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Evaluations of TOPCon Solar Cell Rear Structure on Numerical Simulations

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Abstract

TOPCon (Tunnel Oxide Passivated Contact) is a very new c-Si solar cell structure with potential of higher cell efficiency. TOPCon has advantages of higher open-circuit voltage (*Voc*) and fill factor (*FF*) because of its 1D carrier transport compared to other cell structures of 3D carrier transports. In this study, TOPCon solar cell rear structure properties are evaluated on numerical simulations. Optimum rear tunnel oxide and thin-Si film thickness are shown based on p-type Si wafer with bulk lifetime of 100 µs.

1. Introduction

A TOPCon (Tunnel Oxide Passivated Contact) is a new c-Si solar cell structure proposed by Fraunhofer ISE in 2014 [1], which has high open-circuit voltage (V_{OC}) and fill factor (*FF*) because of its 1D carrier transport compared to other high efficiency c-Si solar cell 3D carrier transports. TOPCon is a very new cell structure and needs fundamental researches. TOPCon has a rear tunnel oxide near rear electrode region, suppressing carrier recombination at rear region. The rear structure property is an important cell parameter for TOPCon structure, determining carrier transport and recombination rate. In this study, rear tunnel oxide thickness and thin-Si film properties are evaluated on Sentaurus Technology-Computer Aided Design (TCAD) software provided by Synopsys, Inc. [2]. Cell performances are evaluated for TOPCon rear structure properties, showing the design guidelines to get higher cell efficiency.

2. Physics

A TOPCon solar cell structure has a tunnel oxide near rear electrode region (see Fig. 1). Feldmann et al. reported the basis of TOPCon is introduced in detail [3]. TOPCon solar cell has two advantages of improving both V_{OC} and *FF*. The improving of V_{OC} arises from suppressing rear surface recombination velocity (SRV) by passivating rear electrode region of fast SRV, and smaller effect of Light-Induced-Degradation (LID) by making bulk doping concentration lower with its 1D carrier transport. The advantages of *FF* is by TOPCon solar cell 1D carrier transport, many existing high cell efficiency c-Si solar cell (PERC, IBC and so on) feature rear point contact structure, passivating most rear area and locally contacted to semiconductor region have 3D carrier transports. This 3D carrier transport makes carrier moving longer and degrades both V_{OC} and *FF*. TOPCon solar cell is a uniform structure for rear region and avoiding this cell loss.

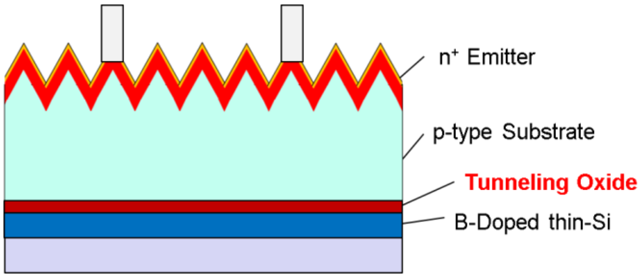

Fig. 1 The 2D structure of p-type TOPCon solar cell

Table I Carrier tunnel model parameters

Parameter	Electron	Hole	Reference
ε_{ox}	3.9		[5]
m_{ox}	0.42	0.58	[5]
m_{Si}	0.19	0.16	[2]
m_C	1.18	0.81	[6]
E_B	3.2	4.6	[5]

3. Simulation modeling

In this study, 2D numerical simulation is done for evaluating the effect of tunnel oxide thickness and rear thin-Si film properties. Unit cell width is 1 mm with front electrode coverage of 5%. Tunnel model of Schenk and Heiser proposed [4] is used, and table I shows the carrier tunnel model parameters both for electron and hole in silicon material. Note that, each parameter means, ε_{ox} is the optical dielectric constant, m_{ox} is the electron or hole effective mass in the oxide, m_{Si} is the effective mass in substrate, m_C is the density of state (DOS) effective masses in Si and E_B is the Si / oxide barrier, respectively. In this study, p-type TOPCon solar cell is considered and hole parameters are important. Front emitter doping is n-type and surface doping concentration of 1×10^{19} cm^{-3} with junction depth of 1.0 µm. Si bulk is 180 µm width, doping concentration is p-type 1×10^{16} cm^{-3}, and bulk lifetime is 100 µs.

4. Simulation results and discussion

First, the effect of tunnel oxide thickness is evaluated. Rear thin-Si film thickness is set to 10 nm and doping concentration of uniformly 1×10^{20} cm^{-3} in this evaluation. Figure 2 shows the cell efficiency versus tunnel oxide thickness. Tunnel oxide thickness of over 1.0 nm degrades cell efficiency drastically. This shows tunnel oxide thickness must be

