Recovery of Radiation Induced Degradation of Bulk Lifetime in Silicon Solar Cells Using Low Temperature Annealing

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Abstract

The EOL efficiency of commercial p-type silicon solar cells with diffused junction is only 13% (1 MeV electrons with 1e15 fluence, AM0). This limits their use in space where the competing EOL efficiency of III-V tandem cells is about 26%. One radiation induced recombination mechanism in p-type silicon was previously associated with BiOi defect or a complex on its bases. Dissociation of this defect was reported by thermal annealing at 200°C-350°C during 10-30 min. In this study we observed that BiOi defect apparently dominates recombination losses in 20-micron-thick p-type silicon solar cells irradiated by 1 MeV electrons. It was also found that BiOi defect can be effectively dissociated by thermal annealing at 100°C during 100 hrs. 98% recovery of EQE and 91% recovery of Voc was achieved. The observed effect creates an opportunity for in-situ annealing of ultrathin silicon solar cells in space with effectively no degradation of EOL efficiency due to electron irradiation.

The projected AM0 efficiency of 20-micron-thick ultrathin silicon solar cells developed by Regher Solar is 19% with a practical roadmap towards 23%. Thus, a light-weight, flexible, low-cost Si solar cell with >20% EOL efficiency may eventually be realized.

Experiment

- 20-micron-thick silicon heterojunction test solar cells and passivated samples were processed on p-type CZ wafers with 1.4 Ohm-cm resistivity and 0.2 ms bulk lifetime.
- 1 MeV electron irradiation with $1x10^{15}$ e/cm^2 fluence was conducted by NIST. Annealing was done in atmosphere using a muffle furnace.
- EQE, Suns-V_{OC} and effective minority carrier lifetime were measured using the tools from PV Measurements and Sinton Instruments respectively. The BOL V_{OC} was 750 mV.

Results

- Observed unexpected recovery of the bulk lifetime in irradiated p-type CZ silicon after annealing at <200°C.
- Achieved 91% EOL V_{OC}, recovery, from 550 mV to 680 mV, after annealing at 100°C for 6200 min.
- No significant pseudo FF difference before and after irradiation was measured. pFF remained about 81%.
- EOL EQE increased from 95% to 98% after annealing at 100°C for 6200 min.

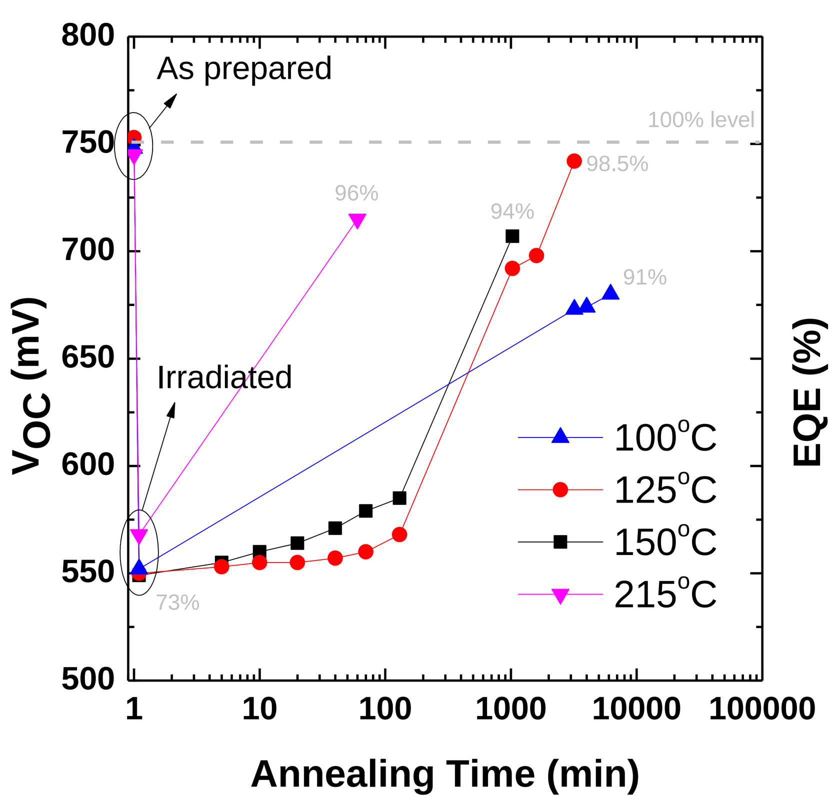


Figure 1. Recovery of Voc in 20-micron-thick p-type CZ cells after prolonged thermal annealing in atmosphere at different temperatures.

