Two-Dimensional Simulations of Thin-Silicon Solar Cells

T.H. Wang, M.R. Page, and T.F. Ciszek

National Renewable Energy Laboratory
1617 Cole Blvd., Golden, CO 80401
mailto: tihu_wang@nrel.gov

1. Introduction

Quantitative analysis or numeric simulation on a cross-section of silicon devices offers many insights into understanding material problems and their effects on device performances as well as device structure optimizations. Such two-dimensional simulations on semiconductor devices are standard design practices and are routinely done with expensive software packages. The availability of less expensive software tools nowadays, such as MicroTec® [1] for 2D modeling of semiconductor devices, affords us a more detailed examination of polycrystalline thin-silicon materials and solar cells.

MicroTec® is based on the diffusion-drift model and does not include energy balance. It has a robust 2D semiconductor device simulator component that efficiently solves the Poisson equation and the continuity equation for electrons and holes with a finite difference technique on a rectangular grid. Only steady-state problems are possible, but the built-in models consider many physical effects such as bandgap narrowing, recombinations (Shockley-Read-Hall [SRH], Auger, radiative, and surface), impact ionization, band-band tunneling, photogeneration, metal-semiconductor contacts (ohmic and Schottky), and concentration- and field-dependent mobilities. This paper presents three case studies that are of interest to polycrystalline thin-silicon solar cell research, the so-called "bad" region effect, grain boundary effect, and device optimization using interdigitated contacts.

2. Inhomogeneity effect

A polycrystalline material having a "bad" region that is photoelectrically inactive and electrically conductive can lead to a severe shunting problem. Figure 1(a) is the schematic representing such a "bad" region of 1 μm in width and 10 μm in length in a 20-μm thick and 20-μm wide device. Simulation results in Fig. 1(b) show that the effect on cell performance really depends on the extent of the defects. Fig.1(c) and (d) show the enhanced SRH recombination in the "bad" region and the resulting non-equilibrium electron and hole concentration distribution at y=5 μm.

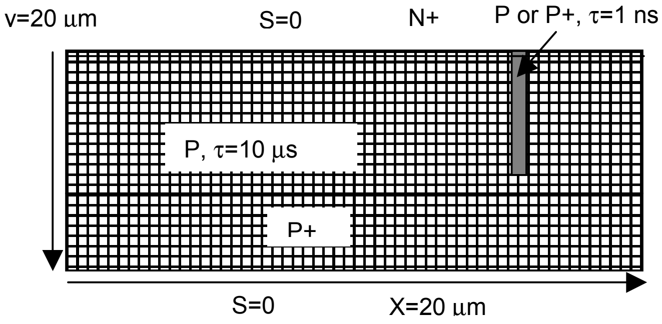


Fig. 1 (a) Model device cross-section with a "bad" region

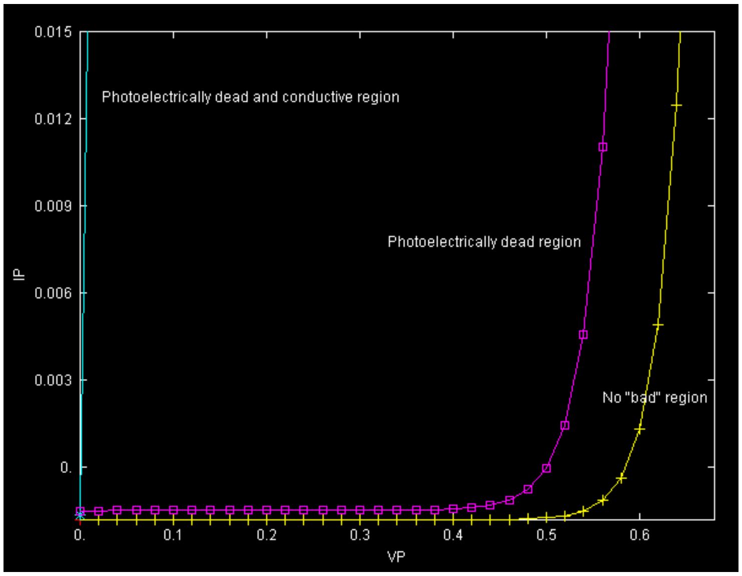
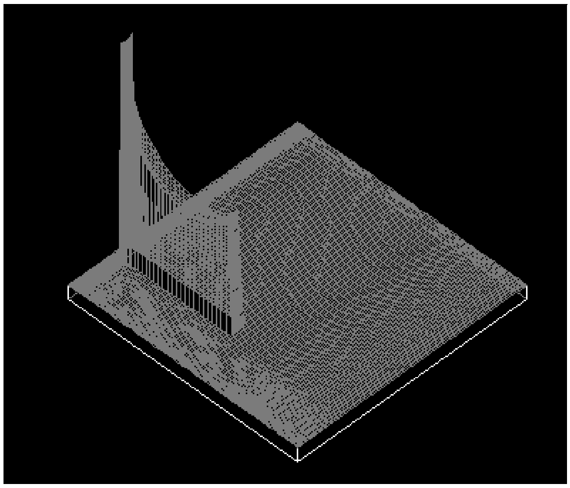


