

Significant progress in CIGS thin-film solar cell technology reported at IWCIGSTech7

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Photovoltaic modules with CIGS absorbers are very effective in converting light directly into electricity. Due to their specific advantages CIGS thin-film modules are among the most promising photovoltaic technologies. Many companies and institutions worldwide contribute to this development with diversified approaches. An efficient exchange of knowledge is essential to move the technology forward. In June 2016, the IW-CIGSTech workshop was organized for the seventh consecutive year in a row. This time, the event took place as a parallel event to the EU-PVSEC/Intersolar Europe in Munich. In the workshop, representatives from industry and academia gathered to discuss the latest developments in the fast-developing field of CIGS (Cu(In,Ga)(Se,S)₂) based solar cells. As a result of last year's workshop, a joint,

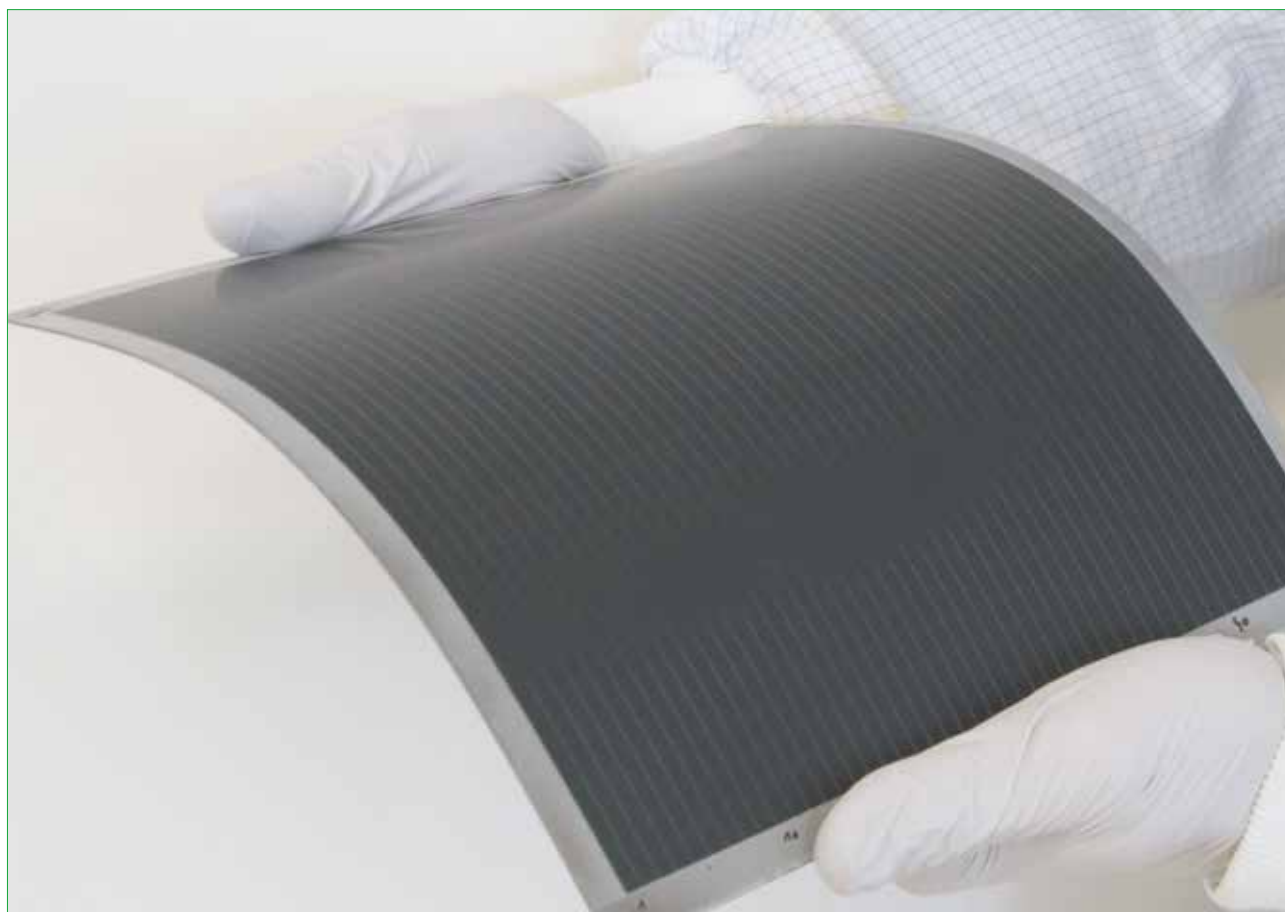
community-wide effort resulted in the broadly acknowledged "White Paper for CIGS thin film solar cell technology" [1]. In this article, we provide a brief impression of the progress and challenges reported in this year's workshop.

