CIGS PANELS BRING PV INTO SHAPE

Photovoltaic modules based on crystalline silicon have contributed significantly to the widespread use of solar energy in recent years. But in the area of photovoltaics (PV) there are a number of other technologies in development or on the market that are recommended for specific applications. One such technology is CIGS panels. About 15 years ago, researchers from ETH Zurich and Empa presented the concept of a very efficient and flexible CIGS module. After a challenging development period, these CIGS modules are now approaching the market.

CIGS modules consist of a plastic film (polymer) that in several process steps is coated with photoactive materials. Photo: Flisom

A technical report about the results of a pilot and demonstration project in the field of photovoltaics, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine HK Gebäudetechnik (issue April 2018).

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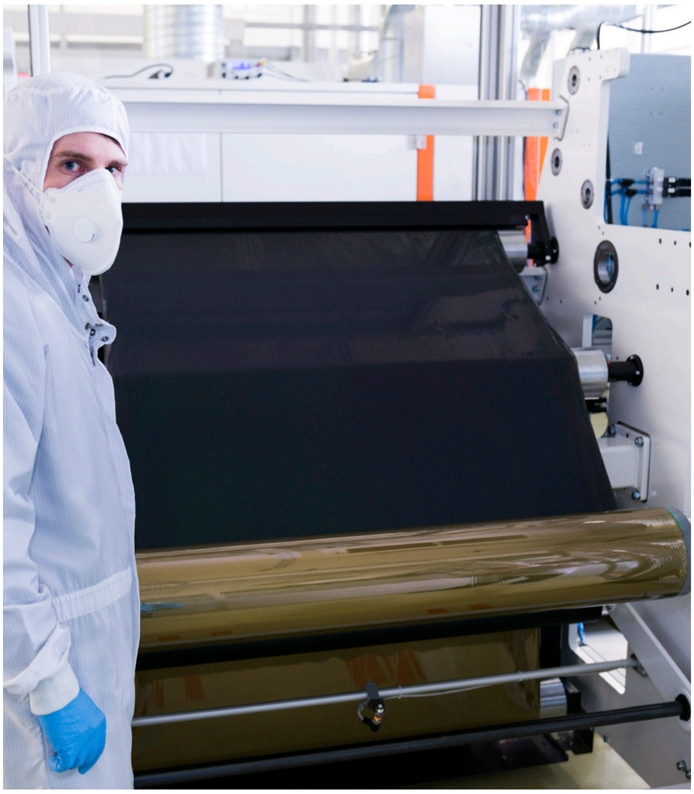
When people discuss PV panels today, they are usually referring to panels made from crystalline silicon cells. These monocrystalline or polycrystalline silicon panels dominate the world market. They have made the upturn in photovoltaics possible in the last 25 years due to sharply falling prices. But photovoltaic technology is far from reaching the end of its technological development. Scientists are tinkering with new technologies in their laboratories to make energy production from solar radiation even more efficient, more user-friendly and even cheaper.

One market challenge to classic silicon panels has been the emergence of thin-film modules. They bear this name because the photoactive layer is about 100 times thinner than that of crystalline silicon cells. Thin-film cells use a variety of semiconductor materials: non-crystalline (amorphous) silicon, cadmium telluride (used by the US manufacturer First Solar), or copper indium gallium diselenide (Cu (In, Ga) Se_2). Modules made of the latter alloy are called CIGS solar modules, so named because of the semiconductor materials used. Over the past decade, when silicon production was temporarily unable to meet high demand, thin-film modules experienced an upturn and gained a market share of around 15%. To date, these modules are asserting themselves on the market: By converting 6 to 16% of solar energy into electrical energy, they have a lower efficiency than modules made of crystalline silicon (15 to 20%), but they do deliver good energy yields in diffuse light, weigh less and are potentially cheaper to produce.

