Ultra-thin single crystal modules capable of 450 W/kg and bending radii <1mm: fabrication and characterization

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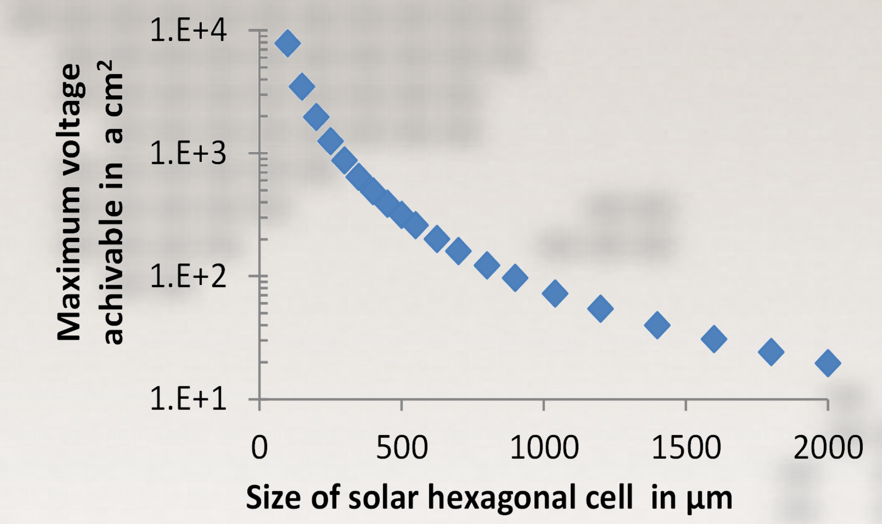
Introduction

Current commercial solar limitations:

- Low specific power
- Limited flexibility
- Low voltage
- Fixed formats
- Cost

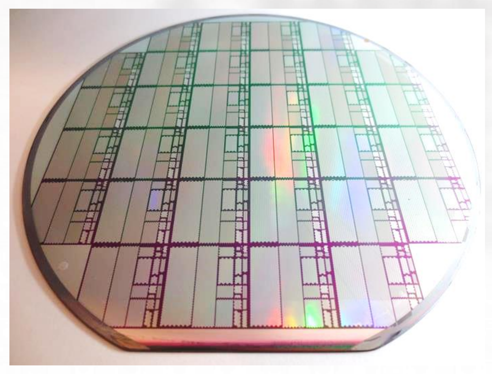
Proposed Ultra-thin single crystal Si modules:

- Light weight
- High specific power
- Flexible
- High voltage
- Good appearance
- Low cost

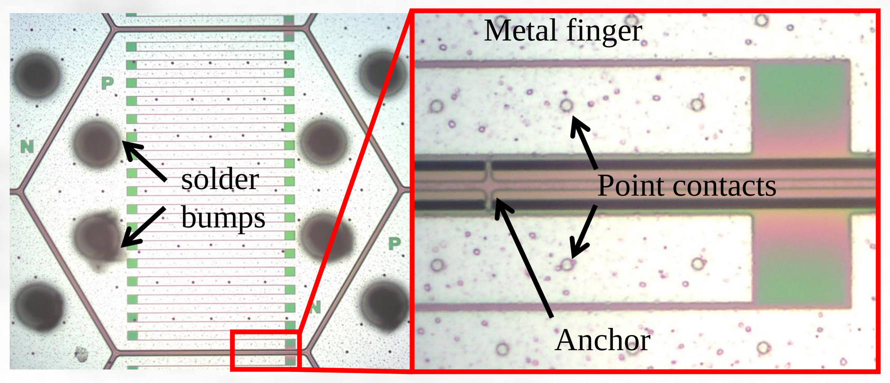


Small cells can achieve high voltages in very small area. The graph shows the maximum voltage as a function of cell diameter measured from corner to corner of the hexagonal shape cell.

