Stability and degradation of organic photovoltaic devices fabricated, aged, and characterized by the ISOS 3 inter-laboratory collaboration

David M. Tanenbaum*[a,b], Martin Hermenau[c], Eszter Voroshazi[d], Matthew T. Lloyd[e], Yulia Galagan[f], Birger Zimmermann[g], Markus Hösel[a], Henrik F. Dam[a], Mikkel Jørgensen[a], Suren Gevorgyan[a], Suleyman Kudret[h], Wouter Maes[h], Laurence Lutsen[h], Dirk Vanderzande[h], Uli Würfel[g], Ronn Andriessen[f], Roland Rösch[i], Harald Hoppe[i], Monica Lira-Cantu[j], Gerardo Teran-Escobar[j],Agnès Rivaton[k], Gülşah Y. Uzunoğlu[l], David Germack[m], Birgitta Andreasen[a], Morten V. Madsen[a], Kion Norrman[a], and Frederik C. Krebs[a]

[a] *Department of Energy Conversion and Storage, Technical University of Denmark, Frederiksborgvej 399, DK-4000 Roskilde, Denmark.*
[b] *Department of Physics and Astronomy, Pomona College, Claremont, CA 91711, USA.*
[c] *Arbeitsgruppe Organische Solarzellen (OSOL),Institut für Angewandte Photophysik,Technische Universität Dresden, 01062 Dresden, Germany,*
[d] *imec, Kapeldreef 75, 3000 Leuven, Belgium and Katholieke Universiteit Leuven, ESAT, Kasteelpark Arenberg 10, 3000 Leuven, Belgium.*
[e] *National Renewable Energy Laboratory, Golden, CO 80401, USA.*
[f] *Holst Centre, High Tech Campus 31, 5656 AE Eindhoven, The Netherlands.*
[g] *Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstrasse 2, D-79110 Freiburg, Germany.*
[h] *Hasselt University, Campus, Agoralaan 1, Building D, WET/OBPC, B-3590 Diepenbeek, Belgium.*
[i] *Institute of Physics, Ilmenau University of Technology, Weimarer Str. 32, 98693 Ilmenau, Germany*
[j] *Centre d'Investigació en Nanociència i Nanotecnologia (CIN2, CSIC), Laboratory of Nanostructured Materials for Photovoltaic Energy, ETSE, Campus UAB, Edifici Q, 2nd Floor, E-08193, Bellaterra (Barcelona), Spain.*
[k] *Clermont Université, Université Blaise Pascal, Laboratorie de Photochemie, Moléculaire et Macromoléculaire (LPMM), BP10448 Clermont-Ferrand, France and CNRS, UMR6505, LPMM, F-63177 Aubière, France.*
[l] *TÜBİTAK National Metrology Institute (UME),Photonic and Electronic Sensors Laboratory, P.O. Box 54, 41470, Gebze, Kocaeli, TURKEY.*
[m] *Condensed Matter Physics, Brookhaven National Lab, Building 510B, Upton, NY 11973.*

Abstract

Seven distinct sets ($n \geq 12$) of state of the art organic photovoltaic devices were prepared by leading research laboratories in a collaboration planned at the Third International Summit on Organic Photovoltaic Stability (ISOS-3). All devices were shipped to DTU and characterized simultaneously up to 1830 h in accordance with established ISOS-3 protocols under three distinct illumination conditions: accelerated full sun simulation; low level indoor fluorescent lighting; and dark storage with daily measurement under full sun simulation. Three nominally identical devices were used in each experiment both to provide an assessment of the homogeneity of the samples and to distribute samples for a variety of post soaking analytical measurements at six distinct laboratories enabling comparison at various stages in the degradation of the devices. Characterization included current-voltage curves, light beam induced current (LBIC) imaging, dark lock-in thermography (DLIT), photoluminescence (PL), electroluminescence (EL), *in situ* incident photon-to-electron conversion efficiency (IPCE), time of flight secondary ion mass spectrometry (TOF-SIMS), cross sectional electron microscopy (SEM), UV visible spectroscopy, fluorescence microscopy, and atomic force microscopy (AFM). Over 100 devices with more than 300 cells were used in the study. We present here design and fabrication details for the seven device sets, benefits and challenges associated with the unprecedented size of the collaboration, characterization protocols, and results both on individual devices and uniformity of device sets, aged in the three illumination conditions for over 1500 hours.

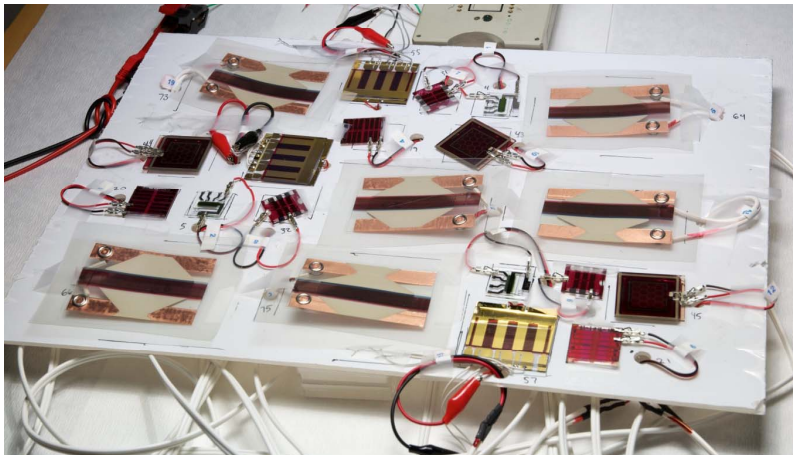

Figure 1. A series of different state of the art OPV devices during IV characterization under 1 sun illumination