Record efficiencies

Over the past few years, record efficiencies have improved at an impressive rate and are catching up with crystalline silicon technology. Presenting a new world record, Stefan Paetel from ZSW in Stuttgart, Germany, reported on his institute's latest certified record value of 22.6%. With his colleagues from the EU-sponsored Sharc25 consortium, he outlined the roadmap 25% efficiency values on a lab scale. Similarly ambitious targets were reported by Shigeru Niki from Japan's

AIST, who leads a NEDO-sponsored consortium working on CIGS. Based on Solar Frontier's sequential deposition technology (22.3% certified record cell), and AIST's in-house co-evaporation technology, 20% mini-module efficiency is aimed for by 2019, paving the way for electricity costs of ¥14 JPY (US\$0.135) per kWh in 2020 and ¥7 by 2030.

Prof. Sun from Nankai University in China presented an overview of academic and industrial developments in China. Several research labs are working on CIGS cells and modules on flexible substrates and glass, with cell efficiencies already above 20%. Reporting on experience with improved yield from CIGS PV plants compared to Si, as well as on production expansion plans from companies such as CNBM and Hanergy he expects the breakthrough of CIGS industrialization within the next 10 years.



Credit: ZSW

CIGS thin-film technology can be used in a variety of applications, such as on flexible substrates.

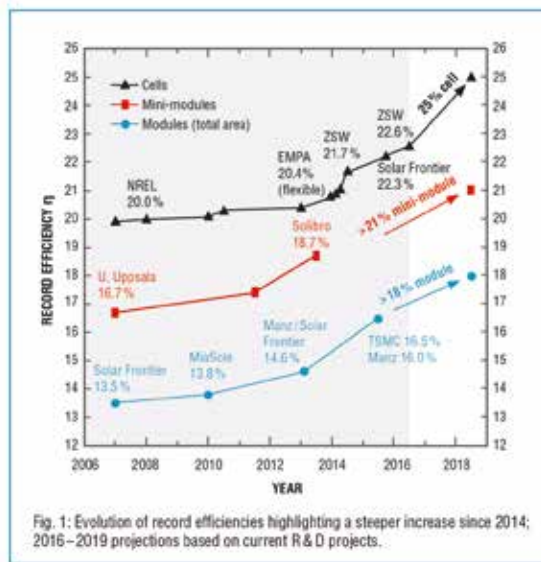


Fig. 1: Evolution of record efficiencies highlighting a steeper increase since 2014; 2016–2019 projections based on current R&D projects.

Figure 1: Evolution of record efficiencies highlighting an increased slope since 2014; 2016–2019 projections based on current R&D projects.

Figure 1 indicates the recent progress in record efficiency at the cell level (black triangles). New processes with the introduction of alkali dopants enter production and provide a significant boost of module performance, paving the way for progress at the mini-module level (red squares) and towards total area module efficiencies (blue dots) of 18%.

Products and technology perspective

An important focus of the workshop was on production issues. The diversification of the production and design of CIGS modules offers multiple possibilities for PV power systems in the future. CIGS glass-glass products cover the classical application fields of power plants, rooftops and building facades. Even though this efficient thin-film technology can be produced on a variety of substrates, glass-based modules are dominating production, as was reported by Takuya Kato from Solar Frontier, Robert Lechner from Avancis and Olle Lundberg from Solibro. Full-size modules from the main players have all reached champion efficiencies in the range of 16%, independent of process technology. Several large-scale production sites are running in Japan and Germany, and several more are planned and in construction in China. At the same time, flexible and light-weight CIGS modules currently in production show average aperture area efficiencies of >16% as well, as reported by Miasolé's Atiye Bayman. Achieving high efficiency with such

products will open new large-scale applications and consumer markets. A variety of substrates and module designs were presented by Global Solar (Urs Schoop reported) and Miasolé, both within the Hanergy group, as well as by Switzerland based Flisom.

Proven reliability and performance

Glass-glass CIGS modules with monolithic series connection of the individual cells demonstrate inherently superior stability over soldered or bonded cell strings. At present, CIGS modules from mass production guarantee a high level of reliability proven by extensive endurance and long-term field tests in numerous installations and climatic conditions with independent verification [2].

A low temperature coefficient, a favourable spectral response and high efficiency under low light conditions are the reason for excellent energy yields and hence low levelized costs of electricity under most climatic conditions. Furthermore, the specific design of thin-film module based on monolithic interconnection of cells across the entire substrate results in intrinsically reduced sensitivity to detrimental effects caused by shading.

Following a long tradition of CIGS Technology since the last century, Stion's Alexander Schwarz presented impressive data of performance, reliability and stability of modules in the field. These data and similar long-term studies presented by Solibro indicated that CIGS is outperforming c-Si at most geographical locations.

