

# Fraunhofer ISE sets efficiency records for silicon-based monolithic triple-junction solar cells

The wafer-bonded cell efficiency record has been raised from 33.3% to 34.1%, while the directly deposited cell record has been set at 24.3%.

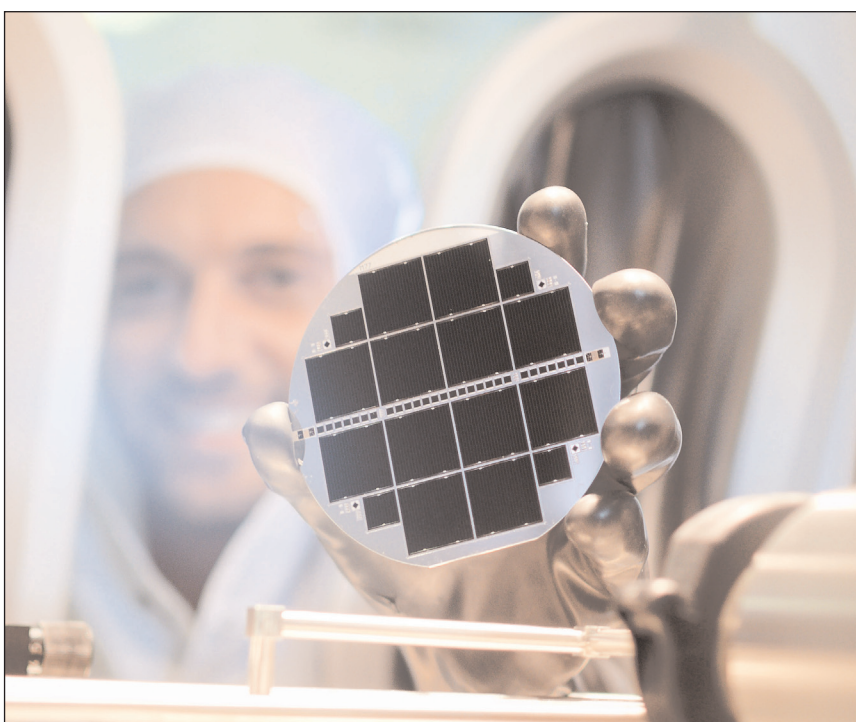
The Fraunhofer Institute for Solar Energy Systems ISE of Freiburg, Germany has again raised the energy conversion efficiency record for monolithic triple-junction solar cells made of silicon and III-V semiconductor materials.

The record for a monolithic multi-junction solar cell manufactured by wafer bonding has been increased from 33.3% to 34.1%.

Fraunhofer ISE has also achieved an efficiency record of 24.3% for a solar cell with the III-V layers deposited directly on the silicon.

“Monolithic multi-junction solar cells are a source of hope for the further development of the silicon solar cells dominating the field today because they can lead to significantly higher efficiency values,” says institute director Dr Andreas Bett. “We believe that we can achieve efficiency values of 36%, which would substantially exceed the physical limit of 29.4% offered by a pure silicon solar cell,” he adds. The high efficiency allows for more output per surface area, allowing savings in solar cell and module materials — an important aspect in regard to the sustainability of photovoltaics.

For the production of multi-junction photovoltaic cells, thin III-V semiconductor layers only a few microns thick are deposited on a silicon solar cell. To optimally exploit the sun’s energy, the different layers absorb light from different spectral ranges: gallium indium phosphide (GaInP) in the 300–660nm range (visible light), aluminium gallium arsenide (AlGaAs) in the 600–840nm range (near infrared light) and silicon in the 800–1200nm range (long-wavelength light). This enables significantly increased efficiencies compared with single-junction silicon solar cells. Like existing conventional silicon solar cells, these cells each have a contact on the front and rear sides, allowing easy integration in solar modules.



Triple-junction solar cells made of III-V semiconductors and silicon.

## Bonded multi-junction photovoltaic cells: 34.1% efficiency

Already well established in microelectronics, the process of direct wafer bonding is employed for creating a monolithic multi-junction solar cell. This involves depositing the III-V layers on a gallium arsenide substrate in an initial step, after which an ion beam is used to deoxidize the surfaces in a high-vacuum chamber before they are pressed together under pressure. The atoms in the III-V semiconductor layers form a bond with the silicon, forming a single unit. Now stacked on top of each other, the GaInP, AlGaAs and silicon sub-cells are interconnected via tunnel diodes. The GaAs substrate is subsequently removed using wet chemistry, a nanostructured rear-side contact is attached and an anti-reflection coating and a contact

grid are applied to the front side.

"In contrast to earlier results, the deposition conditions were improved and a new cell structure was introduced for the uppermost sub-cell made of GaInP which enables even better visible light conversion than before," says Dr Frank Dimroth, head of department III-V Photovoltaics and Concentrator Technology at Fraunhofer ISE.

"With an efficiency of 34.1%, the cell demonstrates the immense potential of this technology."

