The GEMINI Concept: A New Efficient Method To Modelize Local Effects In Solar Cells

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I. INTRODUCTION

SINCE modern solar cells exhibit more and more complex structures, the simulation has become necessary to explore their optimization range. This approach requires reliable and predictive simulations, i.e. that account for all mechanisms significantly impacting the cell performance under all conditions. On the other side, solar cells are always analyzed through their I(V) characteristics under illumination. However a fine analysis of the cell behavior under darkness also brings helpful informations on the cell or/and material quality (shunts, recombinations, etc…). Thus simulations of solar cells would ideally be able to reproduce their behavior both under darkness and illumination.

The widely used two diodes model [1], or the PC1D program [2], indeed useful to analyze data, rely on too many simplifying assumptions, leading to poor predictivity. On the contrary the physical basis of TCAD allows for predictive simulations [3]. Standard TCAD methodology takes advantage of the periodicity of the cell design to build a 2D-cut, which represents about 98% of the whole device. In this way the CPU time is fully optimized. However this standard methodology neglects localized phenomena, such as shunts or high traps density areas, though representative of the material quality.

The aim of this paper is to present the *GE*neral *M*ethod for *I*lluminated and *N*ot *I*lluminated (GEMINI) simulations. This new concept is used to take into account localized phenomena, within a physically-based TCAD environment. The GEMINI allows the physical simulation of solar cells I(V) characteristics under both dark and illumination, without noticeable extra CPU time.

II. RESULTS AND DISCUSSION

To validate the GEMINI concept we applied it on a crystalline silicon, homojunction, n-type technology. 125 pseudo-square solar cells were fabricated at INES (National Institute for Solar Energy) on a pilot line with industrial process.

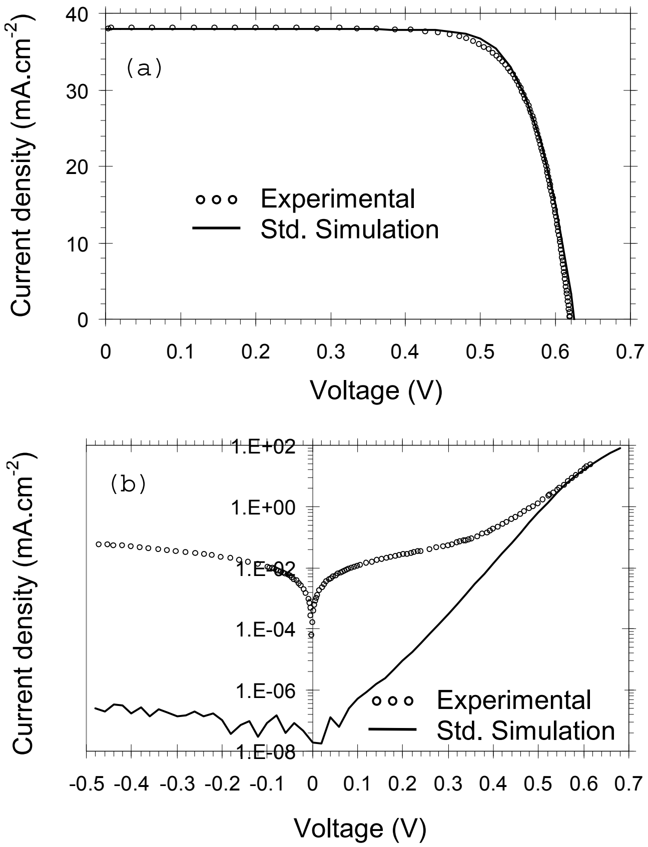

Fig. 1. I(V) characteristics under (a) illumation and (b) darkness simulated with standard TCAD methodology, compared with experimental data.

Our modelization is based on the standard TCAD methodology with usual set of models and parameters, able to fit the I(V) characteristics under 1 sun (see Fig. 1 (a)). However as shown on Fig. 1 (b) the experimental I(V) characteristics under darkness is not reproduced by simulation.

So standard simulations only feature an ideal diode behavior under darkness, whereas the introduction of traps in the depletion region damages the whole diode behavior (including under illumination, not shown), preventing any proper calibration. Thus we use the GEMINI to introduce localized traps. Accounting for the local nature of traps allows the modelization of a parasitic current, which is actually a recombination current. The effect of traps on dark I(V) with the standard and GEMINI concepts is shown in Fig. 2.

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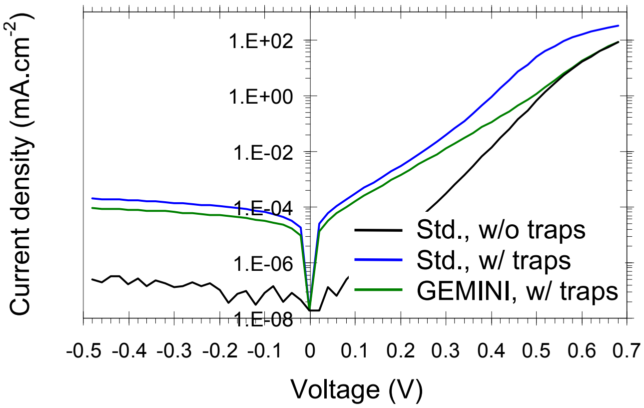

Fig. 2. Simulated I(V) under darkness without (black) and with (blue) traps in the standard TCAD methodology, and with traps with the GEMINI (green).

