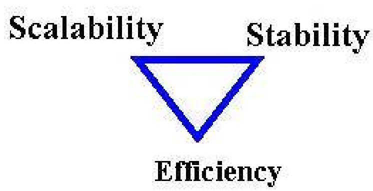
Prof. Eugene A. Katz

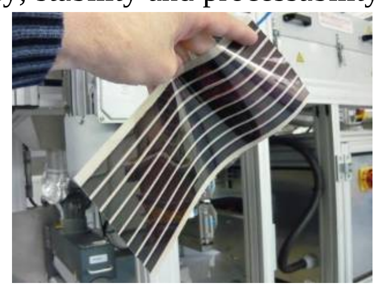
Nano-materials and Device Structures: with and for Solar Energy

Research activity is in four research directions:
(1) Photovoltaic (PV) characterization of fullerene/polymer solar cells and their stability (towards stable and efficient OPV);
(2) Development of organic PV cells with carbon nanotubes in the photoactive layer;
(3) PV characterization of multi-junction III-V solar cells under ultra-high flux of real sunlight;
(4) Novel concepts of ultra-efficient solar cells

PV characterization of fullerene/polymer solar cells and their stability [1-5]: In spite of the high potential of fullerene/polymer PV cells, considerable improvement of their stability needs to be achieved. In collaboration with RISØ National Laboratory (Denmark), Eindhoven University of Technology and other partners of the EC-FP7 grant LARGECELLS (www.largecells.eu) we study a long-term evaluation of photovoltaic performance of fullerene/polymer cells under real sun operation and accelerated conditions. In particular we have developed experimental approach of using concentrated sunlight for PV performance light-induced mechanisms of the degradation of organic solar cells.

The aim of the “LARGECELLS” project is to resolve the greatest challenge facing the development of organic PV devices and to combine high efficiency, stability and processability in a single device.





Publications:

1. T. Tromholt, A. Manor, E. A. Katz and F. C. Krebs. Reversible degradation of inverted organic solar cells by concentrated sunlight. **Nanotechnology,** 22, 225401 (2011).
2. A. Manor, E. A. Katz, T. Tromholt, B. Hirsch and F. C. Krebs. Origin of size effect on efficiency of organic photovoltaics. **J. Appl. Phys.** 109, 074508 (2011).
3. A. Manor, E. A. Katz, T. Tromholt and F. C. Krebs. Electrical and photo-induced degradation of ZnO layers in organic photovoltaics. **Adv. Energy Mater.** v.1, 836-843 (2011).
4. A. Manor, E. A. Katz, R. Andriessen and Y. Galagan. Study of organic photovoltaics by localized concentrated sunlight: towards optimization of charge collection in large-area solar cells. **Appl. Phys. Lett.** v. 99, 173305 (2011).
5. A. Manor and E. A. Katz. Open-circuit voltage of organic photovoltaics: Implications of the generalized Einstein relation for disordered semiconductors. **Solar Energy Mater. Solar Cells**, v. 97, 132-138 (2012).

Organic PV with carbon nanotubes (CNT) in the cell photoactive layer [1-4] (in collaboration with R. Yerushalmi-Rosen)**:** This is an ongoing effort to fabricate solar cells from nanocarbon materials. Present research aims on growth includes electrospinning of fibers comprising of CNT/ polymers and CNT/fullerene/ polymer blends and spin-coating of thin films, of similar compositions as well study of structure and properties of the materials. Being blended with conjugated polymers, CNT may not only act as electron acceptors but also allow the transferred electrons to be efficiently transported along their length, thus improving the cell efficiency. This project is conducted in collaboration with R. Yerushalmi-Rosen.

Publications:

1. C. Bonioux, C. Itzhak, R. Avrahami, E. Zussman, J. Frey, E. A. Katz and R. Yerushalmi-Rozen. Fibers of Functional nanocomposites of Poly(3-hexythophene) containing fullerene derivatives and carbon nanotubes. **J. Polymer Sci. B: Polymer Phys.**, v. 49, 1263-1268 (2011).

2. A. Konkin, C. Bounioux, A. U. Ritter, P. Scharff , A. Aganov, E.A Katz, G. Gobsch, H.Hoppe, G. Ecke and H.-K. Roth. LESR X-band study of morphology and charge carrier interaction in blended P3HT- SWCNT and P3HT- PCBM-SWCNT solid thin films. **Synth. Met.,** v. 161, 2241-2248 (2011).

3. A. I. Shames, C. Bounioux, E. A. Katz, R. Yerushalmi–Rozen, and E. Zussman. Light-induced electron paramagnetic resonance evidence of charge transfer in electrospun fibers containing conjugated polymer / fullerene and conjugated polymer / fullerene / carbon nanotubes blends. **Applied Physics Letters**, v. 100, 113303 (2012).

