Acknowledgement Solland Solar Cells BV

Solar cell characterization

From reliability testing to materials analysis

Electricity from solar or photo-voltaic (PV) cells is one of the most promising sources of sustainable energy. PV cells and modules consist of advanced materials and are manufactured using high-tech processes. Progress in PV technology requires fast and reliable materials characterization, both for cell and module manufacturers as well as materials and equipment suppliers. MiPlaza offers a broad portfolio of test, measurement and analysis services and expertise in the field of photo-voltaic devices.

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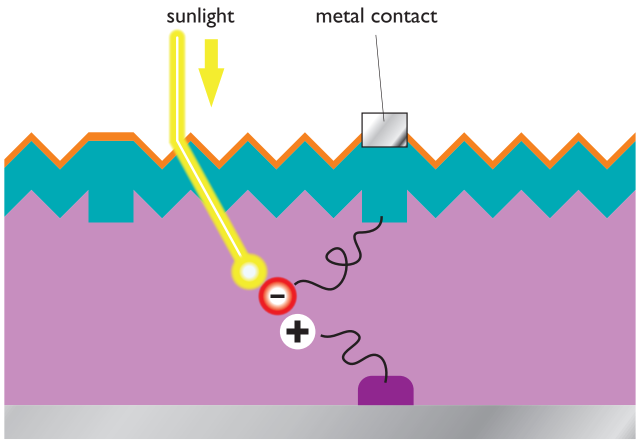

Fig. 1: Schematic drawing of a solar cell.

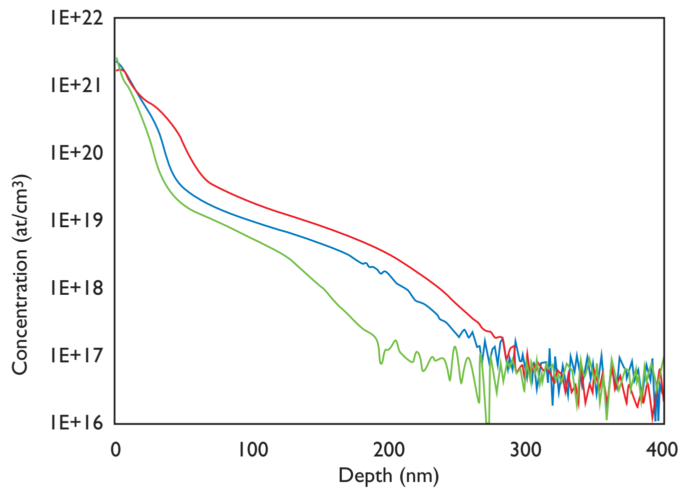

Fig. 2: Concentration depth profiles of phosphorous in silicon, measured using SIMS, of wafers with three slightly different P diffusion process conditions.

Photo-voltaic cell: principle

A photo-voltaic (PV) cell converts light into electricity. Photons penetrating the solar cell are absorbed in a semiconductor material. As a result, electron-hole pairs are generated (see figure 1). Most types of PV cells have an internal electric field (due to a so-called p-n junction) forcing the excited electrons to drift towards the n-doped layer, while holes drift in the opposite direction. By placing metal contacts on the top and bottom of the PV cell, the resulting current can be used externally.

PV materials

PV cells can be made using various semiconducting materials. The vast majority of commercially available cells are made of bulk-Si, mono- or multi-crystalline. Competing technologies are based on CdTe, $CuIn_xGa_{1-x}Se_2$ (CIS or CIGS), GaAs or other III-V materials, or thin-film amorphous Si (a-Si). Finally, emerging PV technologies make use of polymer or small-molecule organic compounds, or metal-organic dyes (DSSC) as light-absorbing materials. Many more materials are necessary for e.g. internal reflection, surface passivation, electrical connection, encapsulation and support.

Dopant diffusion

The p-n junction in (bulk or thin-film) silicon PV cells is typically created by diffusing an excess of n-type dopants into homogeneously p-doped Si (or vice versa). The exact shape of the n-dopant (phosphorous) depth profile is very important for the electro-optic properties of the solar cell. Dopant depth profiles are characterized using Secondary Ion Mass Spectrometry (SIMS). SIMS has extreme sensitivity (down to ppb-level), dynamic range (5 or more orders of magnitude) and depth resolution (1 nm is possible). Figure 2 shows an example of fine tuning the phosphorous depth profile using SIMS.
The total amount of phosphorous, the concentration close to the surface, the junction depth and the slope of the phosphorous profile around the junction are important parameters used in modeling PV cells.

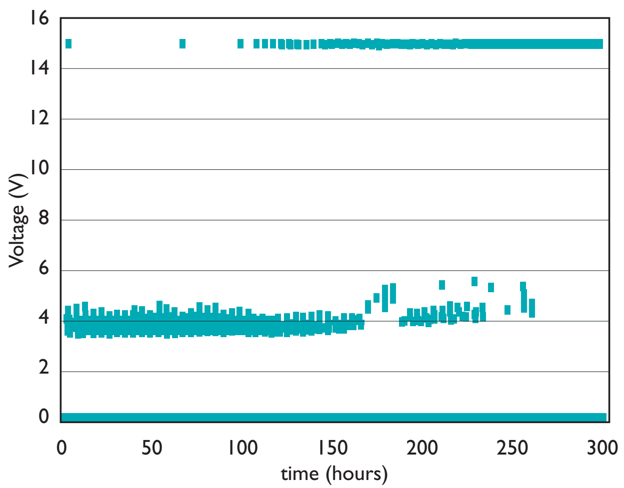

Fig. 3: Thermal cycle test. Current is only flowing above 20°C. The 4V level represents normal operation yield from 1 sun illumination. The 15 V level indicates an open contact.

