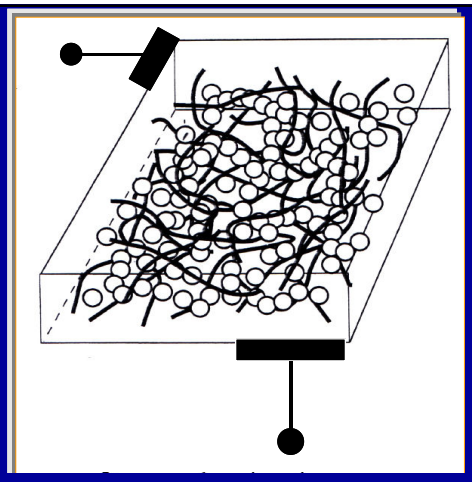
$$\eta = \frac{I_{max}\times V_{max}}{P_{in}} = FF\,\frac{V_{oc}\times I_{sc}}{P_{in}}$$



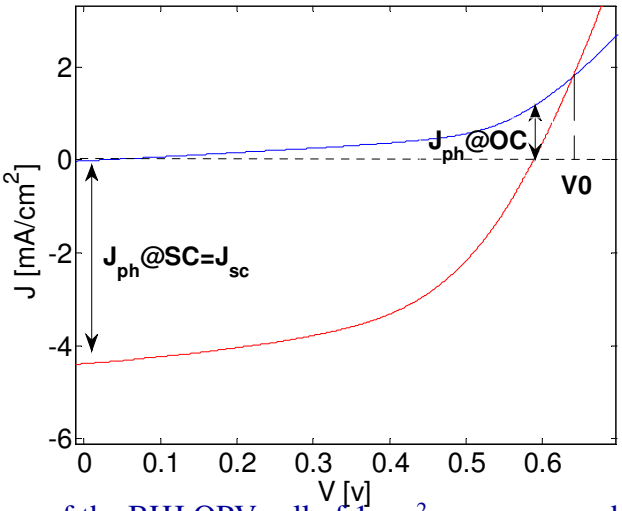


Interpenetrating network of bulk donor/acceptor (conjugated polymer/C_{60}) heterojuction





G. Yu, J. Gao, J.C. Hummelen, F. Wudl and A.J. Heeger, *Science* 270, 1789 (1995).



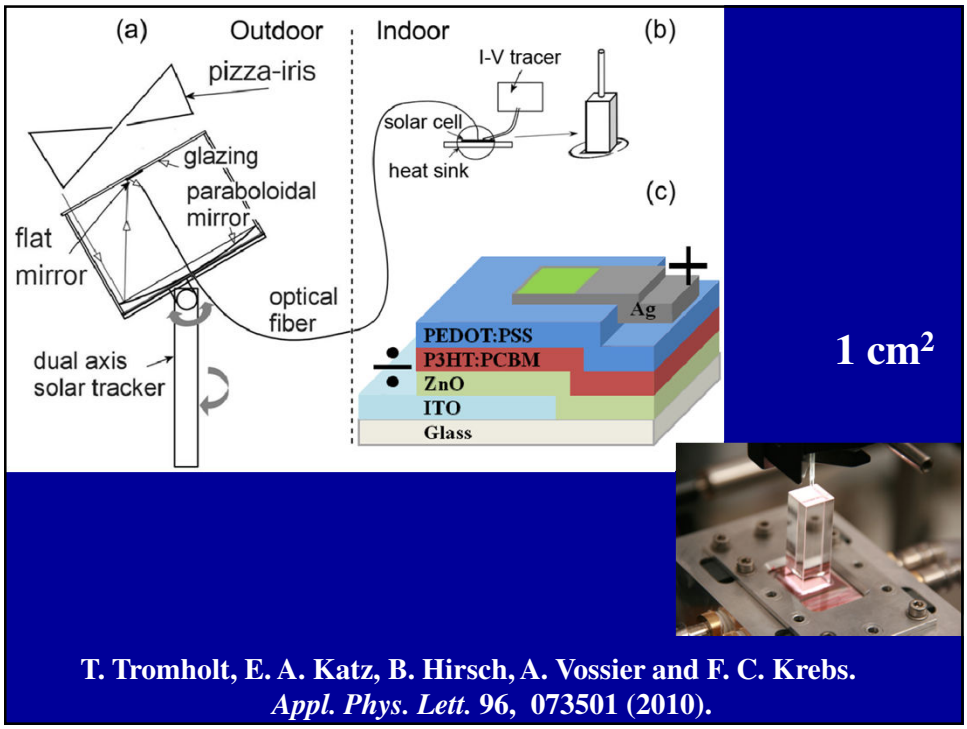
J-V curves of the BHJ OPV cell of 1 cm^2 area measured in the dark (blue curve) and under illumination of 1 sun (red curve). It is evident the $J_{ph} = J_{light} - J_{dark}$ measured at the short-circuit conditions ($J_{ph} \approx J_{sc}$) is much higher that that measured at open circuit. Compensation voltage V_0 at which $J_{light} = J_{dark}$ is indicated.

