

*Title: Advanced spectroscopy of organic and hybrid photovoltaic materials and thin-film solar cells*

**Abstract:**

Organic and recently particularly hybrid (perovskite) thin-film solar cells are progressing very fast, showing extraordinary performance. However, there is still a lack of fundamental understanding of charge carrier transport and recombination losses in these types of solar cells. The charge carrier lifetime and the mobility are two very important parameters in solar cells, as they define the diffusion length of the charge carriers and thus the efficiency. To determine them, various optical and electrical techniques can be applied. We will discuss the peculiarities and limitations of transient photo-voltage and photo-current techniques, such as open circuit voltage decay (OCVD), the small-perturbation transient photo-voltage (TPV) and charge extraction (CE) and the time-of flight (TOF). To fully understand recombination mechanisms in solar cells, it is essential to evaluate them under as large a range of illumination intensities as possible to assess which recombination pathway becomes dominant under each corresponding carrier concentration. As an example, we will discuss the OCVD technique. There we observed several time domains in the voltage transient. On a short timescale, a voltage drop due to free charge carrier recombination is observed and transients are qualitatively similar in organic and perovskite solar cells. [1] On longer times, a rapid voltage drop is often observed, however, these losses are not associated with the absorber material itself, but rather with the entire device. They are due to so-called shunts, which act as additional recombination pathway. By the proper choice of transport materials, it is however possible to remove the shunts and to study the devices under reduced illumination conditions, as charge carriers are efficiently blocked from recombining at the electrodes. [2]

Finally, to address the possible influence of electronic trap states on device performance, we probed the traps in organic and perovskite solar cells via thermally stimulated current (TSC) analysis. In this method the sample is initially cooled down, where trap states are subsequently filled optically. Then, the current flow is monitored upon heating the device up again. This very small current is attributed to charge carriers being thermally released from trap sites in the semiconductor bulk or at the interfaces, which allows to draw conclusions about their energy distribution, depth and density. [3] We will also discuss the influence of the chemical composition as well as morphology on the energetic trap landscape.

[1] A. Baumann et al., Appl. Phys. Lett. Mater. 2, 081501 (2014).

[2] K. Tvingstedt et al., ACS Energy Lett. 2, 424 (2017).

[3] A. Baumann et al., J. Phys. Chem. Lett. 6, 2350 (2015).

**Bio:**

Professor Vladimir Dyakonov holds the Chair of Experimental Physics (Energy research) on the Faculty of Physics and Astronomy of Julius-Maximilian University of Würzburg, Germany since 2004 and he is the Scientific Director of the Bavarian Centre of Applied Energy Research (ZAE Bayern) since 2005. He studied physics at the University of St. Petersburg and received his doctorate at the A. F. Ioffe Physico-Technical Institute in 1996. Since 1990, he has been a visiting researcher at the universities of Bayreuth (Germany), Antwerp (Belgium) and Linz (Austria). He finished his habilitation in experimental physics at the University of Oldenburg (Germany) in 2001. In 2007-2009 he was the Vice-dean of the Faculty of Physics and Astronomy, in 2010-2011 the managing director of Institute of Physics and in 2013-2015 he was the Dean of the Faculty of Physics and Astronomy at the University of Würzburg. Dyakonov's main research interests are in the fields of thin-film photovoltaics, semiconductor spectroscopy and functional energy materials, in general. He published 160 peer-reviewed scientific papers and has h-index of 52.

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