# Advanced Solar Modules for Battlespace Power Utilising 20% Efficient Flexible Elongate Solar Cells

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## ABSTRACT

Elongate silicon solar cells offer the prospect of 20% efficient, ultra thin, flexible, lightweight, robust, solar photovoltaic (PV) panels for battlefield energy generation. Elongate silicon solar cells are long (20-100mm), narrow (0.5-5mm) and efficient (~20%), have excellent partial-shadow-tolerance and operate well in low-light conditions. They are solid state devices, and share extreme reliability with conventional silicon cells.

## 1. Introduction

Reliance on batteries substantially limits capabilities of modern defence forces. Operations in the modern network-centric battlefield environment requires distributed autonomous electrical power to support crucial components of the operational theatre, including:

- Roll-up transportable power modules
- Power for remote sensors
- Flexible lightweight power for soldiers
- Communication relays
- Unattended electrical motors

Elongate silicon solar cells are monocrystalline, long (20-100mm), narrow (0.5-5mm) and efficient (~20%). Elongate silicon cells have attractive attributes including high efficiency under both normal and low illumination levels, flexibility, high reliability, high voltage, high power-to-weight ratio, tolerance of partial shading, suitability for camouflaging and reduced visibility. Flexible elongate solar panels have attractive synergies with flexible batteries.

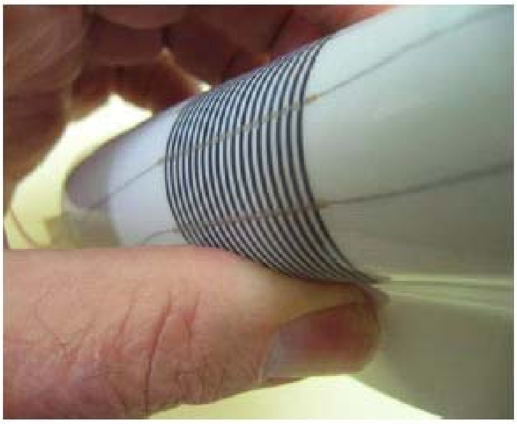

*Figure 1: Flexible 12 volt elongate module*

# 2. Elongate solar cells

Two separate elongate solar cell technologies have been developed at the ANU: Plank solar cells and Sliver® solar cells [1,2]. These two types of solar cells have similar attributes and capabilities.

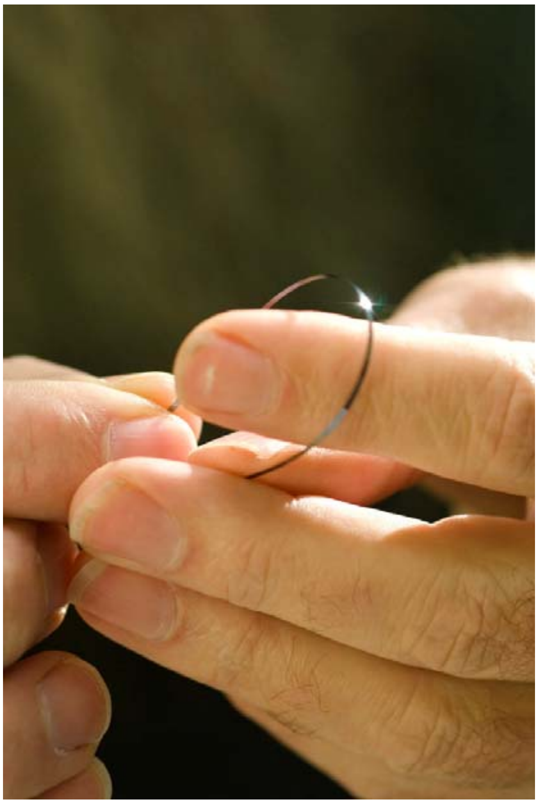

*Figure 2: Flexible elongate*

Substrates for Plank solar cells are prepared by creating long and narrow slots spaced 0.5-5mm apart through a thin (0.01-0.2mm) wafer to create hundreds of individual "planks" of silicon.

Substrates for sliver® cells are prepared by vertically slicing a 0.5-2mm thick wafer into hundreds or thousands of long and thin "slivers" of silicon, and rotating each of the slivers to gain area multiplication.

In each case, wafer processing ensues to convert the long, narrow and thin strips of silicon into solar cells. Sliver® technology is being commercialised for mass power production by the Australian company Origin Energy in Adelaide.