Record efficiencies for BHJ OPV

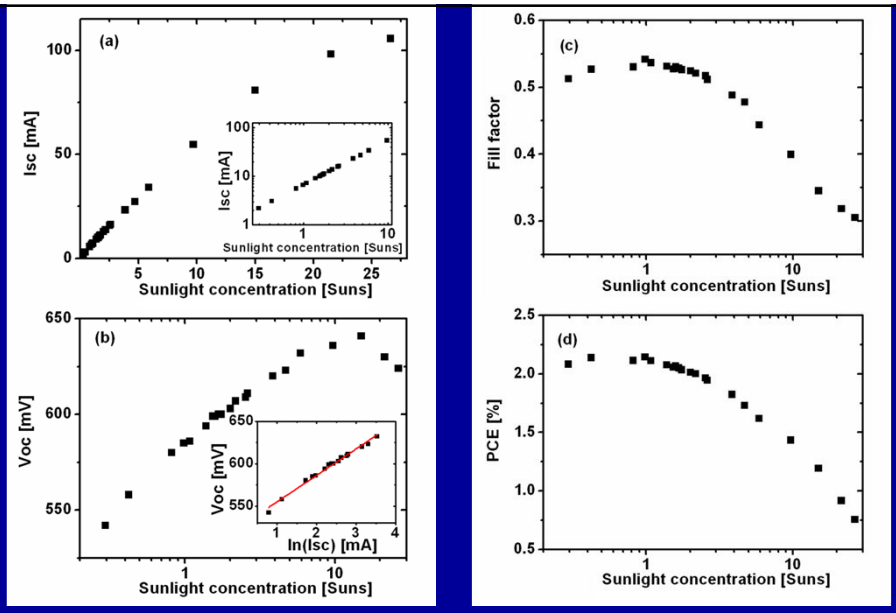
Photoactive layer	Cell area, [cm^2]	*Isc*, [$mAcm^2$]	*Voc* [V]	*FF*	*PCE* [%]	Ref.
P3HT/PCBM	0.148	9.5	0.63	0.68	5	[4]
P3HT/PCBM	0.148	11.1	0.61	0.66	5	[5]
P3HT/PCBM	not mentioned	11.3	0.64	0.69	5.2	[6]
P3HT/PCBM	0.19	11.1	0.65	0.54	4.9	[7]
PSBTBT /PCBM	0.12	12.7	0.68	0.55	5.1	[17]
PCPDTBT:C_{70}-PCBM	0.17	16.2	0.62	0.55	5.5	[19]
PTB4/PCBM	0.095	13.0	0.74	0.61	6.1	[19]
PCDTB: $PC_{70}BM$	0.127	10.593	0.88	0.64	6.0[a]	[20]
—[b]	0.043	10.321	0.81	0.72	6.0[a]	[21]
tandem PCDTB:PCBM/P3HT:$PC_{70}BM$ BHJ	0.045	7.8	1.24	0.67	6.5	[22]
Low band gap polymer[c] /PCBM	0.047	13.3	0.76	0.66	6.8[a]	[3]
Low band gap polymer***/PCBM	0.047			0.71	7.6[a]	[23]
Low band gap polymer[c] /PCBM	not mentioned				8.13[a]	[16]
Latest KONAKA record****	1 .031	14.46	0.816	0.72	8.3	

