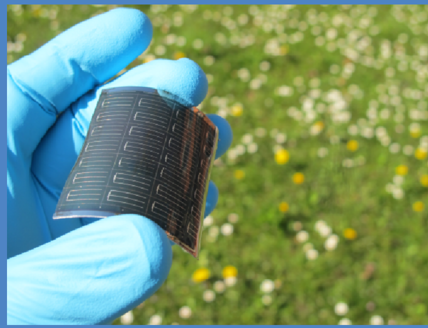
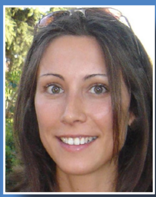
Prof. Christophe Ballif, EPFL

Synergy

SYSTEMS FOR ULTRA-HIGH PERFORMANCE PHOTOVOLTAIC ENERGY HARVESTING



Dr. Julien Bailat, CSEM



Prof. Anna Fontcuberta I Morral, EPFL

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What it's about…

Developing energy harvesting systems with ultra-high efficiencies.

Context and project goals

This project aims to realize photovoltaic (PV) energy harvesting systems based on tandem solar cells with efficiencies beyond those achievable with state-of-the-art industrial single-junction cells by combining the unique technological components – record cells absorbing various parts of the solar spectrum – recently realized by Swiss research institutes. By themselves, the new multi-junction cells will be highly complex systems, and will open opportunities for tomorrow's electricity power plants and for consumer electronic applications, including e.g. watches and powering of low-consumption electronics. The project is supported by key players of the PV field (Meyer Burger) and of the watch and electronic industries (Swatch Group R&D and EM Marin).

For decades, the PV market has been dominated by wafer-based crystalline silicon (c-Si) solar cells with lab record efficiencies of 25%, and production efficiencies of 17-22%. As these values are already close to the theoretical limit of single-junction c-Si cells, further improvements will not be possible by incremental technological innovation. One of the most promising approaches to overcome this limit is to combine two single-junction cells with different optical band gaps to form tandem solar cell systems. This concept has been successfully employed for concentrator PV systems using expensive III-V semiconductors and for thin film Si solar cells, such as a-Si/c-Si tandem cells with limited efficiencies. Highly efficient tandem cell systems involving c-Si or copper indium gallium selenide (CIGS) bottom cells have so far not been successfully realized, mainly due to the difficulty to find a suitable wide-band gap top cell that delivers the necessary photocurrent while exhibiting excellent electrical properties.

Recently, the situation drastically changed with the emergence of highly efficient wide-band gap thin-film solar cells that deliver high photocurrents, based on perovskite or II-VI absorbers. In addition, low-band gap cells based on CIGS compounds have recently reached efficiencies beyond 20%, thus are nearly as efficient as the best c-Si cells. In parallel, heterojunction c-Si solar cells with record efficiencies in the infra-red have been demonstrated. We believe that these recent developments from Swiss labs enable industrially relevant tandem systems with efficiencies beyond 30%.

The project consortium has vast experience and top-notch infrastructures required to fabricate state-of-the-art devices for all these high-efficiency PV technologies, and each group is worldleading in one or several of them. Each of these technologies will be adapted and optimized to be integrated into tandem cells. Specifically, PV-lab at EPFL will develop dedicated a-Si/c-Si heterojunction bottom cells and versatile μc silicon test templates, EMPA chalcogenide cells with tuneable band gaps such as CIGS and kesterite cells, and LPI at EPFL perovskitesensitized solar cells. As a more explorative effort, LMSC at EPFL will also implement GaAs nanowire cells in tandem devices with the potential to surpass the thermodynamic efficiency limit for conventional solar cells. These experimental efforts will be supplemented with optical simulations to ensure optimal device design. Finally, the broad PV-related capabilities of the project consortium are leveraged for up-scaling and the development of PV energy harvesting demonstrator systems for indoor and outdoor applications, an activity that will be led by CSEM.

How it differentiates from similar projects in the field

High-efficiency, low-cost tandem devices are on the agenda of many research groups. Yet, with its very broad knowledge base, long-standing experience with technology transfer, and record devices in many photovoltaic technologies including solar cells based on GaAs nanowires, a-Si/c-Si heterojunctions, chalcogenides, and metallorganic halide perovskites, the Synergy consortium is well positioned to lead the development of ultra-high efficiency tandem cells in this highly competitive environment.

Quick summary of the project status and key results

Highly transparent electrode layers based on hydrogenated indium oxide and indium zinc oxide were developed, which at the same time show excellent charge carrier mobilities. With these conductive oxides, EPFL PV-Lab and EMPA, in collaboration with EPFL LPI realized perovskite cells with a high near-infrared transparency. EMPA has reached efficiencies of up to 14.2% with such a semi-transparent perovskite cell.

Implementing these cells with CIGS or Si bottom cells, mechanically-stacked 4-terminal tandem devices with efficiencies of up to 19.5% were obtained. EMPA has tuned the bandgap of CIGS cells to optimize it for tandem applications by adjusting the gallium content.

Si heterojunction cells were optimized by improving the quantum efficiency in the infrared using highly transparent front and rear contacts. EPFL LPI has developed efficient perovskite cells with TiO_2 and Al_2O_3 scaffold layers, processed at low temperatures, compatible with CIGS and Si heterojunction cell processing.

Moreover, in order to reduce parasitic absorption, EPFL LPI has investigated inorganic hole transport layers, and made cells with a highly transparent nickel oxide hole transport layer with efficiencies of ~14%. EPFL LMSC has successfully integrated p-i-n radially doped GaAs nanowire arrays into transparent polymer films and contacted them with transparent electrodes.

In addition, numerical simulations revealed the efficiency potential of GaAs nanowire/Si tandem cells. CSEM has developed fully-laser-scribed perovskite modules on 5 cm x 5 cm substrates with a dead area of < 16% and an aperture efficiency of 5.5%

Success stories

The combination of a NIR-transparent perovskite top cell from EPFL LPI with a CIGS bottom cell from EMPA enabled a tandem device with 19.5% efficiency, which is the highest reported efficiency for a polycrystalline thin film tandem solar cell.

CSEM achieved the first perovskite mini-module with a size of 5 cm x 5 cm, patterned fully by a laser scribing process. The fraction of dead area was dramatically reduced to less than 16% with respect to the total area, compared to almost 30% of previous results by standard masking techniques.

EPFL PV-Lab has developed highly transparent front electrodes with excellent charge carrier motilities based on indium zinc oxide. With this electrode, PV-Lab has demonstrated infrared-transparent perovskite cells with an efficiency of up to 10.3%.

EMPA has developed a perovskite cell with a high transparency in the infrared and with efficiencies of up to 14.2%.

EPFL LMSC has developed a procedure to integrate GaAs nanowire arrays in a flexible polymer layer and contact them with transparent electrodes.

EPFL LPI has developed a highly efficient perovskite cell processed at low temperatures (<200°C), which is essential to realize monolithic tandem cells with CIGS and Si heterojunction cells.

Patent

A patent has been filed by CSEM for an ideal coupling scheme between a silicon wafer and a perovskite solar cell.

Main publications

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