Simulations of photo- carrier decay on heterojunction with intrinsic thin layer (HIT) solar cells with *n*-type wafers

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***Abstract* -This work presents simulations of photo-excited minority carriers decay in HIT cells. The photo-carrier decay is analyzed as a function of light pulse duration, c-Si material quality and external parameters such as voltage bias and temperature. The simulation results can help interpret capacitance transient as well as photovoltage decay measurements.**

I. INTRODUCTION

The extension of photovoltaic energy usage is directly dependant on the cost reduction and the conversion efficiency increase. Heterojunction with intrinsic thin layer (HIT) cells are very promising candidates for high efficiency/low cost photovoltaic power devices. These devices have an advantage of lower deposition temperature and cost over the "classical" homojunction c-Si cells [1, 2]. HIT cells with *n*-type wafers have achieved efficiencies of 22.3% [3]. Despite the excellent performance achieved, the device physics still remains unknown. A variety of characterization techniques is used to clarify the transport and recombination mechanisms. However, due to the complexity of the devices, the interpretation of characterization results is often challenging. Here we use numerical simulations to help interpret capacitance transient results and learn about the dominant transport mechanisms at the c-Si/a-Si:H heterojunction.

II. MODEL

Sentaurus Device software by Synopsys was used for modeling [4]. The material parameters used in the HIT cell simulations are published elsewhere [5]. The illumination is monochromatic with a wavelength of 600 nm. A schematic of a typical HIT cell is shown in Fig. 1. The heterojunction is formed between *n*-type c-Si wafer and a *p*-doped a-Si:H layer. A thin intrinsic a-Si:H layer is inserted between them for surface passivation. In addition to providing good surface passivation, a-Si:H creates a valence-band offset with c-Si that can be an obstacle for photo-carrier transport. The transport across the heterointerface is simulated by thermionic emission and tunneling.

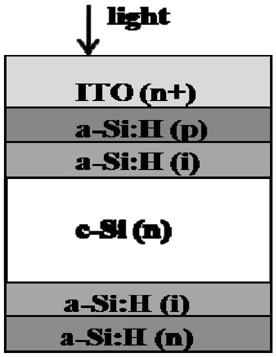

Figure 1. Schematic of a HIT solar cell with *n*-type wafer.

III. RESULTS

When a HIT device is illuminated, excess carriers are generated within the c-Si, and their density exponentially decreases with the distance from the interface. The light generated minority carriers can either be transported across the junction, via thermionic emission or tunneling, or can recombine within the bulk c-Si. To see which mechanisms prevail, we are monitoring how the hole density 5 nm from the c-Si/a-Si:H interface varies with time.

Fig. 2 shows hole density vs. time for different durations of the illumination pulse. With longer illumination time, the number of generated minority carriers increases. The thermionic emission current as well as the tunneling current increase with the number of carriers, but also do the recombination mechanisms within the bulk c-Si. For a specific duration of the light pulse,10 ms in Fig. 2, the capture and emission of carriers balance each other, and the hole density at the interface no longer increases with increased light pulse. The

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experimental and simulated data show similar trends.

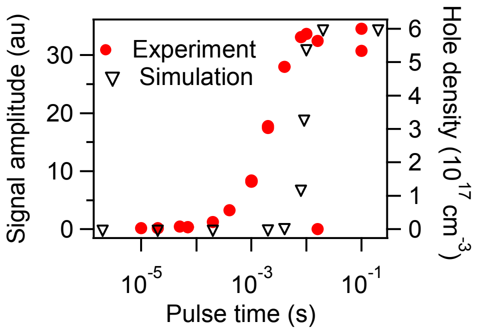

Figure 2. Capacitance transient measurements on HIT cells (circles) and simulated minority carrier density as a function of pulse time (triangles).

Next we analyze how the c-Si defects affect minority carrier decay once the light is switched off. The simulated results are plotted in Fig. 3. The light pulse length is 10 μs. The capture cross section for holes in the c-Si defects is varied for an order of magnitude between two curves. Simulations show two exponential decays: a faster one, with lifetimes less than a millisecond and a slower one, with larger lifetimes. The recombination in the bulk c-Si affects the faster one significantly more than the slower one.

As the dominant recombination mechanism is often observed to vary with temperature, it is important to study temperature dependant lifetimes. Fig. 4 shows temperature dependence of hole density at t = 1 ms after the light has been switched off. As the temperature increases, the higher generation rate competes with the increased recombination. As the bias increases, the space-charge region width decreases and more holes are generated outside of the electric field. Therefore, more holes will diffuse within the absorber rather than be transported over the interface barrier.

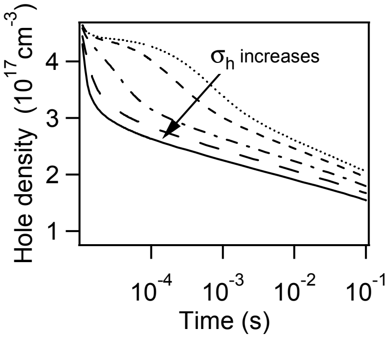

Figure 3. Simulated hole decay as a function of time.

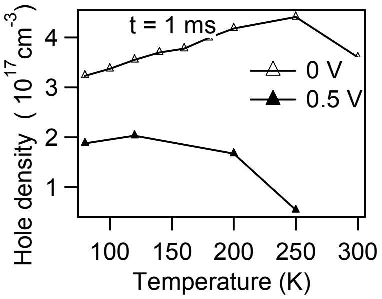

Figure 4. Temperature dependence of minority carrier density at 0 and 0.5 V bias.

Simulations with higher wavelength illumination (not plotted) confirm this. With our choice of parameters, the decay rates overcome the higher generation for $T > 250$ K at 1 ms in zero bias, and for $T > 120$ K at 0.5 V bias.

CONCLUSIONS

We have explored the minority carriers' behavior after a short light pulse illumination. We have found that the bulk c-Si properties are responsible for the fast decays and that the minority carriers will recombine faster in forward bias.

ACKNOWLEDGEMENTS

The authors are thankful to Charles Teplin for reviewing the manuscript and suggestions.

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08-GO28308 with the National Renewable Energy Laboratory. This paper is subject to government rights.

REFERENCES

1. M. Taguchi, H. Sakata, Y. Yoshimine, E. Maruyama, A. Terakawa, and M. Tanaka, in *Proc. 31 IEEE PVSEC* (2005), p. 866.
2. M. Taguchi, et al., Progress in Photovoltaics **8**, 503-513 (2000).
3. S. Taira, et al, in *22^{nd} EU PVSEC* (Milan, 2007), pp. 932-936.
4. Synopsis, "TCAD DEVICE Manual" www.synopsis.com, (Zurich, Switzerland, 2006).
5. A. Kanevce, and W. K. Metzger, Journal of Applied Physics **105** (2009).