The first 20-percent thin-film cell

NREL scientists achieve CIGS cell record

The new world record on chalcopyrite-based solar cells of 20-percent energy conversion efficiency is held by NREL in Golden, Colorado. This high efficiency underscores that CIGS thin-film technology has the potential to challenge crystalline silicon. However, the efficiency of commercial CIGS solar modules is still between 8 and 11 percent.

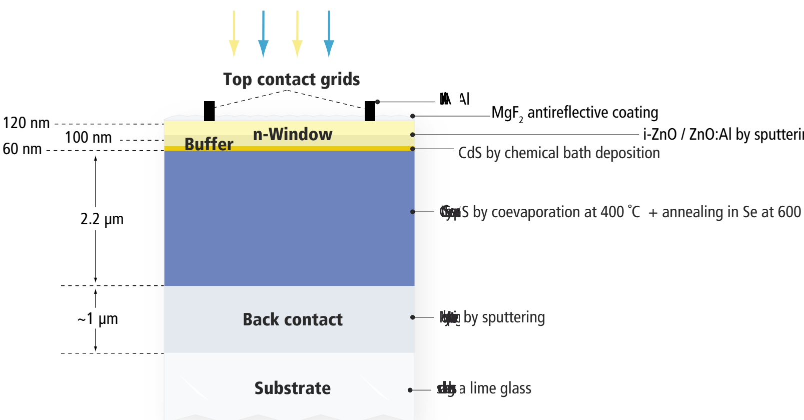
National Renewable Energy Laboratory (NREL)

Record holder: NREL senior scientist Miguel Contreras and his group hit the 20-percent efficiency limit on CIGS solar cells.

They did it again. The US-based National Renewable Energy Laboratory (NREL) improved its world record for copper-indium-gallium-diselinide (CIGS) thin-film solar cells. As if it were no big deal, NREL senior scientist Miguel Contreras, presented this at the 16th International Conference on Ternary and Multinary Compounds (ICTMC 16) in Berlin, Germany, in September and not at the world's largest PV conference, the European PV Solar Energy Conference (EU PVSEC), in Valencia that took place in the same month (see article, p. 34). But a CIGS cell with a 20-percent total area energy conversion efficiency is something many scientists have tried to achieve for a long time, even if the size of this cell was only 0.42 cm^2. In fact, it took the NREL researchers almost a year just to improve their former record to the new level – and the efficiency increase was only 0.1 percentage points (see PI 5/2008, p. 67). However, NREL has held the CIS record now for almost five years in a row.

Moreover, if things were seen through the scientist's glasses, the efficiency would be even higher. »If we were to estimate an active area result, this would have been approximately 21 percent,« says NREL's chalcopyrite expert, Miguel Contreras. The reason is that the obscuration loss due to the top contact grid design normally leads to 5 percent higher active area efficiencies for such solar cells. However, unlike scientists, who like to talk about aperture areas or active areas, end-customers are only interested in total area efficiencies – and this on large areas.

Record CIGS solar cell with 20-percent efficiency made by NREL



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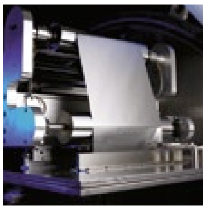
The champion device

At first glance, NREL's record cell seems to be a typical CIGS specimen. Using sputtering technology, a molybdenum layer is deposited on a soda-lime glass substrate to form the electrical back contacts. The CIGS absorber, produced in a three-stage coevaporation process, is located on top of this layer. The pn-junction is formed by the CIGS absorber layer together with a cadmium sulfide (CdS) buffer layer that is deposited in a chemical bath. This is followed by a conductive zinc oxide (ZnO) bi-layer that is applied using a sputtering process and the front contact made by electronic beam-evaporated nickel aluminum grids. Finally, a low refractive magnesium fluoride (MgF_2) coating on the top of the solar cell minimizes light losses through reflection.



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The improvement in the last two record solar cells was achieved using a special CIGS absorber modification that was reached via several annealing steps between the deposition processes. Thereby, the atmosphere in the annealing steps in between the processes are with and without selenium and the temperature reaches 600 °C.

What's impressive about the last two record cells is the very high fill factor of 81 percent, which is not caused by decreased series resistance, but a reduction in surface recombination as deduced by a detailed diode analysis of the current density-voltage data (J-V) for each device. This verifies that the slight modifications to the CIGS surface are responsible for the improved performance. Although the photovoltaic parameters for the new and the former record cells are almost identical, the new cell shows a 1.8 mV higher open circuit voltage (691.8 mV) and a 0.12 mA higher short circuit current (14.97 mA).

20 percent after 20 years

The new cell is the climax of a development that began in the 1980s with US-based Arco Solar Inc., which pioneered R&D in CIGS modules. Already in June 1988 at their laboratory line in Camarillo, California, Arco fabricated a one-of-a-kind CIGS sub-module, measuring 30 × 30 cm, that achieved a 11.1-percent efficiency. At the same time, the world record on CIGS solar cell efficiency was 12.5 percent, held by Boeing. Ten years later in 1998, Arco's 11.1-percent CIGS module still held the efficiency record for this thin-film technology, but was still not commercially available. According to an NREL report, poor adhesion between the CIGS-absorber and the molybdenum back contact was the reason no modules could be produced at equal quality levels. However, a short while later, in the same year, the first commercial modules were introduced at the 2nd PV World Conference in Vienna, Austria. Their origin: Camarillo. But the producer was Siemens Solar, which had acquired Arco's CIS line. The first commercial panels had a 9.4-percent efficiency at a size of 30 × 120 cm. In 2002, Shell Solar GmbH took over the company only to close it four years later when it sold its crystalline solar business. Instead, Shell founded a joint venture with glass company Saint-Gobain under the name Avancis GmbH, which plans to start sales from its new factory in Torgau, Germany, this year.

While many solar module manufacturers are trying to commercialize CIGS module technology (see PI 12/2007, p. 66), the highest efficiency is still 11 percent (an 80 W module from Würth Solar GmbH & Co. KG) – which is way below the record efficiency.

The crux of the matter

In contrast to crystalline silicon, where the difference between top module and record cell is 4.6 percentage points, and CdTe, which has a difference of 5.4 percentage points between top and commercial product, CIGS is a three to five element compound made of copper, indium, selenium, gallium and sulfur. This means that the CIGS deposition technique for thin-film layers requires in-depth knowledge and sophisticated machinery for manufacturing large module sizes in big volumes with over 90-percent yields. But layer uniformity and production yield are ongoing issues. Additionally, one should consider that high-efficiency CIGS solar cells are produced at temperatures over 500 °C, where large area soda-lime glass substrates deform and foils melt.

Although the new world record on chalcopyrite-based solar cells is now 7.5 percentage points higher than it was 20 years ago, commercial module efficiencies seems to be time-invariant, sticking between 8 and 11 percent.

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