Fig. 1 (b) The corresponding I-V curves



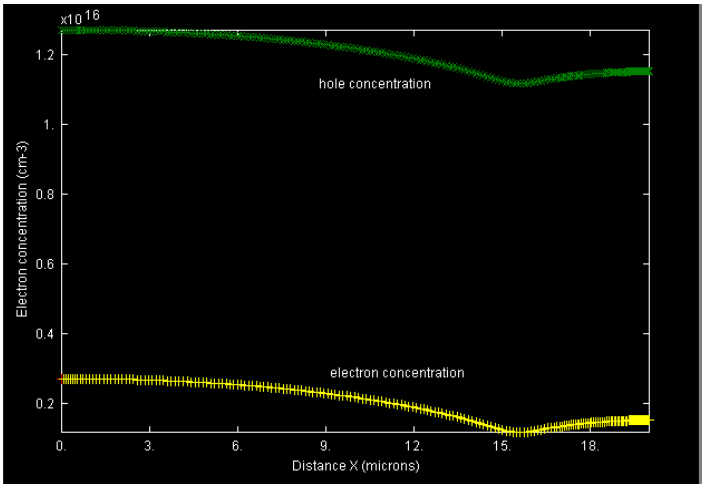


Fig. 1 (c) SRH recombination rate (cm^{-3})

Fig. 1 (d) electron and hole concentration at y=5 µm

If the “bad” region is only photoelectrically inactive (with a minority carrier lifetime of 1 ns) but not electrically conductive, then only a small impact is seen which is caused by increased dark current in the “bad” depletion region. However, if the region is also electrically conductive (represented by degenerate doping), the effect is catastrophic even if the “bad” region does not reach the back contact.

3. Grain boundary effect

The grain boundary recombination activity may be represented by an effective recombination velocity. Fig. 2 shows a sketch of a simple N+/P/P+ thin silicon device with a total thickness of 20 µm and an average grain size of 20 µm. The simulation domain consists of half of a grain (the cross-hatched area). The grain boundary runs vertically across the junction. The calculated IV curves are given in Fig. 3(left) with recombination velocities at the grain boundary varying from 10^{2} to 10^{6} cm/sec. It is seen that for a grain size of 20 µm, a recombination velocity lower than 10^{4} cm/sec is necessary to avoid significant loss of performance. This velocity, however, has to be lowered to 10^{3} cm/sec for a grain size of 2 µm, as shown in Fig. 3(right).

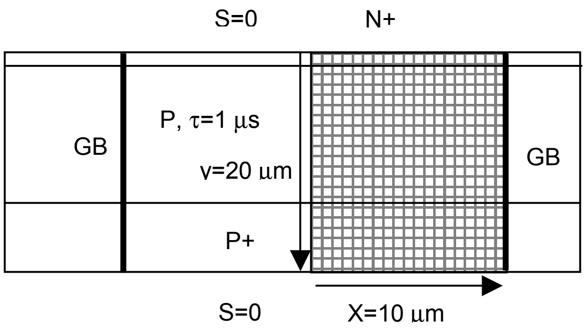


Fig. 2 Sketch of a polycrystalline silicon solar cell having a thickness of 20 μm and average grain size of 20 μm. The shaded area is the simulation domain.

