Local probe microscopies for the study of III-V based solar cells

M. da Lisca[1,2,3], J. Alvarez[1,2,3], Amadeo Michaud[1], Oleksandr Bilousov[1], J.P. Connolly[1,2,3], Stéphane Collin[1,4], J.-P. Kleider[1,2,3]
1 Institut Photovoltaïque d'Ile de France, 30 Route Départementale 128, 91120, Palaiseau
2 Université Paris-Saclay, CentraleSupélec, CNRS, Laboratoire de Génie Electrique et Electronique de Paris, 91192, Gif-sur-Yvette
3 Sorbonne Université, CNRS, Laboratoire de Génie Electrique et Electronique de Paris, 75252, Paris
4 Centre for Nanoscience and Nanotechnology (C2N), CNRS, University Paris-Sud / Paris-Saclay, 91120 Palaiseau

Over the last decade, substantial advances in material and solar cell device engineering have produced significant progress in the development of photovoltaic (PV) technologies. As a result, solar cells have evolved into elaborate structures with numerous layers and interfaces. The characterization of the different building blocks constituting the devices increasingly requires the capacity to carry out local analyses at the nanoscale level yielding information on electronic properties of materials and interfaces. In particular, III-V-based solar devices belong to the PV technology of thin and ultra-thin films in which layers with width of the order of a few nm are often integrated for an optimal surface passivation or for better carrier extraction, considerably enhancing the device efficiency [1].

In this work, we have applied local probe microscopies in ambient conditions for the analysis of a GaAs multilayer stack and solar cell along their cross-sections. In particular, Kelvin probe force microscopy (KPFM) and Resiscope have been used in order to investigate the local surface potential (that is reflected in the measurement of the contact potential difference V_{CPD}) and the local current along the structure, respectively. The current maps were acquired applying different voltages to the samples (from -1 V to + 1V) to replicate the typical voltage range used in the current-voltage (I-V) characterization.

Both techniques provided a successful detection of the whole multilayer structure. Note that, Resiscope is performed in contact mode to assure a stable electrical contact between the AFM tip and the sample. For this reason, the resolution of the current map (Figure 1c) is higher with respect to the V_{CPD} image (Figure 1b), since KPFM is performed in non-contact mode at 10 nm from the surface. Nevertheless, KPFM revealed a strong dependence on the local doping concentration providing a complete detection of the GaAs multilayer stack which exhibited different color contrast in the V_{CPD} image [2].

The measurements were performed in dark conditions and under illumination to directly image the local surface potential variations induced by the application of the light and to measure the local photogenerated current. Furthermore, the acquisition of the $V_{CPD/light}$ signal enabled the evaluation of the surface photovoltage (SPV). As a final step, we have correlated the local SPV to the macro-V_{OC} of the solar cell. In particular, by measuring the SPV on the surface of the GaAs solar cell (planar configuration) as function of the illumination power density we find the same dependence as for V_{OC} from the light-generated current I_l according to: $n\frac{kT}{q}\ln\left(\frac{I_l}{I_0}\right) = V_{OC} = E_{Fn} - E_{Fp} = SPV$, with n=2 at low intensity (<0.2 kW/m²) and n=1 at high intensity (>0.5 kW/m²).

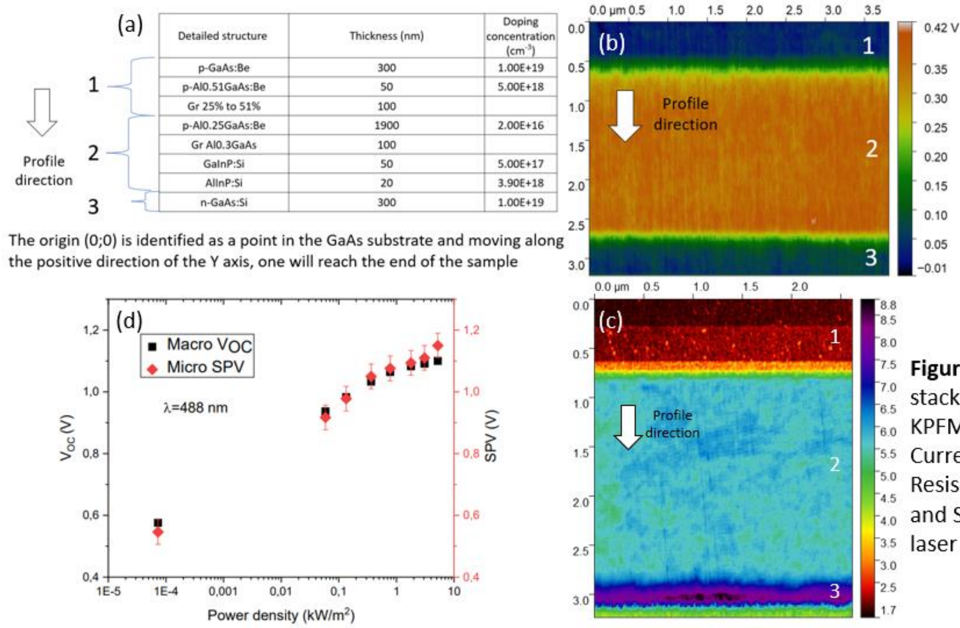

Figure 1: (a) GaAs multilayer stack; (b) V_{CPD} map acquired by KPFM in dark conditions; (c) Current map acquired by Resiscope applying 1 V; (d) V_{OC} and SPV in function of a blue laser (488 nm) power density.

[1] M.A. Green et al.: Solar cell efficiency tables (version 59) (2021)
[2] M. da Lisca et al.: EPJ Photovoltaics Vol 13, No 19 (2022)