

Analysis of Cu(In, Ga)Se₂ Efficiency Gap Between Module and Cell

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Abstract. Film inhomogeneity of Si and CIGS which plays an important role for solar cell scaling are studied. The inhomogeneity is due to the process variations. The Si and CIGS modules with different key material parameter like the lifetime, doping, and band gap are simulated. The simulation results show that CIGS have larger performance degradation from the variation comparing with the Si case. And this could explain why CIGS solar cell has larger efficiency gap between the module and the small cell.

Key words

CIGS solar cell, variation, module, cell

1. Introduction

The Cu(In,Ga)Se₂ (CIGS) thin film solar cell has a potential to reduce production cost for photovoltaic modules. The record efficiency of the CIGS thin film solar cells is ~20% [1], but is degraded after module process^{2,3}. The degradation factors are the film inhomogeneity, series resistance, and additional surface recombination at the edge of the damage area by laser scribing [2], [3]. To figure out whether the efficiency gap is much larger between CIGS module and cell than between the Si module and cell, we focus on the film inhomogeneity issue. In this paper, the variation issues are simulated with different semiconductor parameter like lifetime, doping, and bandgap on both Si and CIGS module.

2. Simulations

The cell performances of the Si and CIGS are simulated under one sun illumination (100 mW/cm², AM 1.5 G). The parameter of CIGS used in the simulation such as refractive index, extinction coefficient, mobility, effective density of state, and dielectric constant are adapted from Ref. 3. Fig. 1 shows the simulation structures of the silicon solar cell and Fig. 2 shows the CIGS module structure with P1, P2 and P3 scribing. For Si module, we use n type substrate which is the potential candidate for high

performance module. The Si wafer thickness is about 675µm. The finger size is chosen to be 1.5mm. The passivation layer and back surface field are adapted in the simulation. For CIGS module, 0.8 µm thickness of Mo is first deposited on the glass substrate. After the P1 laser scribing, 2.05 µm thickness of CIGS is deposited followed by 50 nm thickness of CdS. After the P2 mechanical scribing, 0.55 µm thickness of the transparent conductive oxide (TCO) is deposited followed by the P3 mechanical scribing. P1, P2, P3 are chosen to be 80 µm, 100 µm, and 100 µm, respectively.

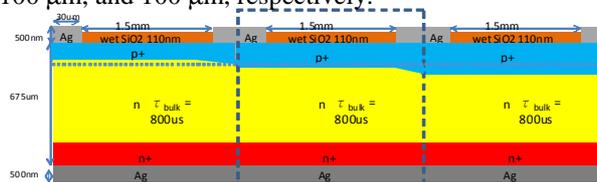


Fig. 1. Simulation structure of Si module used in this paper (not to scaled). The dimensions and the material parameter are chosen as the conventional commercial product.

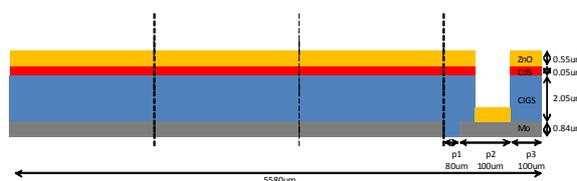


Fig. 2. Simulation structure of CIGS module used in this paper (not to scaled). With P1, P2, and P3 scribing area and the TCO layer, the current transport is different from the Si case.

3. Results and Discussion

Fig. 1 shows the simulated module performances of the Si and CIGS with different lifetime variation. For Si module, the mean lifetime is chosen to be 0.8 ms. The CIGS lifetime variation is simulated using 10 ns, 20 ns, and 250 ns lifetime of bulk CIGS, where covers typical reported lifetime of CIGS films. With the variation of lifetime as large as $0.8 \Delta\tau/\tau$, Si module could have about 8% of efficiency degradation. For CIGS, the degradation increases with decreasing lifetime. And with 10 ns as the mean value, the degradation could exceed 10 % which is larger than the Si case. Although CIGS has much lower lifetime and diffusion length than Si, the degradation due to the variation of lifetime is not as much as the expected. This is due to the structure used for CIGS module where we have TCO layer and all carrier transport directly to the TCO layer first but not transport laterally as the Si module.