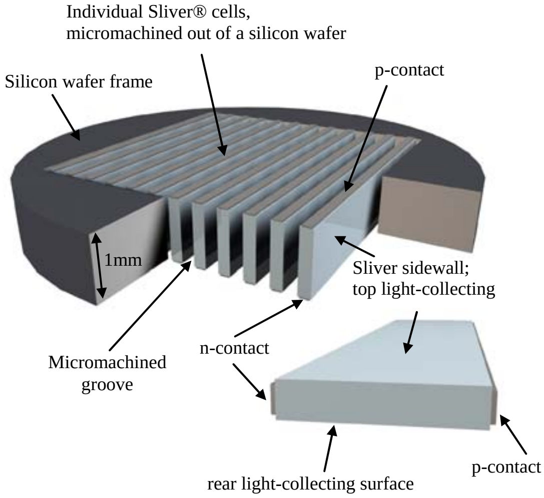


*Figure 3: Sliver® solar cell schematic*

Silicon is the 2nd most abundant element in the Earth's crust and is non-toxic. 90% of world solar cell production is silicon solar cells. Monocrystalline silicon is the "gold standard" material for photovoltaics, with proven high efficiency and durability in harsh operational conditions. Lengthy experience with silicon solar cells allows manufacturers of commercial modules to offer 25 year guarantees.

Conventional silicon solar cells are fabricated on squares or rounds of silicon, about 0.2mm thick and diameter 15cm. These cells are electrically connected and encapsulated behind glass to form a PV module.

Most PV conventional silicon PV modules have nearly zero output when even one cell is shaded. Partial shading is to be expected in defence and security applications. In contrast, elongate modules retain almost full power when partially shaded. Tolerance of partial shading arises from the elongate cell fabrication technique.

Each indivual elongate silicon solar cell has an output voltage of 0.6-0.7 volts. Grouping fifteen 1mm wide, 25mm long cells to form a $4cm^2$ mini module will result in a module with enough voltage output to charge an 8 volt battery for a remote sensor or similar application. Conventional silicon solar cells are too large to create such mini modules, and cutting up conventional cells into smaller cells sharply reduces cell efficiency.

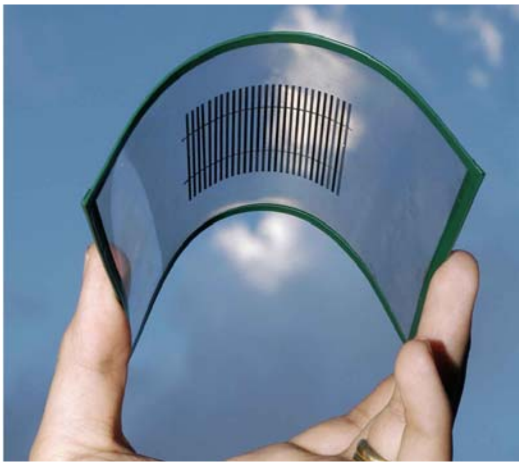

*Figure 4: Flexible, partially transparent, 20 volt elongate mini module*

Optional transparency is easily arranged for elongate modules by spacing the elongate cells slightly apart. This can help reduce visibility.

Conventional silicon cells are too thick to be flexible. Elongate cells are naturally thin and flexible, and can be made ultra thin for ultra flexibility. In contrast to conventional solar cells, elongate cells accept light equally well from both sides (perfectly "bifacial").

Thin elongate cells are light weight but retain high efficiency, and have extreme power/weight ratios. Encapsulation for protection from the environment is not required for elongate cells in specialist applications for which long life (years) is not required. This allows super lightweight power panels to be fabricated, taking advantage of the fact that elongate cells can be up to ten times thinner than conventional cells. Such panels are non-reflective for low visibility.

Elongate cells retain high performance even when illuminated by dim light. Thus they retain superior performance in the shade (although overall power output of any PV module is reduced 10-fold or more in the shade because the available solar power is reduced by this amount).

In addition to these desirable attributes of elongate cells, the development of ultra thin elongate cells will allow substantially better improved ionising radiation tolerance.

# 3. Defence applications

Examples of applications of elongate cells in the defence and security environment include:

<u>Micro solar power source for wireless sensors:</u> Thin elongate cells are ultra flexible (they will bend around a person's finger), and can easily conform to the 3-D shape of sensors. They will also be very efficient (~20%), which is 2-4 times better than alternative thin film cells; so 2-4 times more power is available per square cm.

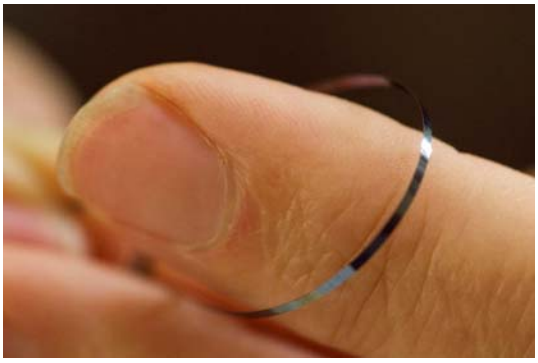

*Figure 5: Flexible elongate*

<u>Low visibility highly reliable solar power source for autonomous maritime sensors:</u> Modules can be mounted vertically because elongate cells accept light falling on either surface equally well. This reduces visibility, allows the collection of light reflected off the sea and means that the orientation of the sensor relative to norht need not be

maintained. High cell efficiency allows for a reduction in module area/visibility.

