Solar power for unmanned autonomous vehicles

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A quantum-dot-based thin-film approach enables development of light, powerful, and flexible photovoltaic cells.

In battlefield environments, the longevity of many electronic sensors such as those found in unmanned aerial vehicles relies on their ability to replenish their energy reserves. Solar radiation is a major potential source of energy and photovoltaic cells offer a promising way to harvest that energy. One possible application is to use the relatively large surface of a microautonomous bat's wings, provided the cells are flexible enough for the wings to flap. In addition, for small platforms with constrained size and weight limitations, it is highly desirable to increase the power density (W/g) substantially from the 0.13W/g that is currently commercially available.

Such cells are currently made using organic cells, amorphous silicon, and pliable arrays of rigid solar cells. Organic solar cells possess benefits in being highly flexible and cheap in production. However, they also have a very short lifetime and low efficiency (∼5%). Amorphous silicon is also pliable and inexpensive, but it also suffers from low efficiency as well as low versatility for circuit design. We have developed a new thin-film, pixellated microchip solar-cell-array approach based on quantum dots (QDs) using a dots-in-a-well (DWELL) structure,[1] which is pliable, light, and efficient. Our new method of making the array does not result in decreasing efficiency as the flexibility improves. Arrays of these microcells are as efficient as conventional solar panels.

A QD is a semiconductor whose excitons are confined in all three spatial dimensions. As a result, they have properties that are between those of bulk semiconductors and discrete molecules. Figure 1 shows the DWELL structure, where the indium arsenide (InAs) QDs are fully embedded in the gallium InAs quantum wells. Our group has successfully grown DWELL structures since 1999,[1] and applied them in various QD devices with state-of-the-art performance, such as low-threshold current-density diode lasers[2] and high-responsivity, long-wave IR detectors.[3]

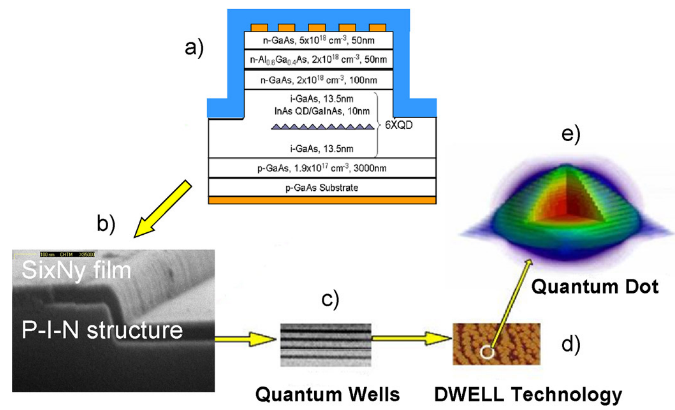

Figure 1. *(a) Schematic diagram of the dots-in-a-well (DWELL) solar cell containing quantum dots (QDs). (n-, i-, p-)GaAs: (n-type, intrinsic, or p-type) gallium arsenide. InAs: Indium arsenide. n-$Al_{0.6}Ga_{0.4}As$: n-type aluminum gallium arsenide. (b) Scanning-electron-microscope images of the solar cell's cross section. SixNY: Silicon nitride. P-I-N: p-type, intrinsic, and n-type semiconductor layered structure. (c) DWELL structure in the intrinsic layer. (d) Atomic-force-microscope image of the QDs. (e) 3D image of a single dot.*

The high dot density ($1\times10^{11}cm^{-2}$) and the DWELL collection mechanism mean that the area seen by the incident photons is larger in the DWELL structure than in a conventional InAs QD structure. This improves the spectral response and conversion efficiency of the solar cells. In addition, the DWELL cells have unique carrier-transport properties. It is well-known that QD structures efficiently confine carriers and thus inhibit the lateral spreading of current to the device perimeter, where edge recombination can dominate. Consequently, QD solar cells are insensitive to edge- or surface-recombination currents that would normally set a floor on the minimum cell area. As a result, the DWELL cells suit applications that require a miniature

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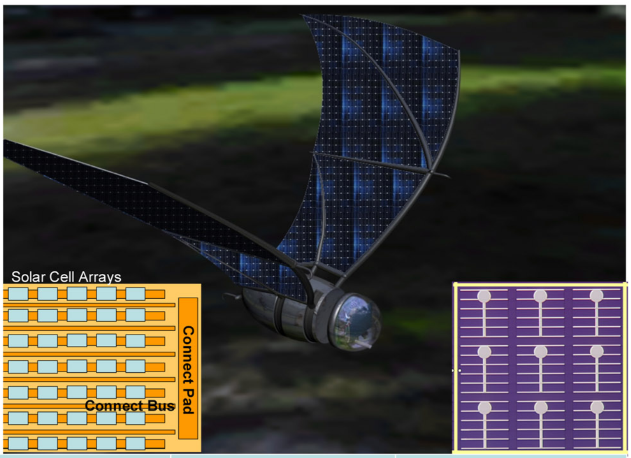
a)



b)

Parameter	Thin-film amorphous silicon (Powerfilm)	InAs DWELL solar cell with KAPTON membrane
Surface area	20 cm x 15 cm	20 cm x 15 cm
thickness	200 micron	5-10 micron
weight	9.2 gram	0.95-1.82 gram
Operating voltage	6V	6.8V
Operating current	200 mA	800 mA
Power output	1.2 W	5.4 W
Efficiency	4%	15%
Specific power	0.13 Watt/gram	3.0-6.0 Watt/gram

Figure 2. *(a) Microautonomous flyer image with flexible solar-technology powered wings. Inset shows the microchip of DWELL solar cells ($400\times400\mu m^2$). (b) Comparison of different thin-film solar-cell performances (Watt/gram) on light-weight substrates.*

device with high charge-collection efficiency.[4,5] Each microcell in the array is about 0.4×0.4mm^2 in size and 10–20μm thick.

For the substrate we used Kapton®, a commercially available plastic that can be purchased with very thin thicknesses. A 0.025mm-thick Kapton substrate is very flexible, light, and structurally strong enough to support the bonded semiconductor die. We made a conductive path for electrical connections and bonding to the die by depositing a conductive layer (aluminum or copper) onto the Kapton. We used photolithography to prepare metal contacts needed for the solar-cell module. Figure 2(a) shows the prototype arrangement of the die onto the conductive seed metal evaporated onto the Kapton (inset at bottom left).

With the DWELL solar cell and microchip flexible solar-cell technology, we have calculated a specific power value that can be achieved based on the demonstrated processing limits. Figure 2(a) shows the microautomonous flyer with flexible solar-powered wings. The bottom-right inset shows a microscope picture of the microchip solar cell while the bottom-left inset shows the integrated solar-cell arrays on the evaporated conductive circuit on Kapton. Figure 2(b) compares operating parameters for the best-performing brand-name amorphous-silicon technology, Powerfilm^{TM}, and our flexible thin-film microautonomous systems technology (MAST) solar photovoltaics. Assuming the total size of the wing is 100×150mm^2 and the thinned solar cell is $\sim$5–10μm thick, our results show that the DWELL InAs QD-based thin-film MAST solar technology can achieve more than 3.0W/g with the current power-conversion efficiency of $\sim$15%, which is more than one order of magnitude greater than that of PowerFilm. As a next step, we will integrate these InAs DWELL solar cells onto novel, lightweight membranes suitable for wings based on the realized high specific power.

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