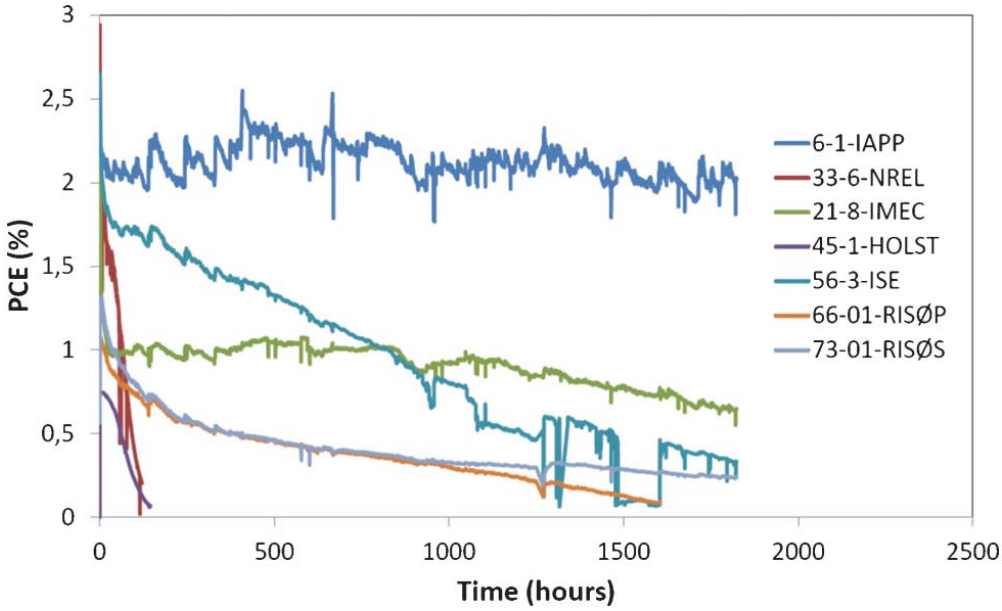

Figure 2. A plot of photovoltaic conversion efficiency (PCE) over time under 1 sun illumination for a series of different state of the art OPV devices.

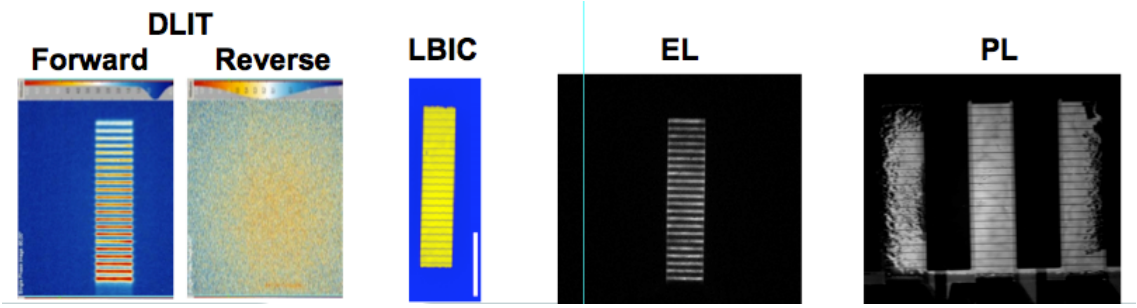

Figure 3. A series of different imaging techniques applied to a single OPV device. Each technique provides distinct but complementary information.

Relevant References

[1] D.M. Tanenbaum, M. Hermenau, E. Voroshazi, M.T. Lloyd, Y. Galagan, B. Zimmermann, M. Hösel, H.F. Dam, M. Jørgensen, S.A. Gevorgyan, S. Kudret, W. Maes, L. Lutsen, D. Vanderzande, U. Würfel, R. Andriessen, R. Rösch, H. Hoppe, M. Lira-Cantu, A. Rivaton, G.Y. Uzunoğlu, D. Germack, B. Andreasen, M.V. Madsen, K. Norrman, F.C. Krebs, *The ISOS-3 inter-laboratory collaboration focused on the stability of a variety of organic photovoltaic devices*., RSC Advances, 2 (2012) 882-893.

[2] R. Rosch, D.M. Tanenbaum, M. Jørgensen, M. Seeland, Maik Bärenklau, M. Hermenau, E. Voroshazi, M.T. Lloyd, Y. Galagan, B. Zimmermann, M. Hösel, H.F. Dam, S.A. Gevorgyan, S. Kudret, W. Maes, L. Lutsen, D. Vanderzande, U. Würfel, R. Andriessen, G. Teran-Escobar, M. Lira-Cantu, A. Rivaton, G.Y. Uzunoğlu, D. Germack, B. Andreasen, M.V. Madsen, K. Norrman, H. Hoppe, F.C. Krebs, *The ISOS-3 inter-laboratory collaboration- Investigation of the degradation mechanism of a variety of organic photovoltaic devices by combination of imaging techniques*., RSC Advances. In press, (2012).

[3] M. Lira-Cantu, G. Teran-Escobar, D.M. Tanenbaum, E. Voroshazi, M. Hermenau, K. Norrman, M.T. Lloyd, Y. Galagang, M.H. Birger Zimmermannh, Henrik F. Damb, Mikkel Jørgensenb, Suren Gevorgyanb, Laurence Lutseni, Dirk Vanderzandej, Uli Würfelh, Ronn Andriesseng, Roland Röschk, Harald Hoppek, Agnès Rivatonn, Gülşah Y. Uzunoğlul, David Germackm, Birgitta Andreasenb, Morten V. Madsenb, Eva Bundgaardb and Frederik C. Krebsb, *On the stability of a variety of organic photovoltaic devices by IPCE and in-situ IPCE analyses - The ISOS-3 inter-laboratory collaboration*., In Preparation (2012).