But the impact of localized traps is not yet satisfying. To get a correct calibration of the dark current it is necessary to add a local shunt of the junction, with the GEMINI. Here again "local" means *localized in the cell and not shunting the whole device*, a specific parasitic behavior that can be modelized only with the GEMINI. Fig. 3 shows the effect of a local shunting with respect to standard TCAD simulation.

The combination of both local traps and a local shunt with the GEMINI leads to a perfect fit of the experimental data (Fig. 4 (a)). It's worth noticing that calibration of I(V) characteristics under illumination is not damaged, as shown in Fig. 4 (b), but is even enhanced in the kink. This double fit has been made possible by including all main mechanisms driving the cell behavior. Thus experimental trends are now expected to be predictible in any condition. For instance the temperature behavior under darkness has been reproduced without any additional parameter fitting (also shown in Fig. 4 (a)). This is the evidence of the robustness of the GEMINI approach.

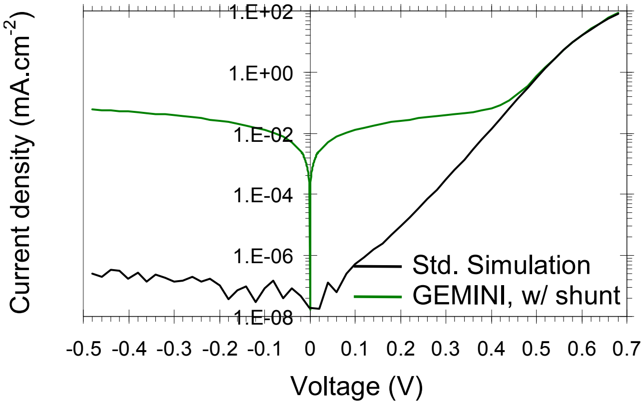

Fig. 3. Simulated I(V) under darkness with the standard TCAD methodology (black curve), and with a local shunt with the GEMINI (green curve).

III. CONCLUSION

We presented here the GEMINI, a new modelization approach for taking local phenomena into account. GEMINI is based on physical TCAD simulations and does not rely on arbitrary mathematical functions. The validity of the GEMINI has been demonstrated on the simulation of n-type silicon solar cells, both under illumination and darkness conditions at different temperatures. Simulation of solar cells in such a wide range of conditions has been performed with a unique set of models and parameters. This new capability gives the opportunity to use TCAD simulation as a "characterization tool" for fast and fine analysis of the main physical mechanisms responsible for the cell behavior. Meanwhile taking into account such global and local mechanisms allows for high level of predictivity, thus allowing for a cheap and precise optimization of the cell design.

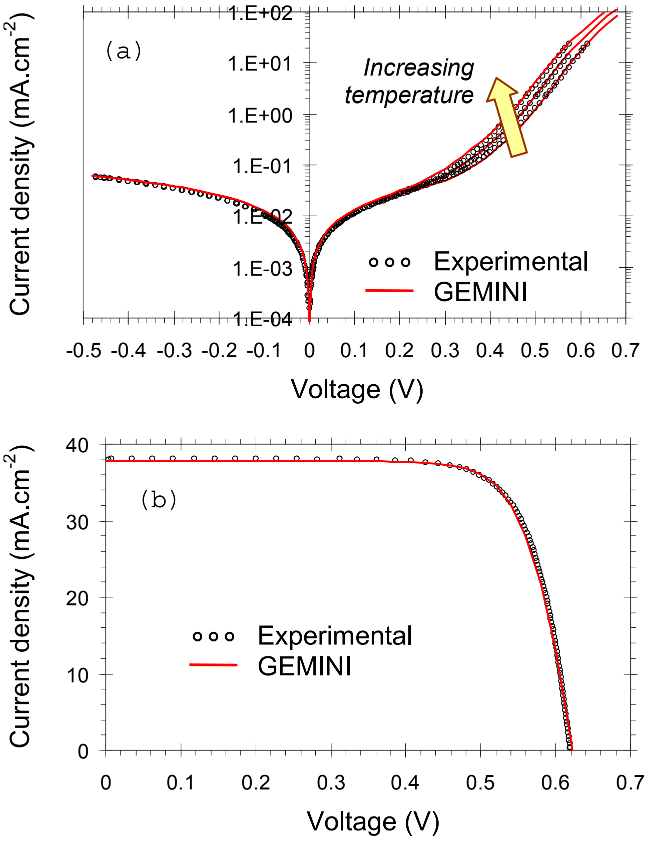

Fig. 4. I(V) characteristics (a) under darkness at 25, 35, 45°C, and (b) under illumination simulated with the GEMINI, compared with experimental data.

The GEMINI can be used on all large area semiconductor devices for which localized phenomena are important. In the photovoltaic domain for example low bias current under darkness was still misunderstood [4]. However it can easily be explained and modelled with the GEMINI, which has become very helpful for simulating not only silicon homo- or heterojunction solar cells, but also non-silicon cells.

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