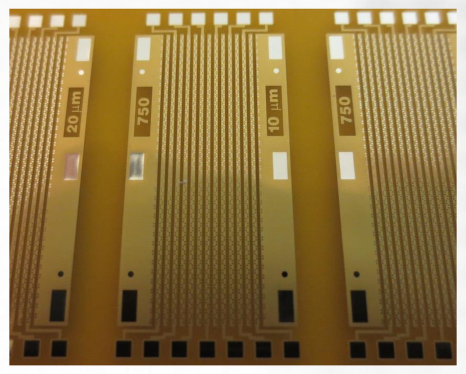
Fabrication



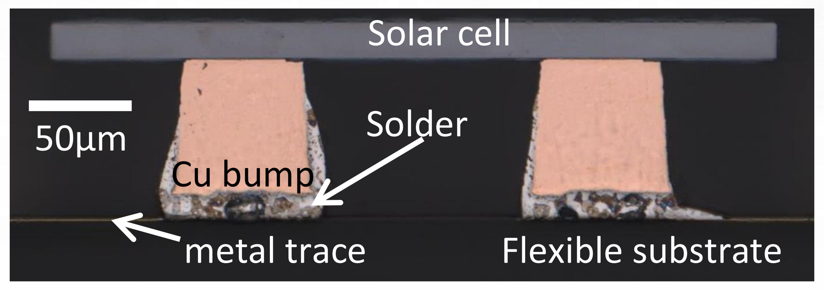
The cells are created in regular thickness wafers using standard processing tools.



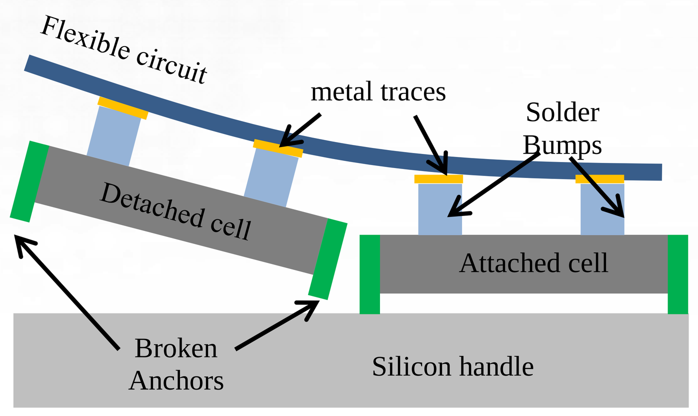
The fabricated cells have interdigitated back point contacts. At the end of the fabrication, the cell is fully functional and attached to the handle substrate by thin tethers.



A patterned flex circuit that matches the position of the solder bumps was fabricated to receive the cells.



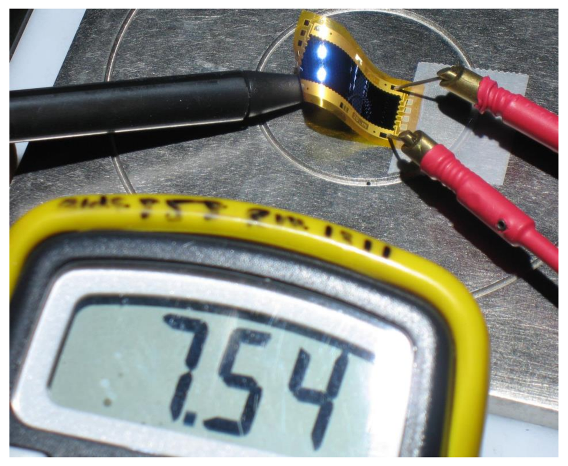
Once the solder wets the receiving substrate, the temperature is lowered so the solder can harden. After the stack is cooled below the melting temperature of the solder, the cells are electrically and mechanically connected to the flexible circuit



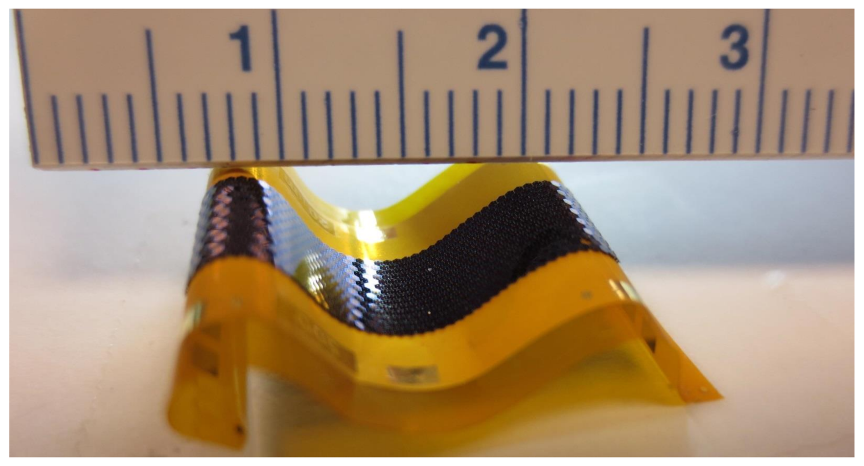
The flex circuit is physically pulled and all the anchors attaching the cells to the handle wafer are broken, thus completing the transfer of the cells to the flex circuit.