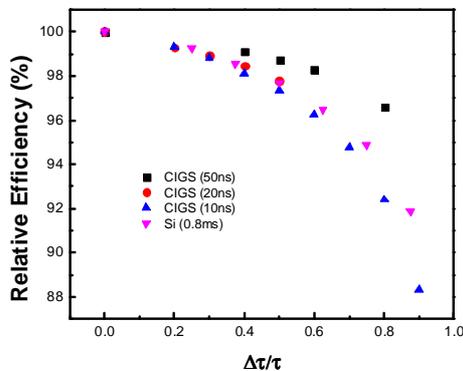


Fig. 2. The simulated efficiency vs lifetime variation. The lifetime of Si module has a mean value of 0.8 ms. For CIGS, three different lifetime are used in the simulation.

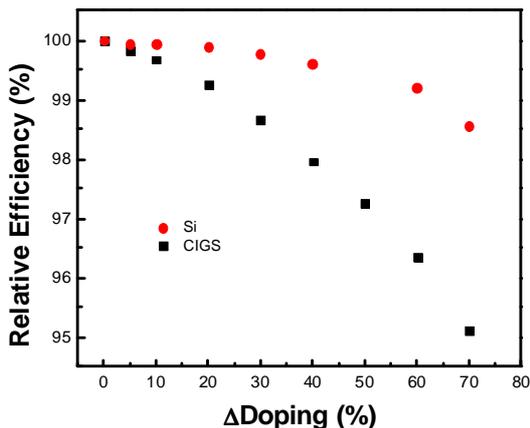


Fig. 3. The simulated efficiency vs doping variation. Si has a much smaller variation of the doping than the CIGS case.

Fig. 3. shows the variation of doping density issue on Si and CIGS modules. With lower doping concentration, the open circuit voltage would degrade. For Si module, the p plus region is mainly produced by the spin on dopant or

the implantation processes. Both these two techniques has a very low variation (even smaller than 10%). But in CIGS module, for both coevaporation and sputter CIGS processes, the variation is much larger than the Si case.

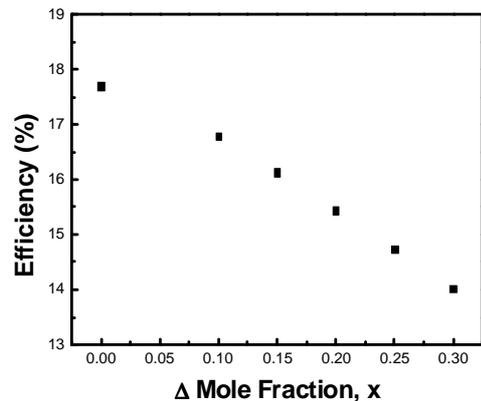


Fig. 4. The simulated efficiency vs mole fraction variation. Ga/In mole fraction variation plays an important role for bandgap.

Fig. 4 (a) shows the simulated efficiency with different Ga/In mole fraction in CIGS module. This is another important variation issue for CIGS module which is also hard to control over the entire module area. Comparing with the Si module, this is also an extra variation parameter for CIGS module. The CIGS module efficiency decreases with increasing Ga/In mole fraction. With the mole fraction variation at about 0.3, the efficiency could degrade to about 14 % where the initial efficiency without variation is about 17.6%.