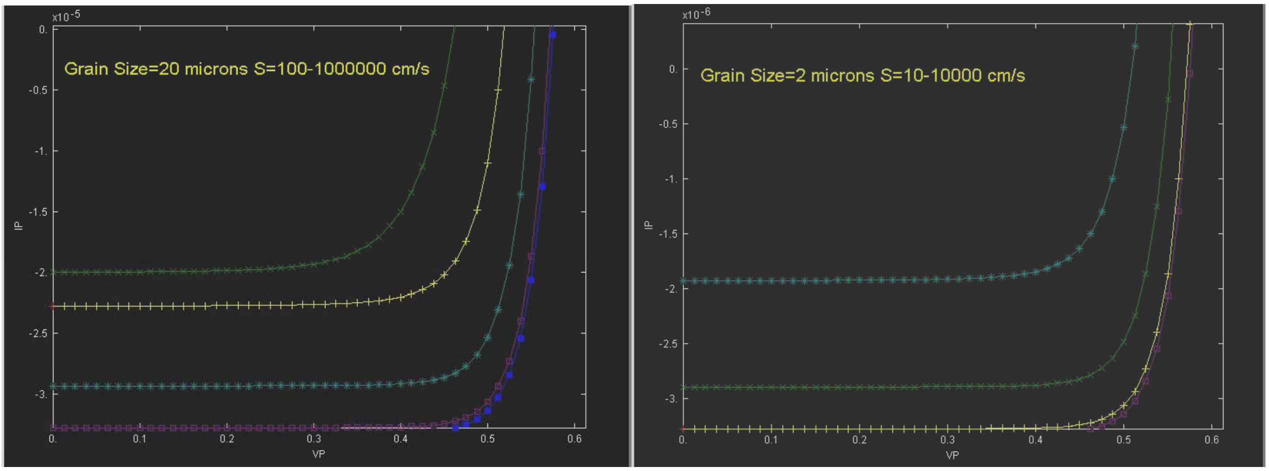


Fig. 3 (left) Simulated IV curves for a thin silicon solar cell with a grain size of 20 μm. The curves from top to bottom are for recombination velocities of 10^6, 10^5, 10^4, 10^3, and 10^2 cm/sec, respectively. (right) Simulated IV curves for a thin silicon solar cell with a grain size of 2 μm. The curves from top to bottom are for recombination velocities of 10^4, 10^3, 10^2, and 10 cm/sec, respectively.

4. Optimizing device designs

A device structure of interdigitated contacts on the same surface of a thin-silicon film has many advantages over a conventional planar structure such as simplified processing and connections, especially when an insulating substrate is used that makes it possible to monolithically integrate cells to sub-modules.

Analytically speaking, the spacing between the alternating N- and P-contacts is limited by twice the effective diffusion length of the minority charge carriers. However, with 2D simulations, we may optimize the design, and a much larger spacing on the order of 100 μm can be used even when the diffusion length is only about 20 μm, making screen-printing the contacts a possibility. Figure 4 shows some examples of varying device parameters and the corresponding I-V curves.

5. Conclusions

Two-dimensional simulation of thin-silicon solar cells is very useful to gain further understanding of material problems and their effects on device performances as well as to aid device design optimizations. Three case studies are presented on the so-called “bad” region effect, grain boundary effect, and device optimization using interdigitated contacts.

If a “bad” region is only photoelectrically inactive but not electrically conductive, then only a small impact is seen which is caused by increased dark current in the “bad” depletion region. However, if the region is also electrically conductive (represented by degenerate doping, not even reaching the back contact), the effect is then catastrophic. The effects of grain boundary recombination on device performances are examined with grain sizes of 2 and 20 µm respectively, and it is found that 10^4 cm/sec recombination velocity is adequate for 20 µm grain-sized thin silicon whereas a low recombination velocity of 10^3 cm/sec must be accomplished for a 2µm grain-sized silicon. 2D simulation indicates that it is possible to design a thin-silicon device with interdigitated contatcts that has an intercontact spacing large enough to use the screen-printing technique.

