Three-dimensional numerical simulation of rear point contact solar cells

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High efficiency single-crystal solar cells (SCs) commonly adopt a rear point contact surface with bottom passivation to reduce recombination losses at the back of the device and enhance the internal bottom reflection coefficient. The main drawback of the rear point contact scheme is the relatively larger parasitic series resistance due to the spreading base contribution and to the back contact resistance. Still, PERL (passivated emitter, rear locally diffused) SCs have shown conversion efficiencies above 20%.

Three-dimensional (3D) numerical simulations can model carrier transport occurring in rear point contact SCs and hence optimize the device design, as well as study the impact of the loss mechanisms. We used Sentaurus TCAD [1] for electrical simulations, while the optical generation rate map inside the semiconductor was calculated using an internally developed tool based on electromagnetic plane wave propagation. In order to achieve realistic predictions, the physical TCAD models have been calibrated as described in [2], including band-gap-narrowing [3], velocity saturation at high electric fields [4], doping-dependent carrier lifetimes [5], and surface recombination velocities at front and rear passivated interfaces [6]. The surface velocity at electrodes was set to 10^6 cm/s and parasitic resistances at the front and back contacts were modeled with a post-processing tool.

We find the main figures of merit of a rear point contact cell as a function of the metallization fraction for different values of substrate resistivity. We further analyze the PERL SC by computing the efficiency as a function the metallization fraction at constant hole pitch, variable contact hole diameter, and different substrate resistivity values. Our analysis shows the metallization fraction to be a fundamental parameter in the design of a rear point contact cell. For relatively small values of metallization fraction, the series back-contact resistance and the base parasitic spreading resistance become significant, leading to larger fill factor degradation. On the other hand, large values of metallization fraction lead to larger recombination losses as well as lower effective internal bottom reflectivity. The optimum metallization fraction is strongly dependent on the p^+ local diffusion, specific back-contact resistivity, base doping concentration, as well as the contact size. In order to enhance the efficiency in a rear point contact design, both the specific back-contact resistivity and the hole size have to be minimized; however, simulations have highlighted that the former parameter is the most sensitive to the optimization. Once the specific back-contact resistivity and the hole size are minimized, the substrate resistivity clearly plays a crucial role in determining the maximum efficiency. Our simulations show that the optimum design of a rear point contact cell is only weakly sensitive to the uncertainties of the main geometrical parameters, like the hole size and the hole pitch.

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