Gradients, tail states and radiative voltage losses in thin film solar cells

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The concept of radiative voltage loss due to absorption edge widening was introduced by Rau et al. [1]. Since then, more attention has been paid to the steepness of the absorption edge in solar cells. The absorption edge can be described by a distribution of step-function band gaps [1]. Also, Urbach tails have been used to describe the steepness of the absorption edge [2]. Sometimes, the two descriptions are used as equivalent [3].
We use a combination of transmission/reflection spectroscopy and photoluminescence (PL) spectroscopy for a full description of the absorption edge of absorbers. For solar cells, we use the combination of short circuit quantum efficiency (EQE) spectra with PL spectra and electroluminescence spectra.
Using CIGSe as an example, we have shown that the width of the band gap distribution and the Urbach energy of tails states are not correlated, and that the width of the band gap distribution depends critically on the presence of a band gap gradient throughout the film. Band gap distribution width above 40meV are only observed in samples that contain an intentional Ga gradient. The radiative loss in CIGSe solar cells is around 20mV, much smaller than the non-radiative loss, but not negligible. We will use literature data on CdTe solar cells, to analyse the influence of a bandgap gradient in these cells, as well. Potential microscopic origins for tail states and the band gap distribution widening will be discussed.

[1] U. Rau, B. Blank, T. C. M. Müller, and T. Kirchartz, Physical Review Applied 7, 044016 (2017).
[2] S. De Wolf, J. Holovsky, S.-J. Moon, P. Löper, B. Niesen, M. Ledinsky, F.-J. Haug, J.-H. Yum, and C. Ballif, The Journal of Physical Chemistry Letters 5, 1035 (2014).
[3] D. Abou-Ras, Journal of Vacuum Science & Technology A 42, 022803 (2024).