*** certificated by NREAL**
**** composition of the photoactive layer remains proprietary to Plextronics**

***** remains proprietary to Solarmer; **** remains proprietary to Konarka**

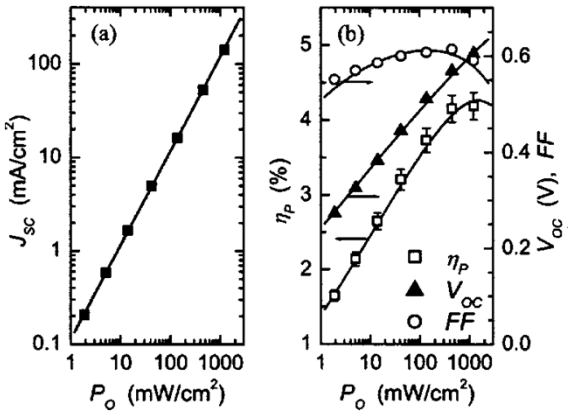


T. Tromholt, E. A. Katz, B. Hirsch, A. Vossier and F. C. Krebs.
***Appl. Phys. Lett.* 96, 073501 (2010).**



T. Tromholt, E. A. Katz, B. Hirsch, A. Vossier and F. C. Krebs. *Appl. Phys. Lett.* 96, 073501 (2010). **1 cm²**

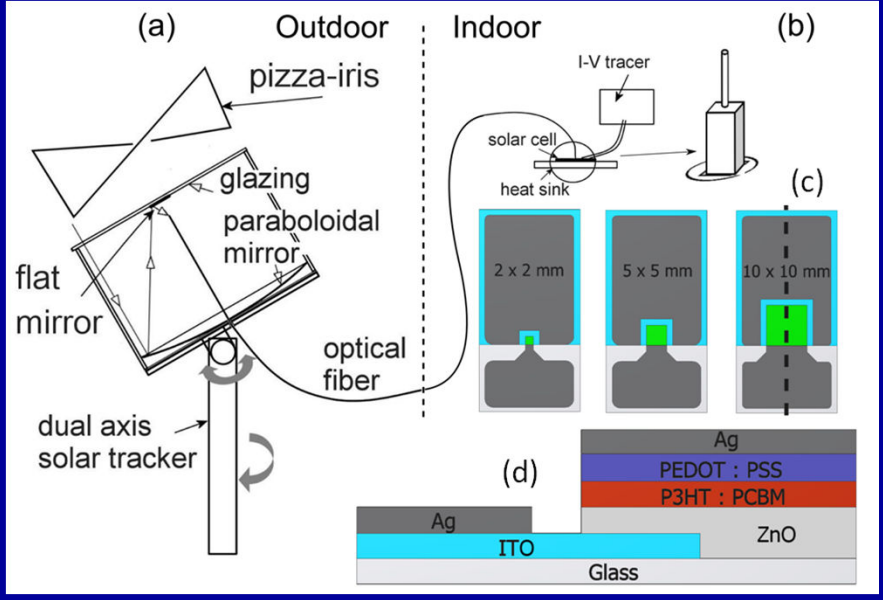
J. Xue, S. Uchida, B.P. Rand and S. R. Forrest, Appl. Phys. Lett. 84, 3013 (2004)