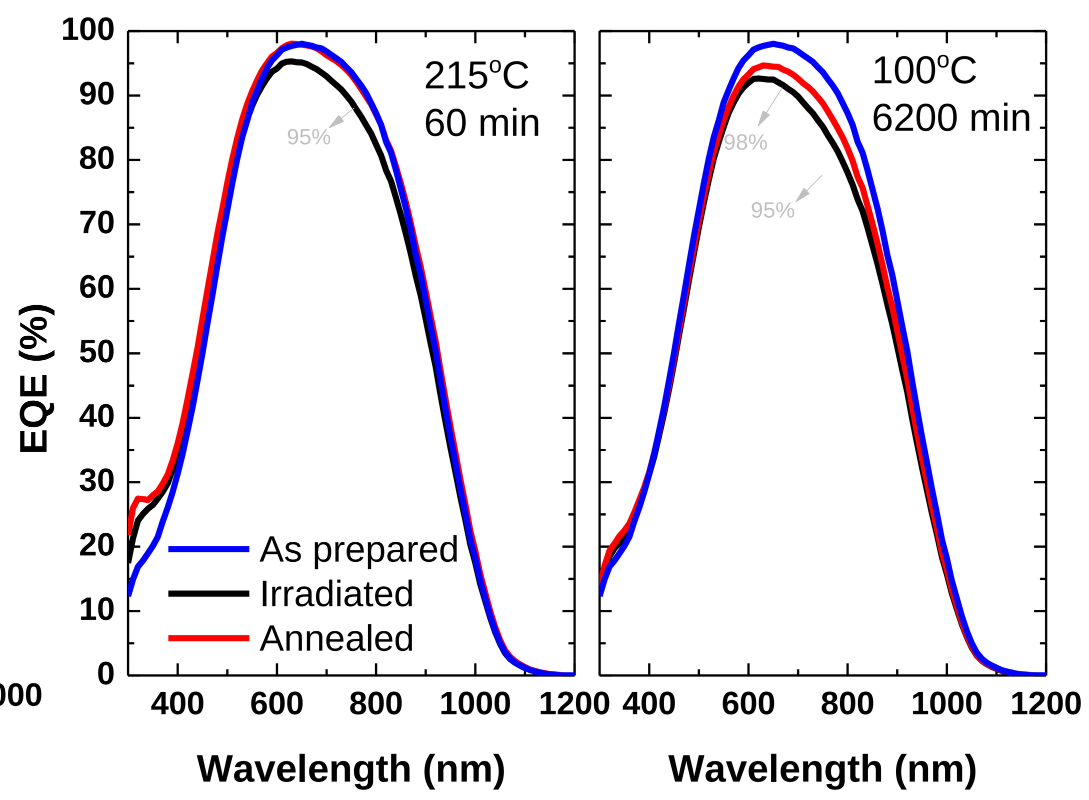
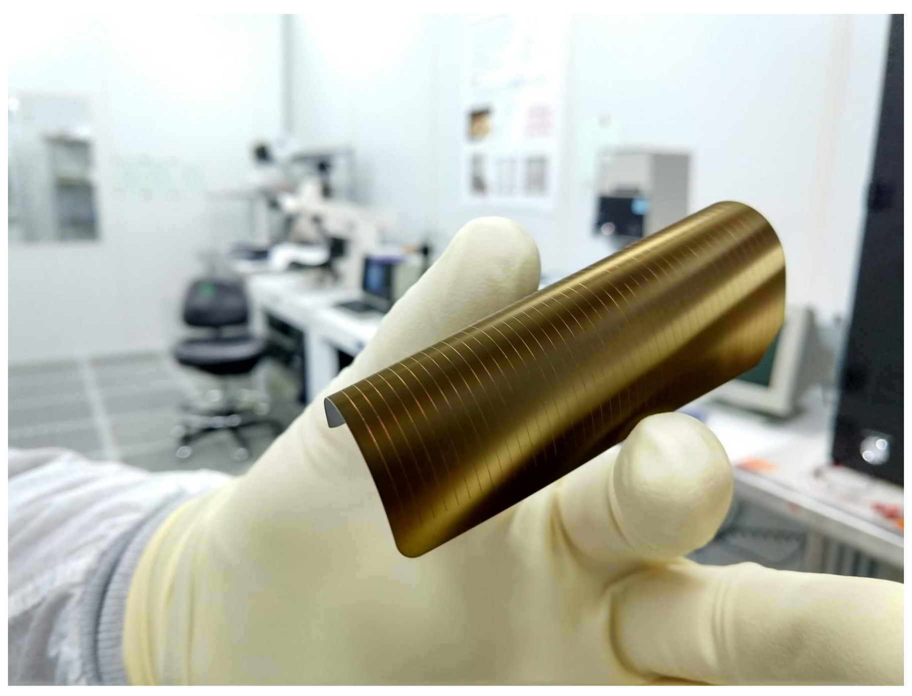