4. C. Bounioux, E. A. Katz and R. Yerushalmi – Rozen. Conjugated polymers - carbon nanotubes based functional materials for organic photovoltaics: a critical review. **Polymers for Advanced Technologies**, v. 23, 1129 (2012).

Multi-junction III-V concentrator solar cells under ultra-high flux of real sunlight and development of novel device architectures (in collaboration with J.M. Gordon and D. Feuermann) **[1-6]**: Multi-junction solar cells recently demonstrated conversion efficiencies above 40% under sunlight concetration of several hundred suns (1 sun ≡ 1 mW/mm^2). The trade-off of reducing costly solar cell material pushes the development of solar cells towards accepting ever-higher concentration levels. In practice, effective concentrations of 1000 suns and higher are feasible. The behavior of PV cells in this regime is far from fully understood. Testing is typically performed by exposing the cells to light under pulse solar simulators for very short periods of time. In contrast, we propose to characterize concentrator cells under continuous radiation using natural sunlight concentrated to ultra-high flux. With multi-junction cells of various devise architecture, we are investigating efficiency as a function of controlled variation of light intensity (ranging from 1 to 10,000 suns), spectrum, flux maps and cell temperature for variety of device architectures. Novel device architecture for ultra-high concentration PV has been suggested [4].

Publications:

1. A. Braun, B. Hirsch, E. A. Katz, J. M. Gordon, W. Guter, A. W. Bett. Localized irradiation effects on tunnel diode transitions in multijunction concentrator photovoltaics. **Solar Energy Mater. Solar Cells,** v. 93, 1692-1695 (2009).

2. A. Vossier, B. Hirsch, E. A. Katz and J. M. Gordon. On the ultra-miniaturization of concentrator solar cells. **Solar Energy Mater. Solar Cells,** v. 95, 1188-1192 (2011).

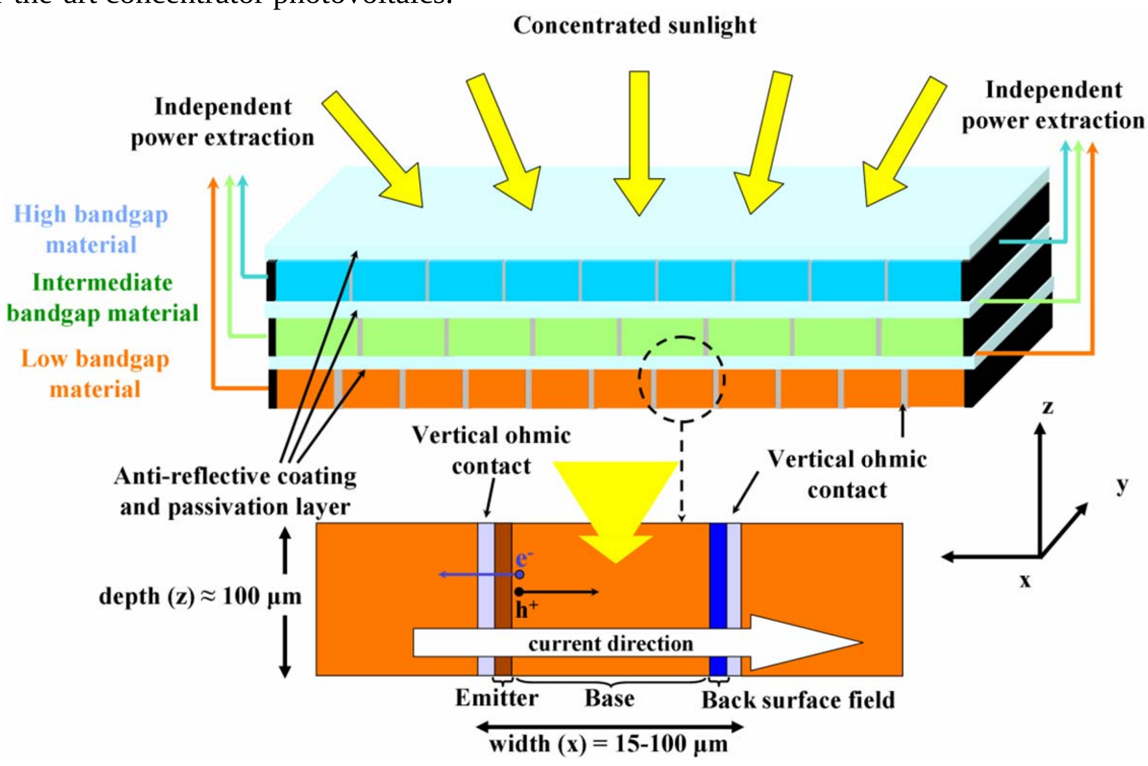
3. A. Braun, N. Szabó, K. Schwarzburg, T. Hannappel, E. A. Katz and J.M. Gordon. Current-limiting behavior in multijunction solar cells. **Appl. Phys. Lett.**, v. 98, 223506 (2011).