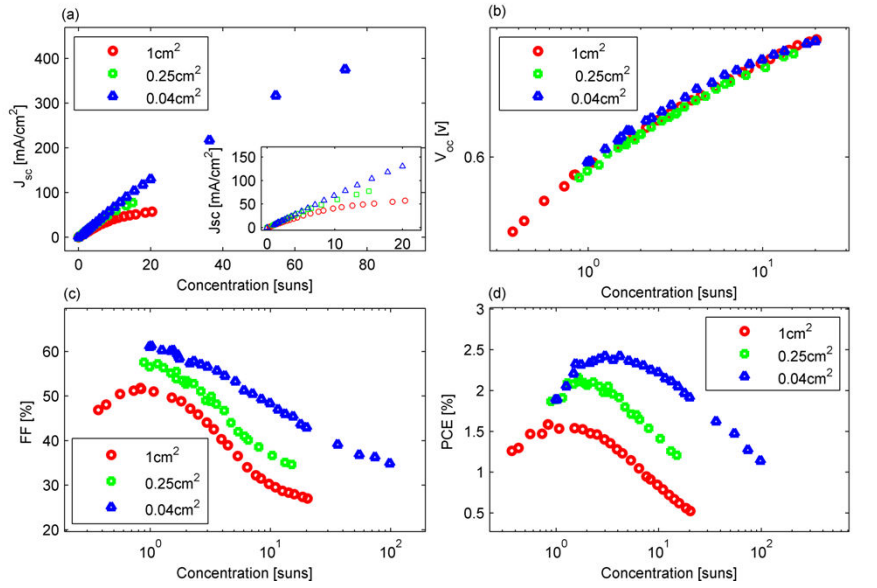
CuPc/C_{60} double-layer solar cell,

Active area of 0.0075 cm²

PCE = 4.2 % under 4-12 suns



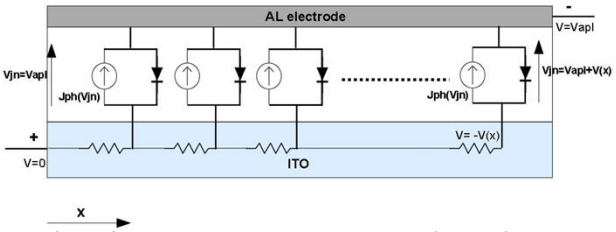
A. Manor, E. A. Katz, T. Tromholt, B. Hirsch and F. C. Krebs, *J. Appl. Phys.* 109, 074508 (2011).



A. Manor, E. A. Katz, T. Tromholt, B. Hirsch and F. C. Krebs, *J. Appl. Phys.* 109, 074508 (2011).

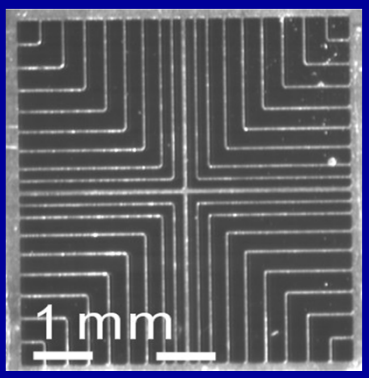
Hypothesis on the underlying mechanism of the size effect on *Jsc* and *FF* of OPV cells

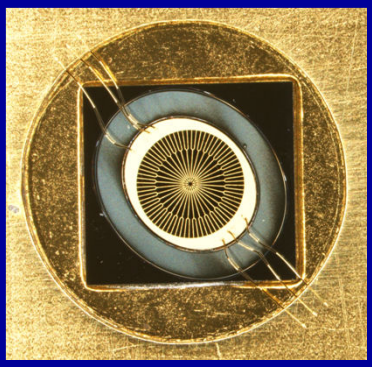
The observed results can be explained on the base of model of distributed series resistance of ITO front electrode in OPV or any other similar electrodes in which current flows parallel to the cell surface



The current density *J* is not constant along the device. It is clear that close to the left edge of the ITO layer, where the charges are extracted, the current density is the highest, while at the other end of the device the density must be zero. This is because the charged that flow from the side distant to the exit experience more series resistance.