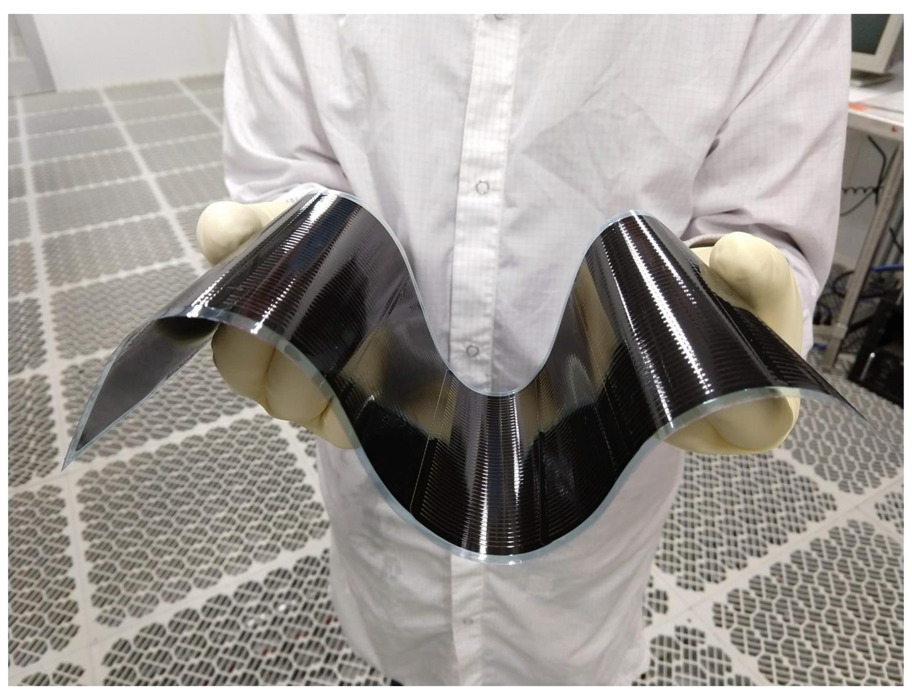