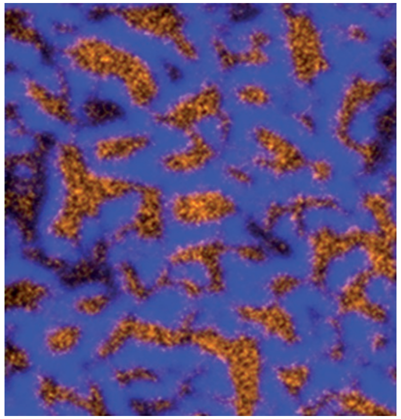

Fig. 4: Imaging of the polymer surface, showing regions of PCBM (orange) and PPV (blue).

Reliability testing

The combination of the MiPlaza Reliability Centre - hosting various types of climate chambers (damp heat, temperature cycle, temperature shock, …) - with MiPlaza's analytical expertise allows us to offer not only dedicated analytical requests, but also to gain insight in reliability, life time, defect engineering and more.

Thermal cycling is one of the standard accelerated lifetime tests for solar cell modules. Current is allowed to flow through the modules and at the same time, the temperature is cycled between -40 °C and 85 °C. Usually, good quality modules pass this test. However, poor soldering quality between cell and electrical contacts may introduce failures. Figure 3 shows an example of the response plot of a failing module; already in the first 50 hours of cycling, a contact failed once upon temperature rise. After 260 hours, the module had failed irreversibly.

Segregation in polymer solar cells

Another analysis technique available from MiPlaza is Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). This type of analysis is applied in the development of a highly efficient, large-area polymer solar cell. The active material consists of a mixture of an electron-donor material (PPV) and electron acceptor material (PCBM). Photo-induced electron transfer from donor to acceptor takes place across the interface between donor and acceptor regions. Nanoscale mixing of donor and acceptor is essential for performance of the device, as the diffusion length of the exciton is limited to ~10 nm. ToF-SIMS was applied to study the lateral distribution of the two components (see figure 4).

In addition, concentration depth profiles (resolution typically 5 nm) were made to study (interface) contamination and layer-to-layer diffusion. Due to the very low detection limits, good lateral resolution and fast parallel detection of signals, ToF-SIMS is a very suitable technique to use in the R&D and production control of polymer solar samples.

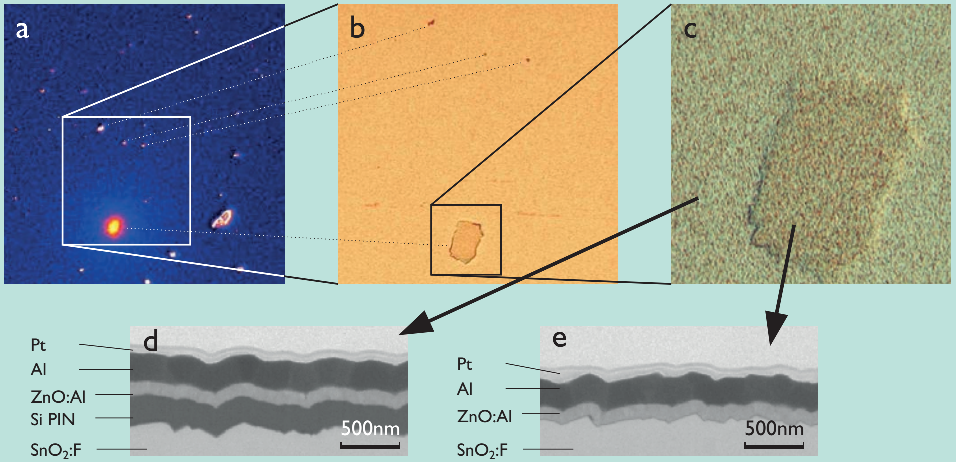

Fig. 5: failure analysis: a) The large red and yellow point in the thermographic picture indicates the position of the shunt. The other white points are dust particles. b) Optical microscopy image of the same defect. Dotted lines connect identical features in figures a and b. c) More detailed optical microscopy image. d and e) SEM images of the cross-sections outside and in the defect area, respectively. The SiPIN layer is missing at the location of the defect.

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Failure analysis of shunts

The production yield of thin film amorphous silicon solar cells is lowered by the appearance of shunts. An essential first step in failure analysis is their localization in shorted cells. Lock-in thermography is a powerful technique for detection of these defects. This technique is based on the application of a periodically pulsed electrical signal to the PV cell. Any defects dissipating energy lead to periodically oscillating local heat sources that are imaged by the IR camera. The lock-in technique has a sensitivity that is considerably better than any other direct thermal imaging technique. After exact localization of the heat sources (figure 5a), a subsequent inspection can be performed using optical microscopy (figures 5b and c). For root cause analysis, using a Focused Ion Beam (FIB) a cross-section can be prepared exactly at the position of interest. Subsequent scanning electron microscopy (SEM) studies (figures 5d and e) on the cross-section show that the Si PIN layer is absent at the position of the defect (figure 5e). Thus, the ZnO:Al of the back-contact is in immediate contact with the SnO_2:F of the front-contact, explaining the shunt.

Other competences:

MiPlaza's portfolio of reliability and analytical capabilities with respect to photo-voltaic cells is continuously expanding. Examples are:

- Grain size and texture of thin films of poly-Si, ZnO, etcetera
- Permeability of encapsulating foils
- Molecular analysis of ageing of polymer foils
- Interface reactions & corrosion
- Surface topography of anti-reflection textures
- Lifetime testing of complete modules

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