Inorganic PV





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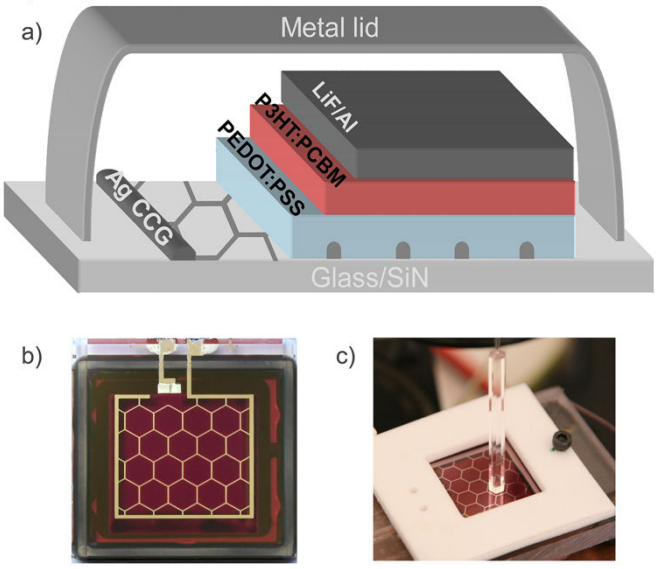
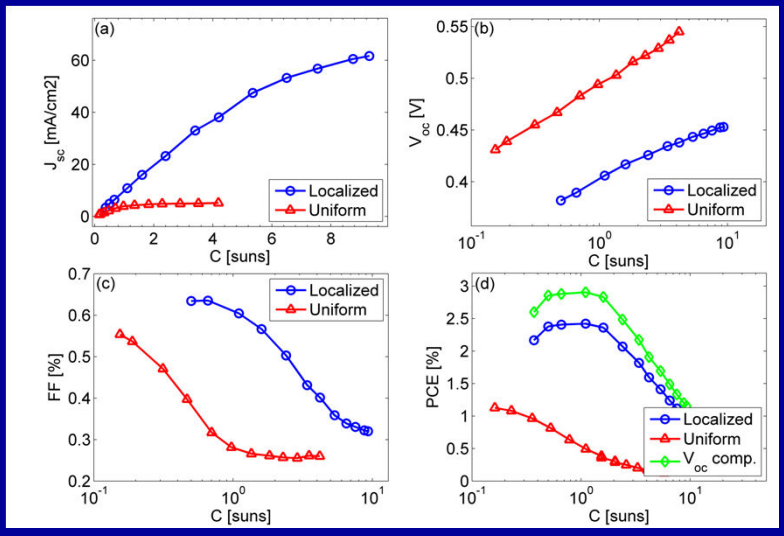


A. Manor, E. A. Katz, R. Andriessen and Y. Galagan, *Appl. Phys. Lett.*, in press



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2. Highly concentrated sunlight for accelerated tests of the OPV operational life-time

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Solar Energy Materials & Solar Cells 92 (2008) 727–731
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Flexible organic P3HT:PCBM bulk-heterojunction modules with more than 1 year outdoor lifetime

Jens A. Hauch[a,*], Pavel Schilinsky[a], Stelios A. Choulis[a], Richard Childers[b], Markus Biele[a], Christoph J. Brabec[a]

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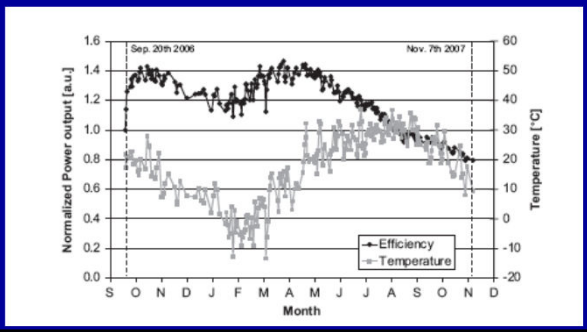
[b]Konarka Technologies Inc., 116 John Street, Suite 12, Lowell, MA 01852, USA



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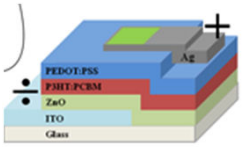
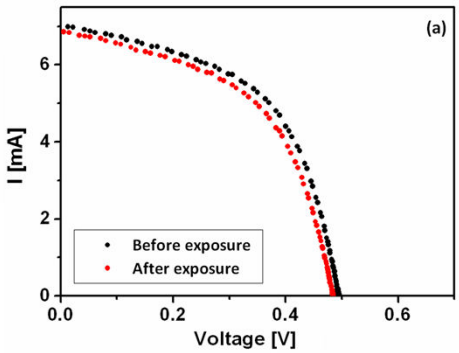
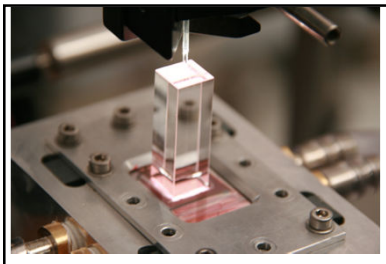


Active are of 1 cm²



I-V curves before and after 3 hours of light exposure (1 sun, 50°C).