Figure 2. Recovery of EQE in annealed 20-micron-thick p-type CZ cells.





Discussion

- Previously reported isochronal annealing (10 min) of 50-micron-thick diffused junction solar cells on p-type CZ wafers led to >95% power recovery at 400°C and had no improvement at lower temperatures.
- At the same time, dissociation of E_C-0.27eV (E_C-0.18eV) often attributed to BiOi or a complex on its basis was reported at 200°C.
- In this work the recovery of bulk lifetime, and hence, V_{OC} of the cells, was observed during a prolonged annealing at 100°C.
- It's not clear which mechanism could take place in irradiated cells during annealing since no bulk defect dissociation has been reported at such low temperatures before.
- Coincidently, this defect seems to dominate recombination losses in p-type Cz cells causing V_{OC} to drop to 550 mV.
- A more systematic study of defect distribution in 20-micron-thick Si heterojunction cells after 1 MeV electron irradiation will be necessary to understand the nature of recovery during thermal annealing.

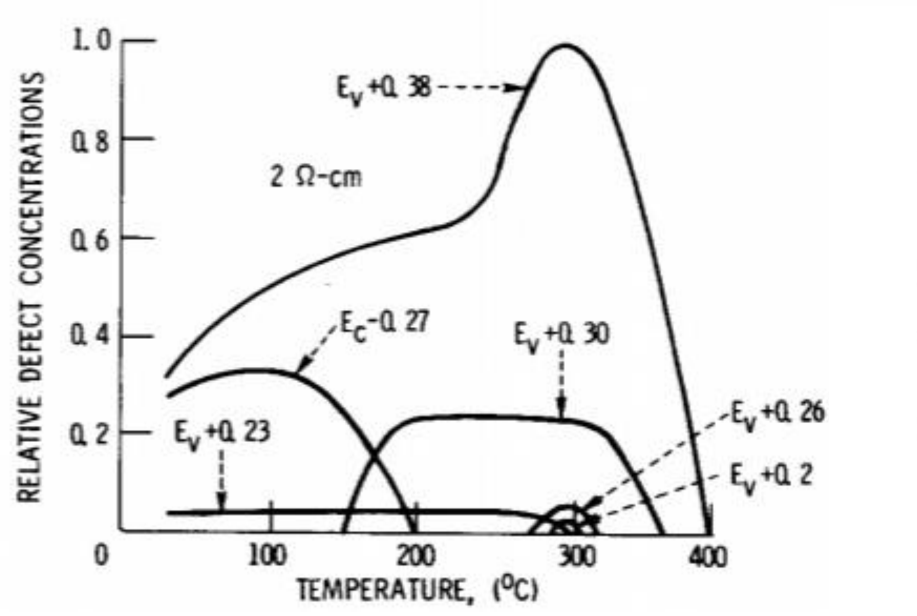


Figure 3. Relative defect concentrations and energy levels during isochronal anneal after 1-MeV electron irradiation; fluence = 10^{15} /cm^2 [Weinberg 1980].

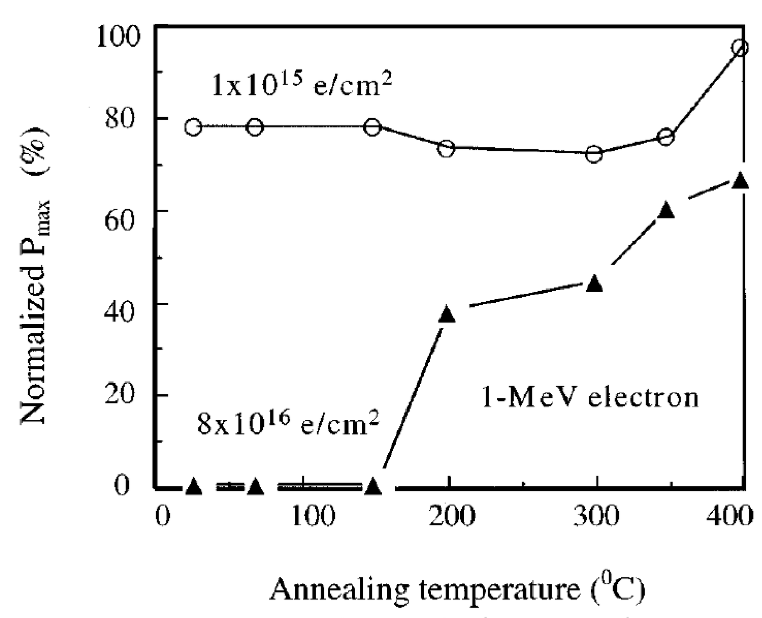


Figure 4. Isochronal (10 min) annealing recovery of maximum output power of Si solar cells irradiated with 1 MeV $1x10^{15}$ and $8x10^{16}$ cm^{-2} electrons [Yamaguchi 1999].

	type	thick-ness	Jsc (mA/cm2)			Voc (mV)			FF (%)			Eff (%)		
			BOL	EOL	%	BOL	EOL	%	BOL	EOL	%	BOL	EOL	%
Regher	n	20	44.4	28.9	**0.65**	0.760	0.480	**0.63**	78.0	76.0	**0.97**	19.3	7.7	**0.40**
Regher	p	20	44.4	41.3	**0.95**	0.750	0.560	**0.75**	78.0	77.0	**0.99**	19.0	13.0	**0.69**
Regher-100C	p	20	44.4	43.5	**0.98**	0.750	0.680	**0.91**	78.0	77.0	**0.99**	19.0	16.7	**0.88**
Commercial	p	130	45.8	38.9	**0.85**	0.628	0.559	**0.89**	79.7	78.7	**0.99**	16.9	12.5	**0.74**

Table I. Projected efficiency of 20-micron-thick solar cells based on the EOL values of V_{OC} and J_{SC} obtained in this study.

Summary

- Annealing of Si solar cells at 100°C can become one way to reduce high energy electron induced power degradation in space solar cells. Either natural heating of the cells in space or a slight supplemental heating can be used to avoid power loss.
- The projected EOL efficiency of the annealed Si cells improves from 13% to 16.7%.
- Deeper understanding of the nature of high energy electrons and protons induced defects in Si will help to optimize the choice of the wafer material and cell structure that may lead to completely avoiding this degradation mechanism.

References

- [Weinberg 1980] I. Weinberg and C. K. Swartz, Appl. Phys. Lett. 36, 693 (1980).
- [Yamaguchi 1999] M. Yamaguchi, et al., J. Appl. Phys. 86, 217 (1999).

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