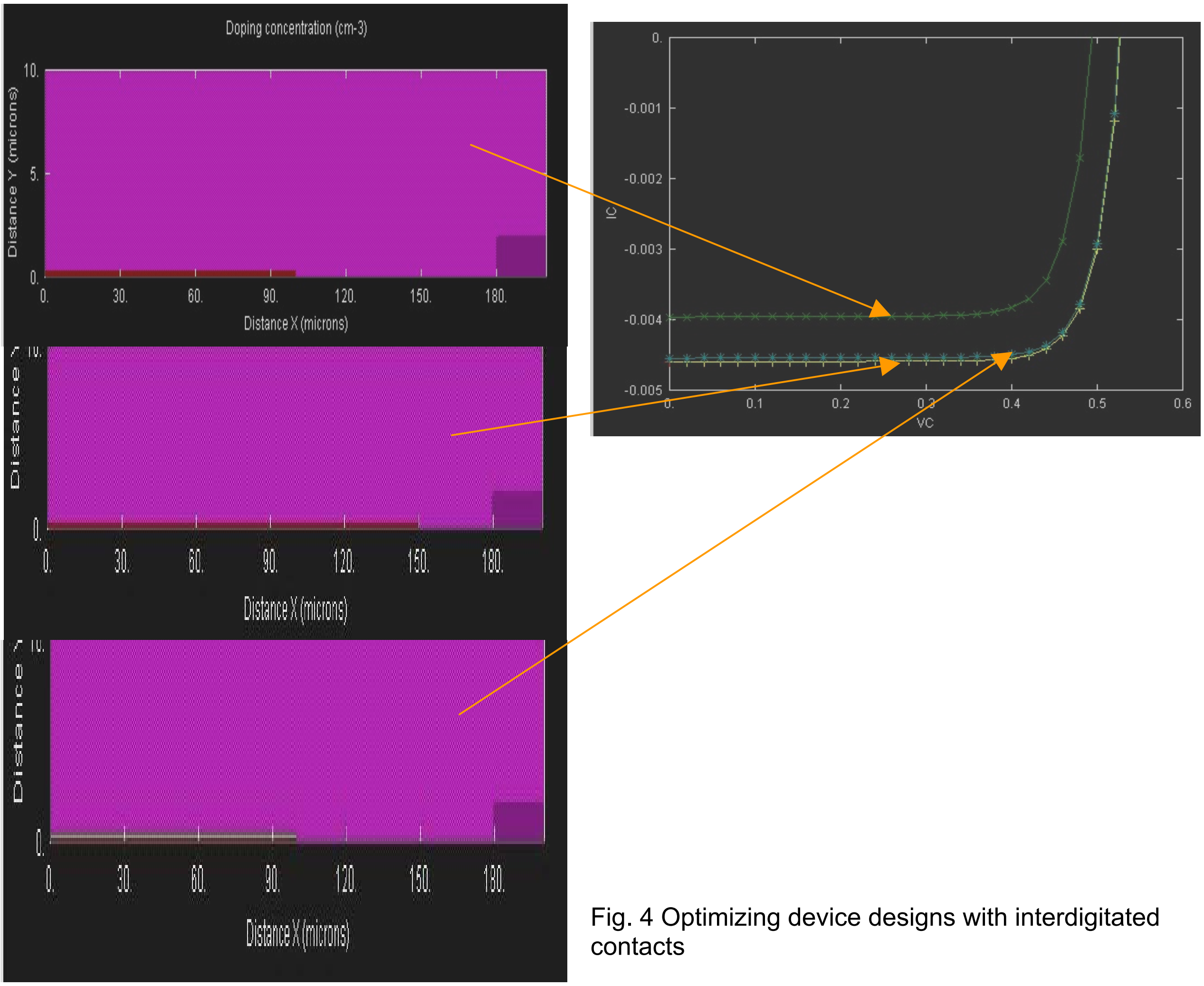


Fig. 4 Optimizing device designs with interdigitated contacts

Acknowledgement

This project was supported by the U.S. Department of Energy under contract No. DE-AC36-99-GO10337 to the National Renewable Energy Laboratory.

Reference

[1] Siborg Systems Inc., *MicroTec User’s Manual*,1998