Developments at the GW production level

Currently the biggest production units, ranging in capacity from 100 to 1,000MWp per year, are located in Germany, the US and in Japan. In China, ground-breaking for factories of hundreds of megawatts in size have already taken place and further operations in the gigawatt range are planned. These are operated at high yields well beyond 90% over the whole value chain. At present, the total world-wide CIGS production capacity is about 2GWp per annum. Although companies use different fabrication methods, all of them show excellent results, demonstrating that CIGS production technology has reached the first stage of industrial maturity. Even when using non-abundant elements like Indium, a supply limitation is not expected at any planned and projected production volume. This is due to the continuous reduction of the amounts of Indium needed in combination with progress in recycling. Production costs of US\$0.4/Wp are already projected even for low capacities of 150MW, with further reductions of 25-40% expected by improving module efficiencies and exploiting scaling effects on materials cost and capex for multi-gigawatt fabs. Nevertheless, further cost-reduction potential is expected within the next decade if supported by continued, effective R&D activities.

For production lines on a gigawatt level, equipment manufacturers play a key role. The tolerance of the CIGS absorber material allows a wide scope of process techniques to be exploited. Kay Orgassa from Manz gave an update on the further development of Manz's well known co-evaporation-based 'CIGSfab'. Next to further improvement in module efficiency and line yield, he reported on experiments on how to transfer the highly successful lab-scale alkali Post Deposition Treatment (PDT) into production. Dirk Beisenherz from Singulus gave an overview of his company's core sequential CIGS processing technologies: precursor sputtering, Se deposition, rapid thermal processing (RTP) ovens and buffer deposition. He also showed how this equipment was scaled up towards GW production level. In order to enable further capex reductions, Sebastian Schmidt from the Helmholtz Zentrum Berlin presented exploratory work to develop high-efficiency, high-throughput RTP equipment, with the key feature that it operates at atmospheric pressure (based on a Smit Thermal Solution system).

The huge future potential of CIGS

technology was demonstrated in the oral and poster presentations by research institutes from a.o. Switzerland, France, Japan, the Netherlands, Luxemburg, China and Germany. Recent results of material modifications and device optimization, such as those presented by Daniel Lincot from IPVF (France), revealed the still enormous room for further efficiency developments. In the longer term, in combination with suitable wide bandgap absorbers (e.g. Perovskites), CIGS can be used as a bottom cell in tandem devices that enable efficiency values well beyond 30%, as was outlined in the presentation by Stephan Buecheler from EMPA (Switzerland). This demonstrates impressively that not only is CIGS a competitive PV technology, but in addition it comprises a potential not yet exploited for further improvements.

Still, there are some clear challenges facing the CIGS community as a whole. Most importantly, a lack of standardization in process equipment, product size, quality control and in-house testing procedures so far prevent CIGS technology from reaping the full economy-of-scale benefit. Therefore, in the course of IW-CIGSTech 7, major players of the industry and its suppliers as well as research institutions agreed to build on the initial joint effort of the White Paper. They intend to cooperate

more closely in future, for example by sharing information on joint technical issues, providing up-to-date ecological footprint data, developing a CIGS technology roadmap and keeping the public up to date on the advantages of the CIGS technology.

In summary, the IWCIGSTech7 workshop presentations gave a concise and impressive insight into the present status and future potential of CIGS technology. Due to its continued success in gathering the vast majority of technological actors in the field, the community-driven IWCIGSTech workshop is certain to see its next version in 2017.

References

- [1] "White Paper for CIGS thin film solar cell technology", cigs-pv.net
- [2] See for instance data from the independent DKASC outdoor test site in Alice Springs, www.dkasolarcentre.com.au

About the Authors



Rutger Schlatmann is director of PVcomB, the PV technology transfer centre at the Helmholtz-Zentrum Berlin and full professor (W3) at the HTW Berlin. He obtained his PhD at the FOM Institute Amolf in Amsterdam. Before 2008, he was as R&D manager at Helianthos, a company developing flexible

solar modules. His research interests include CIGS, Si HJT and multi-junction solar cells. He is a steering committee member of the European Technology & Innovation Platform PV.



Hans-Werner Schock has worked since the early 1970s on the development of polycrystalline II-VI and I-III-VI₂ compound semiconductor thin-film solar cells. From 2004 to 2012 he was director of the Institute of Technology at the "Helmholtz Zentrum Berlin für Materialien und Energie". For his achievements in the development of thin-film solar cells he received the "Becquerel Prize" of the European Commission in 2010.



Michael Powalla is head of the Photovoltaics Division and member of the board at Zentrum für Sonnenenergie und Wasserstoff-Forschung Baden-Württemberg (Centre for Solar Energy and Hydrogen Research) in Stuttgart, Germany. He earned his PhD in 1998 at the University of Stuttgart. As a physicist, he devotes his attention to materials and processes of energy conversion with a focus on photovoltaics. Prof. Powalla holds a professorship for thin-film photovoltaics at Karlsruhe Institute of Technology (KIT).

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