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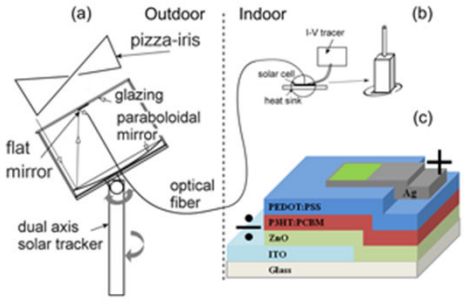
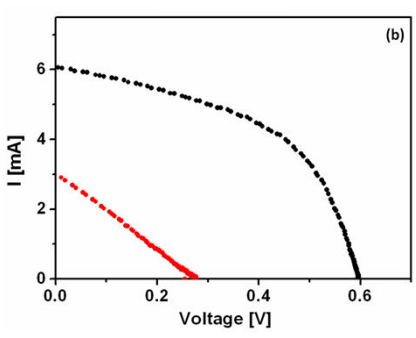
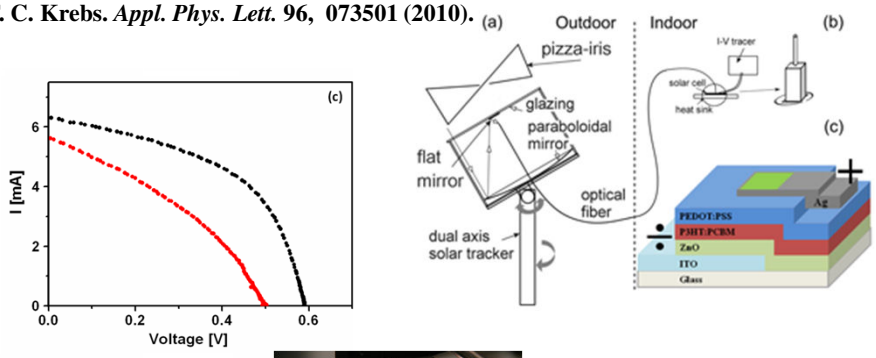


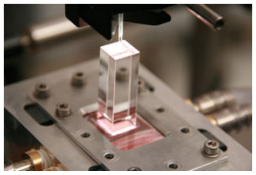


Active are of 1 cm²

I-V curves before and after 3 hours of light exposure (58 suns, 55°C).