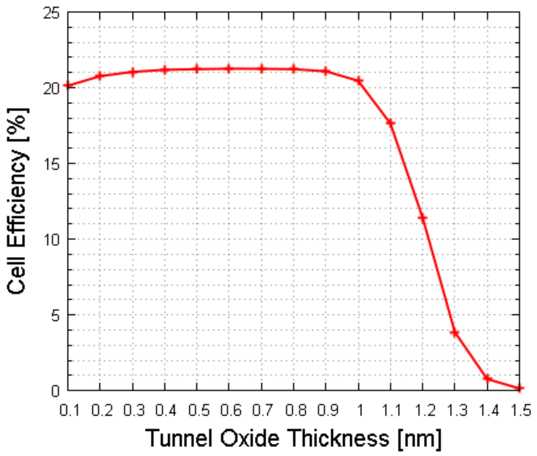

Fig. 2 Cell efficiency versus tunnel oxide thickness on p-type TOPCon

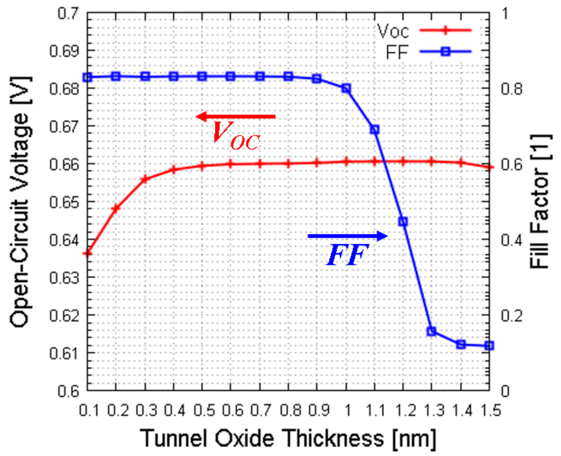

Fig. 3 Open-circuit voltage (Left) and fill factor (right) versus tunnel oxide thickness on p-type TOPCon

under 1.0 nm for good carrier transport. The oxide thickness between 0.5 nm to 1.0 nm is good, and optimum oxide thickness is 0.6 nm with cell efficiency of 21.26%. Figure 3 shows both V_{OC} and FF versus tunnel oxide thickness. As this graph shows, FF is the dominant cell performance on this evaluation, the thicker tunnel oxide thickness over 1.0 nm makes FF degradation rapidly and consequently worse cell efficiency. On the other hand, too thinner tunnel oxide thickness under 0.5 nm makes V_{OC} worse, this is because of weaker effect of suppressing recombination. These two factors are tradeoff, the thinner oxide thickness makes FF better and the thicker thickness makes V_{OC} better, and the tunnel oxide thickness of 0.6 nm is optimum value on this evaluation.

Second, the effect of rear thin-Si film thickness is evaluated with tunnel oxide thickness of 0.6 nm. Figure 4 shows the relationship between rear thin-Si film thickness and cell efficiency or open-circuit voltage for each thin-Si film doping concentration. This graph shows there is little effect to cell efficiency with rear thin-Si film thickness when doping concentration is over 1×10^{18} cm^{-3}. The doping concentration has

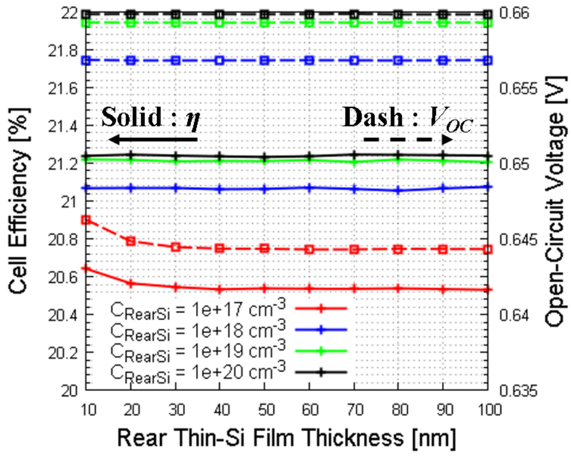

Fig. 4 Cell efficiency versus rear thin-Si film thickness on p-type TOPCon

strong impact to cell performances, higher doping concentration makes cell performances better. The doping concentration of higher than 1×10^{19} cm^{-3} is better for better cell performances, and this seems because of back-surface-field (BSF) effect that suppresses carrier recombination at electrode regions. Feldmann et al. reported that the higher doping concentration of rear Si film makes V_{OC} higher [3]. Cell efficiency and open-circuit voltage show the same trend, means these two factor has strong relationship about rear thin-Si film thickness. For light doping concentration, the thinner rear Si-film is better because fast recombination region with weaker BSF effect is small.

5. Conclusions

The evaluations of TOPCon solar cell rear structure properties are shown. For p-type Si bulk, tunnel oxide thickness must be under 1.0 nm to get performances. Optimum tunnel oxide thickness is 0.6 nm for p-type Si with bulk lifetime of 100 μs. Rear thin-Si film thickness has little effect to cell performances under thickness of 100 nm. More than that, the doping concentration of rear thin-Si film has strong impact to cell performances, the higher doping concentration makes cell performances better, and this is because of BSF effect that suppresses carrier recombination at electrode regions.

Acknowledgements

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References

[1] F. Feldmann et al., Sol. Energy Mater. Sol. Cells. **120** (2014) 270-274
[2] Sentaurus, Synopsys TCAD Software Release L-2016.03-SP2
[3] F. Feldmann et al., Sol. Energy Mater. Sol. Cells. **131** (2014) 46-50
[4] A. Schenk et al., J. App. Phys. **81** (1997) 7900-7908
[5] R. K. Chanana, ISOR-J. App. Phys. **6** (2014) 1-7
[6] H. D. Barber, Solid-State Electronics **10** (1967) 1039-1051