Results

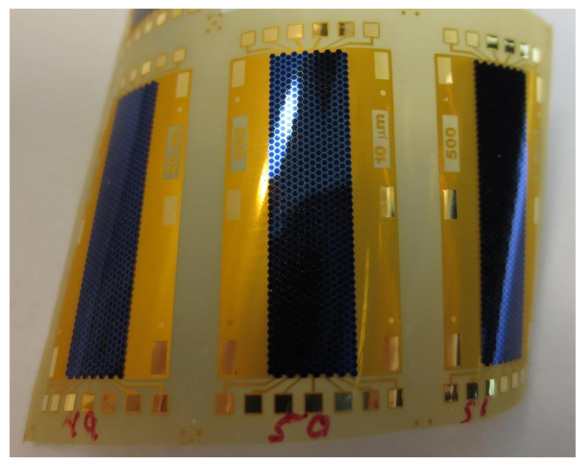
Ultra-thin formats create noninvasive products that are capable of being attached to any conventional electronic device without increasing the weight while adding solar-powered charging capability.



Solar mini-module operating while being flexed. Multiple series parallel connections keep the voltage unchanged while flexed.



Bent flexible solar mini-module with bending radii <1mm.

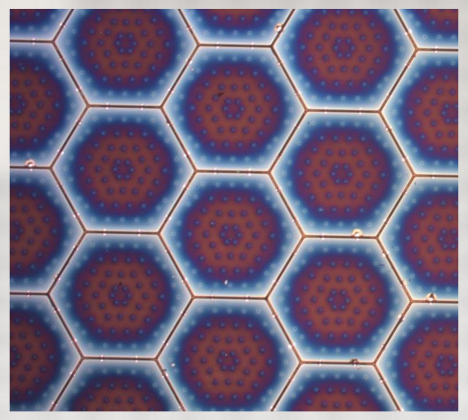


The silicon is about 10 times thinner (about 20 µm) compared to commercial silicon cells.

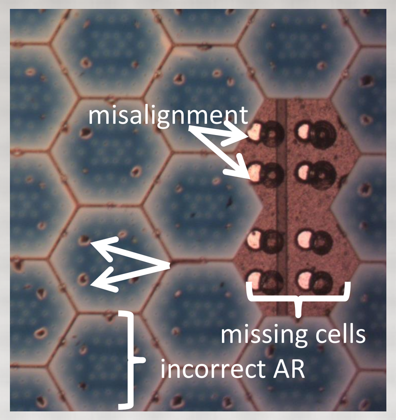
Characterization

A total of 15 mini-modules were analyzed. Efficiencies ranged from 4.9% to 13.7% with an average of 8% and a standard deviation of 2.9%. The best cell has a specific power of 455 W/kg. Current and voltage Here we show best and worst cases for ease of analysis.

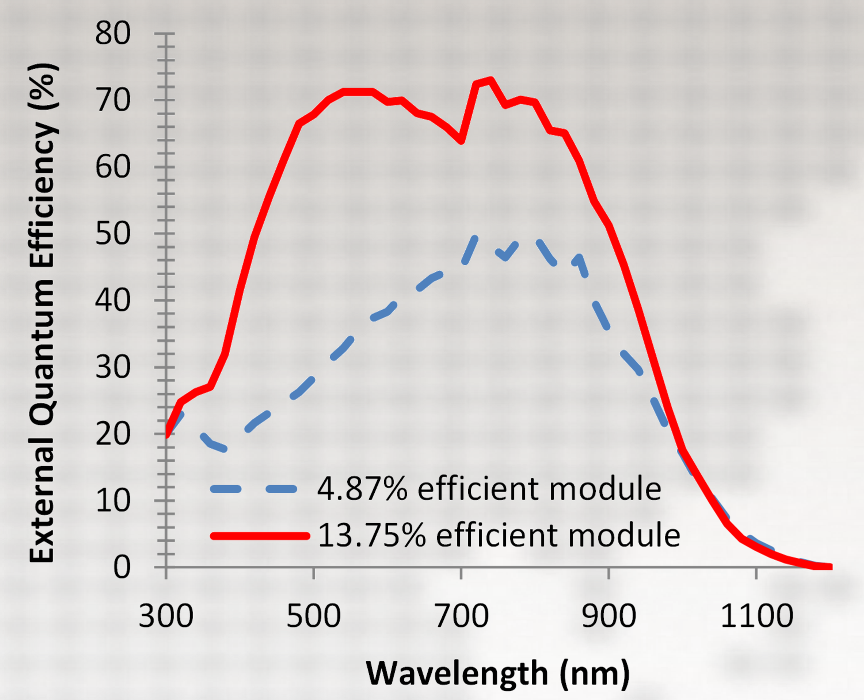
Comparison of best vs. worst cells on modules



Zoomed image of cells that produced a 13.7 % efficient mini-module using 720 μm cells.