T. Tromholt, E. A. Katz, B. Hirsch, A. Vossier and F. C. Krebs. *Appl. Phys. Lett.* 96, 073501 (2010).

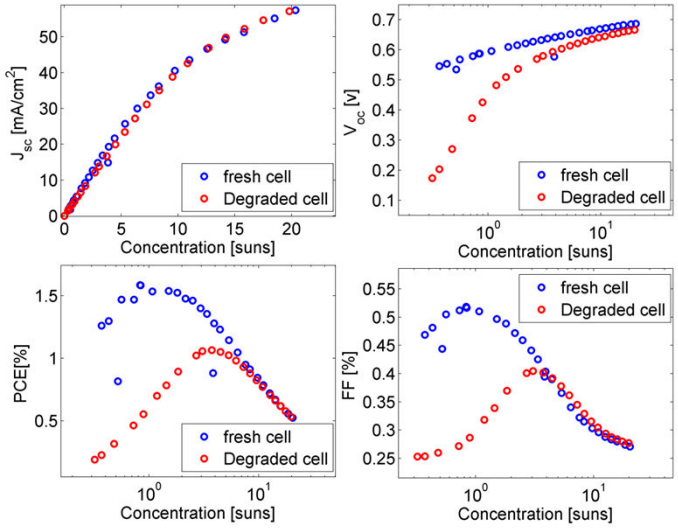




Active are of 1 cm²

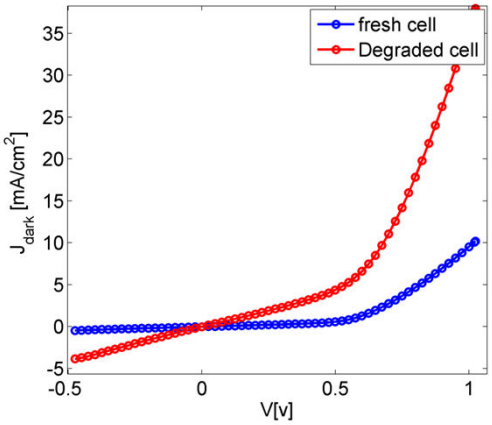
I-V curves before and after 3 hours of light exposure (55 suns, 30°C).

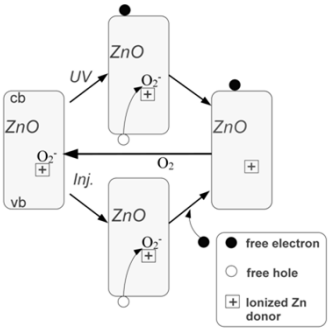
~5 suns, 100 minutes



T. Tromholt, A. Manor, E.A. Katz and F. C. Krebs. Adv. Energy Mater. 1, 836 (2011).

Dark J-V shows strong shunting effects: can be correlated to Voc decrease when understanding cell's current loss mechanisms





Shunting effects imply of non-selective contacts: current leakage decreases Voc, FF and efficiency.

Hence degradation effected one of the cell's blocking layers.

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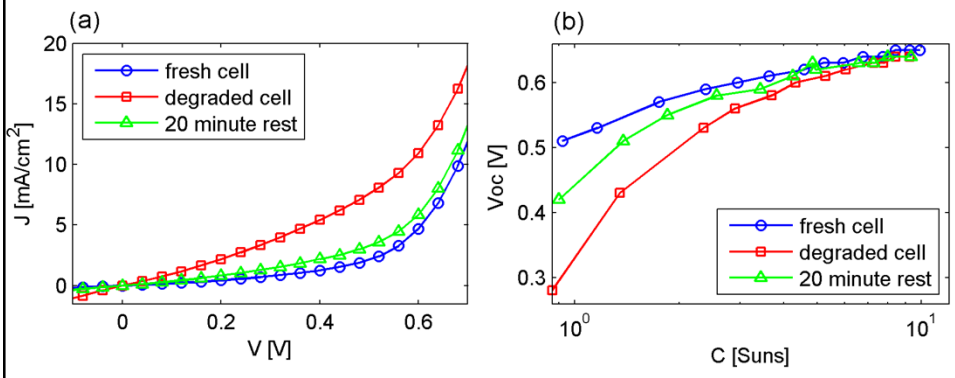
Reversible character of the degradation



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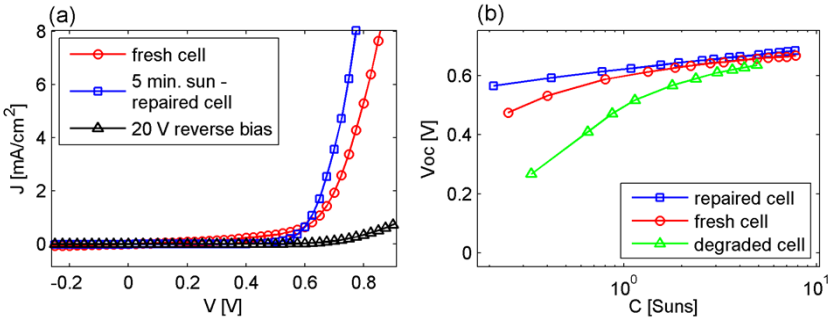
Applying short reverse bias pulses (-20 V for 2 seconds) resulted in even sharper recovery



Almost no initial shunting, although conduction in the injection regime was also sacrificed.

Natural sun treatment (1 sun, 5 min): recovery of injection conductivity while keeping shunting level minimized.

Conclusion

Concentrated sunlight is a very powerful tool for study PV performance and stability of organic solar cells (towards optimization of their efficiency and life-time)