Roll-up-transportable low visibility solar power modules for power in remote regions: taking advantage of 20% cell efficiency, flexibility, bifacial acceptance of light and reliability. A 1,000W, 7m$^2$ roll-up elongate module would weigh as little as 3kg, and would be smaller than a wine cask when furled.

Wearable solar power: taking advantage of high cell efficiency, shadow tolerance and flexibility. Cells placed on the helmet of a soldier could generate about 2W in sunshine.

Power for security sensors in low-light: For example, window break sensor mini power panels mounted as a small patch in a corner of the window can take advantage of high cell efficiency in dim light, acceptance of light from either side (room or external light) and ease of reaching battery voltage.

Low visibility, ultra light solar power for UAVs: taking advantage of high cell efficiency, flexibility and bifacial acceptance of light (to receive light from both the sun and the ground).

*Table 1. Attributes of flexible thin elongate silicon solar cells*

| **Performance parameter** | **Elongates** | **Thin film*** | **Thin elongate cell attributes** |
|---|---|---|---|
| Solar conversion efficiency | 20% | 5 to10% | Required module area is halved or quartered compared with alternatives |
| Physical flexibility | ✓✓ | ✓ | Cells are super flexible – they can be wrapped around a person's finger |
| Bifaciality | ✓✓ | ✓? | Module is perfectly bifacial – it doesn't care which side the light comes from |
| Ability to build battery voltage in micro modules | ✓✓ | ✓? | Micromodules (1cm$^2$) can easily reach 4Volts to charge batteries |
| Solid state | ✓✓ | ? | No gels, no liquids, no leaks |
| Proven reliability | ✓✓ | ? | Single crystal silicon is the "gold standard" of photovoltaics |
| Tolerance of moving shadows | ✓✓ | ✓ | Parallel interconnection of submodules provides excellent shadow tolerance. |
| Low optical visibility | ✓✓ | X | Efficient modules are much smaller and less visible than alternatives |
| Low radar signature | ✓✓ | ✓ | Low sheet conductivity |
| Low IR signature | ✓ | ✓ | Operate at a lower temperature |
| Power to weight ratio (W/gm) for UAV/satellite applications | ✓✓ | X | The cells are very efficient and very lightweight, giving large P/W ratio |
| Ionising radiation tolerance | ✓✓ | ? | Improved because of cell thinness |
| Ability to perform in low/hazy light conditions | ✓✓ | ✓ | Cells maintain their large efficiency advantage in dim light. |
| Optional module transparency | ✓✓ | ✓ | Assists with camouflage |
| Ability to dispense with covering glass or plastic | ✓ | X | Super lightweight and non-reflective modules can be constructed |
| Tolerance of oblique angles of incidence of sunlight | ✓ | ✓ | Determined by reflection from the covering glass or plastic. |
| Perform well at very low temperatures | ✓✓ | ? | For deep space power supplies |
| *: Typical performance parameters of amorphous silicon, crystalline-silicon–on-glass, dye-sensitised, organic and other (potentially) flexible thin film solar cells. | | | |

# 4. References

[1] K.J. Weber, A.W. Blakers, M.J. Stocks, J. H. Babaei, V.A. Everett, A.J Neuendorf, and P.J. Verlinden, "A Novel Low Cost, High Efficiency Micromachined Silicon Solar Cell", *Electron Device Letters* 25, 37, 2004

*Figure 6: Elongate solar cells*

[2] Evan Franklin, Andrew Blakers, Klaus Weber, Vernie Everett and Prakash Deenapanray, Towards a Simplified 20% Efficient Sliver Cell, 4th World Conference on Photovoltaic Energy Conversion, Hawaii May 2006

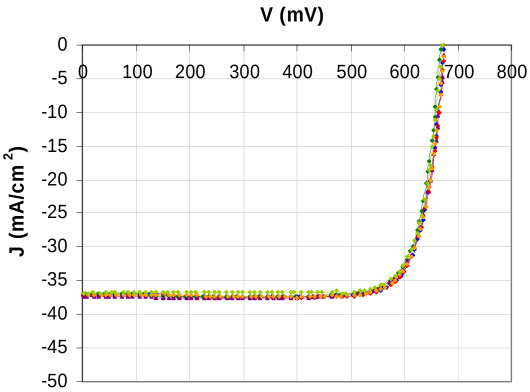


*Figure 7: Current voltage curves of 20% efficient elongate solar cells*