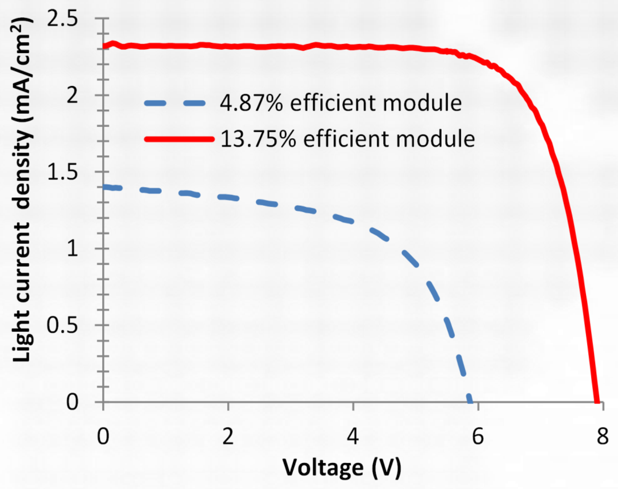


Zoomed image of cells that produced a 4.9 % efficient mini-module using 500 μm cells.

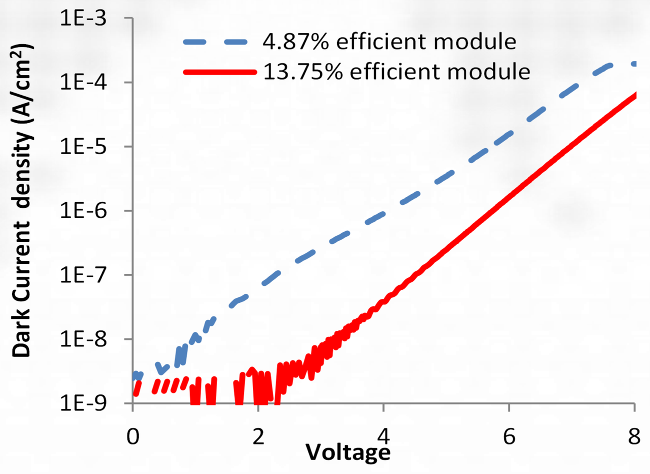


EQE measurements show that tear offs produce high surface recombination velocity that trap carriers with high energy.

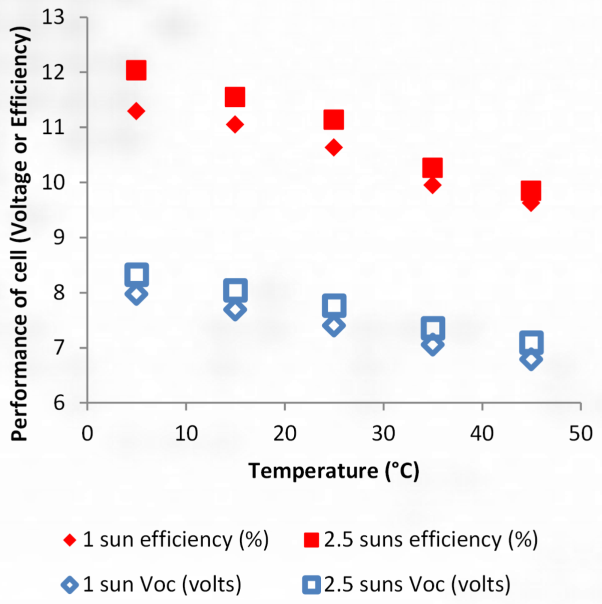
J-V characteristics of the best and worst flexible micro-cells.



The light current and voltage were limited due to missing cells and tear offs in the cells.



The difference in dark currents confirms the influence of tear offs in increasing surface recombination.



A temperature dependence study shows that the micro cells behave as macro sized solar cells. Voc slope is 2.14V/° C for each cell. The performance shown is for a module with nominal efficiency of 10.7%

Conclusion

This technology has proven:

- Specific power of 450 W/Kg
- Feasibility for high voltages >1000 V/cm2
- Flexible modules with bending radii of 1 mm
- High conversion efficiencies of 13.75% on flexible materials

Problems identified with low efficient cells are:

- Missing cells (accounting for more up to 5% absolute loss in efficiency)
- Tear offs (accounting for about 2.5% absolute loss in efficiency)
- AR coating(less than .5% absolute loss in efficiency)

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