6.2.2 CELLO Research

- ***Cello*** stands for “solar CELl LOcal characterization”. As we know by now, its working principle is rather involved.
However, when we conceived CELLO, it looked not too difficult.
As it happens ever so often, CELLO resulted "by accident".
The story is cool enough to be given here.
- In 1998 we had a lot of young high-school students as guests of the Faculty of Engineering since we hosted the “Schleswig-Holstein Jugend Forscht” event. We decided to present something about solar cells. The idea was to take a finished solar cell made from the (then not very good) multi-crystalline Si, illuminate it and show that it produced some current and voltage at some load resistor. Then we wanted to demonstrate that the silicon contained good and bad regions. To show that, we covered a good region by a small piece of paper and that lowered the current substantially while the voltage changed only slightly. Then we did the same thing with a bad area, producing only a small change in current (since the bad area was not contributing much in the first place) and some slight voltage change.
This worked quite well but induced us to wonder if we could quantify the “slight voltage changes”. Of course my part of the “we” (i.e. J. Carstensen and I) couldn't, but Jürgen Carstensen could.
First it was realized that scanning a dark spot over an illuminated sold cell produced data different from scanning a light spot over a dark solar cell (i.e. the established “Light Beam Induced Current or LBIC technique). Then it dawned on us that you didn’t have to scan a dark spot (not easy to do) but that it was enough to induce a local disturbance of an illuminated solar cell by scanning a modulated laser beam.
    - That was already a complicated enterprise. Your held a solar cell at some fixed point on its I-V characteristics, meaning you needed a constant high-intensity full area illumination and either a constant current or voltage power supply. Fixing illumination and current would produce a constant voltage, fixing illumination and voltage produced a constant current, respectively.
    Now you disturb some small local area by hitting it with a light-beam that is intensity modulated with a certain frequency. The system can only respond by a (small) change of the voltage (if you run it galvanostatically) or the current (if you run it potentiostatically). You record amplitude and phase shift of the response.
    If your illuminated spot is small (for good spatial resolution), your response signal is very small, too. That means that your global illumination intensity and the current / voltage supply has to be extremely stable to allow monitoring very small deltas - something not easy to do. Next you repeat the measurement with a different modulation frequency.
    In other words: You are essentially doing some kind of local impedance spectroscopy.
    Even better, you may employ more than just one Laser, using different wave lengths and thus penetrations depths. The most sophisticated CELLO system that we built used four co-axial Lasers, all modulated with several superimposed frequencies, and the response was collected in real time by doing a FFT analysis to extract the various modulation frequencies.
    We are talking soothing like 400.000 lines of software by now and extremely sophisticated hardware.
- All you need on top of that is a theory that relates the measured data to the solar cell data. This, as it turned out, is a tricky undertaking. Doing it, however, allowed to extract all relevant solar cell parameters and to create maps of these parameters in real time.
    - Cello, in other words, is an extremely sophisticated piece of hardware and software. I'm rather proud of it, notwithstanding the fact that my personal contribution was minor (plenty of of discussions and supplying the needed resources, i.e. money).
    The real heroes were:
    J. Carstensen who did the theory and wrote the software,
    G. Popkirov who designed and built the electronic part of the hardware,
    J. Bahr who designed and built the system, in particular the optics and the (temperature controlled) specimen stage
- CELLO still is the most advanced and versatile instrument for characterizing a solar cell. Standard techniques like LBIC relate to CELLO like a light microscope to a transmission electron microscope (TEM). And just like a TEM, it requires operators with a profound knowledge of solar cell physics and advanced math.

Publications

- There are plenty of publications (starting with No. 110); consult the list
Her I will give you a power point presentational from 2013 first.
    - Jan Martin Wagner, Jürgen Carstensen "CELLO"
    It gives a brief and well illustrated overview of the technique.
    One paper will suffice, all the others are easily accessible.

275 J. Carstensen, A. Schütt, and H. Föll, "CELLO FFT impedance analysis as a routine tool for identifying various defect types on crystalline silicon solar cells", in Proc. 24th European Photovoltaic Solar Energy Conference, 1AO.4.5, Hamburg (2009).

Pictures

The pictures in a lot of publications are black and white but there are enough color ones too. I do not need to supply a lot here, in other words.
I'll just let you have a few that happen to be still around in my conputer.

CELLO Pictures