New Application Areas

Today, CIGS modules are manufactured by a number of US companies, but also by the German company AVANCIS (Torgau / Saxony), which became part of the Chinese building materials and glass company CNBM in 2014. CIGS modules are also sold by the Japanese company Solar Frontier. Most often, the CIGS absorber layer, which absorbs sunlight and converts it into electrical current, is deposited on a solid glass substrate. But thin-film cells can also be deposited on flexible plastic substrates, which creates bendable PV modules. CIGS modules are comparatively light at 1.5 to 4 kg / m^2, compared to 10 to 12 kg / m^2 glass-coated silicon modules. Visually, CIGS modules can be distinguished by their homogeneous black surface. Such features make CIGS modules suitable for building-integrated applications, including lightweight roofs. Also possible are special applications such as in the aerospace industry or in car and ship building. CIGS modules thus have the potential to open new areas of application for photovoltaics.



Flisom produces its solar modules using a roll-to-roll process. This means that at each process step, the one-meter-wide substrate web made of polymer is unrolled, processed and then rolled up again. Photo: Flisom

The Swiss industry is now poised to make a major contribution to the development of flexible CIGS modules—an innovation based on the long-term research work of Dr. Ing. Ayodhya N. Tiwari, at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in Dübendorf. Tiwari, head of the Empa Laboratory for Thin Film and Photovoltaics, has held the world record for energy conversion efficiency of a flexible CIGS solar cell (20.4%) since 2013. In 2005 Tiwari founded the company Flisom (short for: ‘Flexible Solar modules’). The spin-off of ETH Zurich gradually developed a cost-effective manufacturing process for CIGS solar modules on a flexible plastic film. In 2009, the first pilot plant was opened at Empa. In autumn 2015, a 20 million franc production plant was built in Niederhasli (ZH), the first of its kind in the world, which was tested for the first time with the support of the Swiss Federal Office of Energy as part of the P + D program and has since been optimized so that it now manufactures marketable CIGS solar modules. In the fall of

Since 2015 a production facility for CIGS modules stands in Niederhasli (ZH), in which Flisom is now producing marketable solar modules.
Photo: Flisom

2017, a 30 kW PV system with such CIGS modules was put into operation on the Empa campus.

First Coated, then Cut and Processed

Visitors to the Flisom production plant in the industrial area of Niederhasli must don white overalls and blue plastic shoes. The path to the production hall leads through a lock. "We do not manufacture in a clean room, but we want to keep the production hall as free of dust as possible," explains Ulfert Rühle, an electrical engineer trained at the University of Stuttgart, who has worked with thin-film cells for over 20 years and is responsible for Business and Product Development at Flisom. Rühle leads the journalist to a glass wall, behind which stands a room-high production machine, which the company built itself. This is where a major production step takes place: in a vacuum, the gaseous semiconductor materials copper, indium, gallium and selenium are vapor-deposited on the flexible carrier layer. It is one of six production steps for coating the modules (see text box). In each step, the one meter wide substrate web of polymer is unrolled, processed and then rolled up again ('roll-to-roll process').

At the back of the production hall, CIGS modules are produced from 37 x 74 cm module blanks ('submodules'): the edges are trimmed, the submodules are connected to form larger units, the contact bands are installed, laminating and front foils are applied, finally the junction box is attached. The workers wear hair nets and black gloves. "There is a lot of manual work required here, because fully automated production would still be too expensive given the current production volume," says Ulfert Rühle. At the end of the production line during quality testing, lights start flashing. In the solar simulator and the climate chamber, the modules are tested for reliability. The production hall is bustling with activity. Flisom is currently working on a major contract for a building listed under historic preservation in Holland. On an area of 2000 m^2, the pliable CIGS modules will be used since they can be adapted to the curvature of the barrel roof.

Further Increase in Efficiency

At the production plant in Niederhasli, the 65 employees of Flisom can produce CIGS modules with a total output of 15 MW per year. This amount is enough to power 3,750 four-per-

CELLS DO NOT HAVE TO BE INDIVIDUALLY INTERCONNECTED

Like other solar modules, CIGS solar modules convert sunlight into electricity. In CIGS modules, sunlight is absorbed through a 1 to 2 micron thick layer consisting of the semiconducting metals copper, indium, gallium and selenium. This process sets charge charriers free. The electrons form electrical current, which flows from the zinc oxide layer (positive pole / front contact) through the CIGS semiconductor materials to the molybdenum layer (negative pole / back contact).