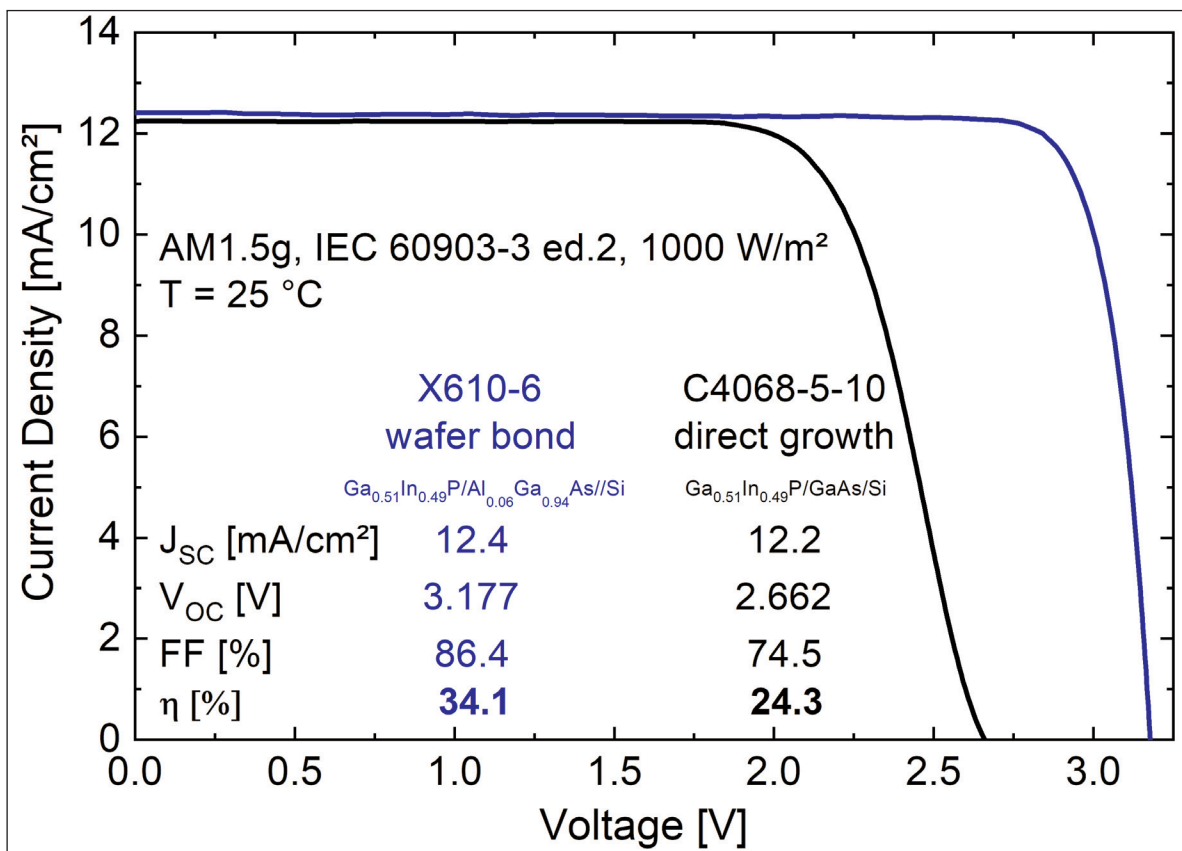
The former record for this cell class was area of 4cm<sup>2</sup>.

33.3% efficiency.

### Multi-junction photovoltaic cell with directly deposited semiconductor layers: 24.3% efficiency

Directly depositing the III-V layers (GaInP/GaAs) on the silicon solar cells involves considerably fewer process steps than wafer bonding and avoids the use of expensive GaAs substrates, so it is quite advantageous in industrial implementation. Nonetheless, the atomic structure must be very carefully controlled to ensure that the gallium and phosphorous atoms are arranged on the correct lattice sites at the interface to the silicon material.

Defects in the semiconductor layers can also have an adverse effect on the cells' efficiency. "We were able to make major progress in this area — current generation in the three sub-cells is now barely affected by these defects, which has enabled us to realize 24.3% efficiency for this technology for the first time," says Dimroth.



IV characteristics of both of the new III-V/silicon triple-junction solar cells, measured at Fraunhofer ISE CalLab PV Cells under AM1.5g standard test conditions. The cells each have an

"The potential is comparable to that of the wafer-bonded cells," he adds. "We've got our work cut out for us in the coming years in order to prove that this is the case." In December 2018, Fraunhofer ISE introduced this type of solar cell with an efficiency record of 22.3%.

In heading toward the industrial mass production of monolithic multi-junction photovoltaic cells, Fraunhofer ISE researchers see particular challenges in finding an affordable process for manufacturing the III-V layers. Direct growth on silicon is currently the most promising approach, but other methods are being researched where the GaAs substrates can be recycled many times over after the semiconductor layers are transferred to the silicon. For cost-effective solar cell production new deposition machines with higher throughput and deposition area will be required. These are all methods that researchers at ISE will pursue in the coming years.

Work on wafer-bonded solar cells is funded by the German Federal Ministry for Economic Affairs and Energy (PoTaSi project, FKz. 0324247). Work on directly grown cells, in which partners Aixtron SE, TU Ilmenau and Philipps-Universität Marburg were involved, was funded by the German Federal Ministry of Education and Research (MehrSi project, FKz. 03SF0525A). ■

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