4. A. Braun, A. Vossier, E. A. Katz, N. J. Ekins-Daukes, J.M. Gordon. Multiple-bandgap vertical-junction architectures for ultra-efficient concentrator solar cells. **Energy and Environmental Science**, v. 5, 8523-8527 (2012).

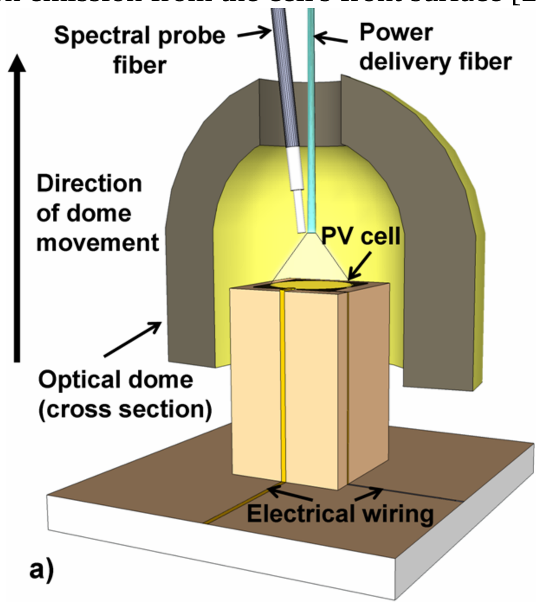
5. A. Braun, B. Hirsch, A. Vossier, E. A. Katz and J.M. Gordon. Temperature dynamics of multijunction concentrator solar cells up to ultra-high irradiance. **Progress in Photovoltaics: Research and Applications**, v. 21, 202–208 (2013).
6. A. Braun, E. A. Katz and J. M. Gordon. Basic aspects of the temperature coefficients of concentrator solar cell performance parameters. **Progress in Photovoltaics: Research and Applications**, in press.

Novel concepts of ultra-efficient solar cells (in collaboration with J.M. Gordon):

The quest for ultra-efficient photovoltaics (currently exceeding 40% conversion efficiency) has focused on strategies that conflate multiple bandgap materials and optical concentration. The solutions have essentially been deemed the exclusive realm of direct band gap III–V semiconductors, monolithically stacked, with the associated constraints of requiring tunnel diodes and current matching among the sub-cells. We have suggested a new unorthodox strategy, where deploying vertical-junction subcells in multiple layers creates the possibility of attaining comparable or even higher efficiencies with indirect bandgap materials (including silicon and germanium) [1]. These multiple-bandgap vertical-junction cells offer the possibility of autonomous power conditioning of each material (layer), eliminating the need for tunnel diodes and metallization grids and markedly lowering cell series resistance such that efficiency peaks at irradiance values of several thousand suns, which is noticeably higher than in current state-of-the-art concentrator photovoltaics.



Although one approach for improving the performance of ultra-efficient solar cells is through optical concentration (principally by increasing open-circuit voltage), an equally potent alternative is decreasing the cell's recombination current – an aim that can be realized by externally recycling cell photon emission. While the theory for the potential benefit of photon recycling has been elucidated, experimental proof-of-concept had proven elusive – requiring a photovoltaic device possessing a high external luminescent efficiency, combined with efficient light recycling optics. The associated prospect of approaching – and even surpassing – the nominally fundamental (Shockley–Queisser) limit for solar cell conversion efficiency is tantalizing and, in principle, achievable. Recently we have reported experimental evidence of enhancing the performance of today's champion singlejunction commercial GaAs cells by external recycling of photon emission from the cell's front surface [2].



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1. A. Braun, A. Vossier, E. A. Katz, N. J. Ekins-Daukes, J.M. Gordon. Multiple-bandgap vertical-junction architectures for ultra-efficient concentrator solar cells. **Energy and Environmental Science**, v. 5, 8523-8527 (2012).
2. A. Braun, E. A. Katz, D. Feuermann, B.M. Kayes, J.M. Gordon. Photovoltaic performance enhancement by recycling photon emission. **Energy and Environmental Science**, v. 6, 1499 - 1503 (2013).