To produce a CIGS module, a plastic film (polymer) is coated in several process steps: First, the molybdenum is applied on a 1 m wide and several hundreds of meters long film through a sputtering process. Secondly, a laser carves electrically insulating structuring lines into the molybdenum. Thus, a serial circuitry of stripe cells is produced on the substrate, whereby the complex interconnection of individual cells is omitted ('monolithic interconnection'). Third, the absorber layer of copper, indium, gallium and selenium is vapor-deposited. Fourth, a buffer layer is applied in a wet-chemical process. Fifth, the zinc oxide layer is applied. Sixth, the front contact made of zinc oxide is laser ablated to direct the flow of current in the desired direction. Now the module blanks ('submodules') are ready to be processed in the rear part of the production hall into finished modules.

Flisom uses a roll-to-roll process for the six process steps mentioned above. This means that at each process step, the substrate is unrolled, processed and then rolled up again. The Flisom manufacturing method differs from other methods for producing flexible CIGS cells by the monolithic interconnection method and the use of a polymer film as a substrate. In the monolithic interconnection of the individual cells to the module method, the front side of a cell is connected directly to the back side of the next cell in a series circuit during the manufacturing process. This saves additional metallic contacts, such as those required for crystalline silicon solar cells. This makes the technology more cost-efficient to automate and more flexible in product design. BV

son households–this production capacity, however, is not yet exhausted. Rather, the goal over the past two years has been to eradicate the teething troubles that occur in any facility of this kind, and to progressively optimize production. For example, the manufacturing processes have been improved so that the modules today have a consistent quality over the entire roll width of one meter. Although Flisom now produces marketable modules, the technology development process is not yet complete. Further process optimization should ensure that the current efficiency of the modules, which is already in the double-digit percentage range, can be further increased and brought closer to the record value of 20.4% in the future, as has been demonstrated in the laboratory.

Flisom had initially considered positioning itself in the market as a manufacturer of production lines for CIGS modules. For the time being, however, the company has put this strategic goal on ice. "First, we want to gain experience with our own technology and establish ourselves on the market as a module manufacturer," says Rühle. Flisom plans to build another production line by 2019, which will have around ten times the capacity of the existing plant in Niederhasli. It is designed to produce modules that can compete with crystalline silicon modules in price. For cost reasons, the plant will be built in other European countries, in India or the US – the exact location has not yet been determined. The development department, on the other hand, plans to stay in Switzerland.

The solar modules of the Flisom company are recommended, among other things, for building-integrated photovoltaic applications (on the left) and can be mounted on curved surfaces (on the right): In the US and Europe, the company has already implemented a first application in aviation. Photo/Model image: Flisom

Demanding Market Entry

The India based TATA Group and Swiss investors are supporting Flisom AG with a double-digit million investment. In order to conquer part of the PV module world market with flexible CIGS modules, the company needs perseverance. Flisom faces stiff competition from established companies that have been producing CIGS modules on flexible substrates for a long time, such as the two US companies Global Solar Energy and MiaSolé, both of which have been part of the Chinese Hanergy Group since 2013, or Solopower Systems based in Portland, Oregon.

- The **final report** on the project can be found at: https://www.aramis.admin.ch/Texte/?ProjectID=37151

- **Information** about the project is given by Dr. Ing. Stefan Nowak (stefan.nowak [at] netenergy.ch), head of the SFOE research program Photovoltaics.

- Further **technical papers** on research, pilot, demonstration and flagship projects in the field of photovoltaics can be found at www.bfe.admin.ch/CT/PV.

PILOT, DEMONSTRATION AND FLAGSHIP PROJECTS OF SFOE

The construction, testing and optimization of a production line for CIGS solar cells by Flisom AG is one of the pilot and demonstration projects with which the Swiss Federal Office of Energy (SFOE) promotes the development of economical and rational energy technologies and the use of renewable energy. The SFOE sponsors pilot, demonstration and flagship projects with 40% of non-amortizable, chargeable costs. Applications can be submitted at any time.

- **Information**:
  www.bfe.admin.ch/pilotdemonstration
  www.bfe.admin.ch/leuchtturmprogramm

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