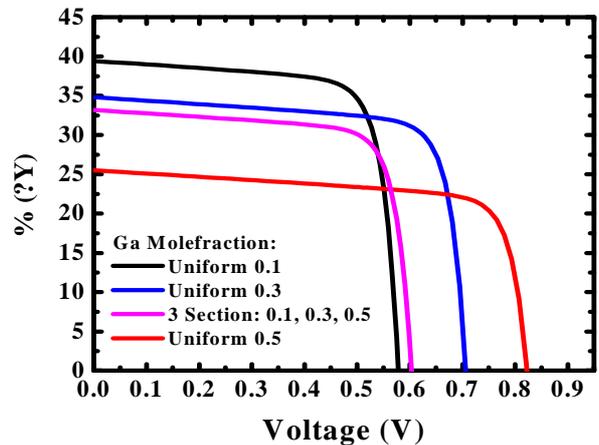


Fig. 5. The simulated I/V-curve of one CIGS module with three different Ga molefraction section and three CIGS module with uniform Ga molefraction which are 0.1, 0.3, and 0.5, respectively.

To further understand why the molefraction plays an very important role for the variation issue, simulations of CIGS modules with uniform Ga molefraction are examined. As shown in Fig. 5, J_{sc} decreases with increasing Ga molefraction, and V_{oc} increases with increasing Ga molefraction. There's a tradeoff between

this two factor when increasing the Ga molefraction. The optimize Ga molefraction is about 0.3 in our simulation as shown in Fig. 6. In the three section simulation as shown in Fig. 5, the V_{oc} is only slightly larger than the smallest one of the uniform cases, and the J_{sc} is in the between. This explains why in our Ga molefraction variation simulation, the efficiency is even worth than the smallest efficiency of the uniform cases. This is because as the voltage of the CIGS material is larger than the section of the CIGS material with the smallest V_{oc} in the uniform case, the current of that section will be in the oposite direction and the total current would drop to zero very quickly. The phenomenon can also be seen in our simulation and is shown in Fig. 7

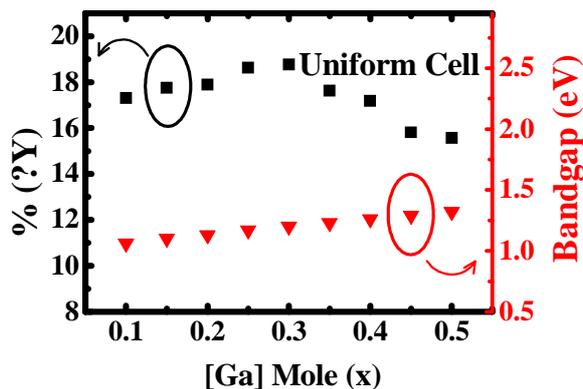


Fig. 6 The simulated efficiency and bandgap vs. Ga molefraction.

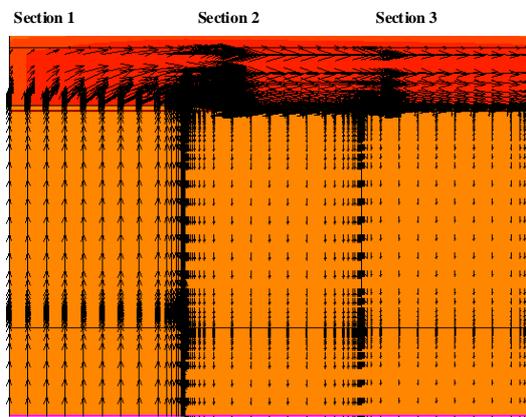


Fig. 6 The simulated current flow of the three section CIGS module with different Ga molefraction..

4. Conclusion

To figure out efficiency gap between the module and cell for both the Si and CIGS solar cell, film inhomogeneities considering different parameter variation are simulated. The efficiency degradation of CIGS module considering lifetime has almost the same order with the Si module. But for the doping case, CIGS module degrades much faster the Si module. Besides, CIGS module has an extra variation issue, Ga/In mole fraction, which could degrade the efficiency much larger. Combines all the variation

issues, we could successfully explained the larger efficiency gap of the CIGS between the module and cell.

Acknowledgement

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