ProME^{3}ThE^{2}US^2 PROJECT

A Novel Technology to Exceed 50% Efficiency in Solar Concentration Systems.

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Scenario

Energy conversion from concentrated solar systems is presently performed by semiconducting cells in Concentrating Photovoltaics (CPVs) and by a thermodynamic heat transfer to high operating temperature engines in Concentrating Solar Plants (CSPs). In both cases, the economics of the solar plant are still not competitive with electricity generated from conventional fuels, since the cost of solar electricity is typically twice or higher. One strategy to increase cost effectiveness and make concentrated solar electricity more competitive is to develop technologies characterized by a higher conversion efficiency. It corresponds to development of multi-junction cells on the CPV side (above 40%) and to operations at higher temperatures combined to advanced thermodynamic cycles on the CSP side (over 40% at a converter-level). The resulting system efficiency is in the 25-30% range. A parallel approach is reducing the installed plant cost by developing simpler, lower cost alternatives to plant components such as cheaper reflector materials and optimized tracker mechanics. One aspect of CSP that remains untouched is the heat-to-electricity converter. This conversion relies on proven heat engine technologies that have been developed for many decades for conventional power plants, such as Rankine (steam) and Brayton (gas) turbine cycles. In addition, a separate high-temperature receiver and a heat transport system for introducing the heat from the receiver into the thermodynamic cycle are required. Thus, the thermo-mechanical conversion approach leads to technologically complicated systems that add a significant contribution to the cost, complexity, operational and maintenance requirements of the solar power plant. Therefore CSP is not a scaling technology and makes

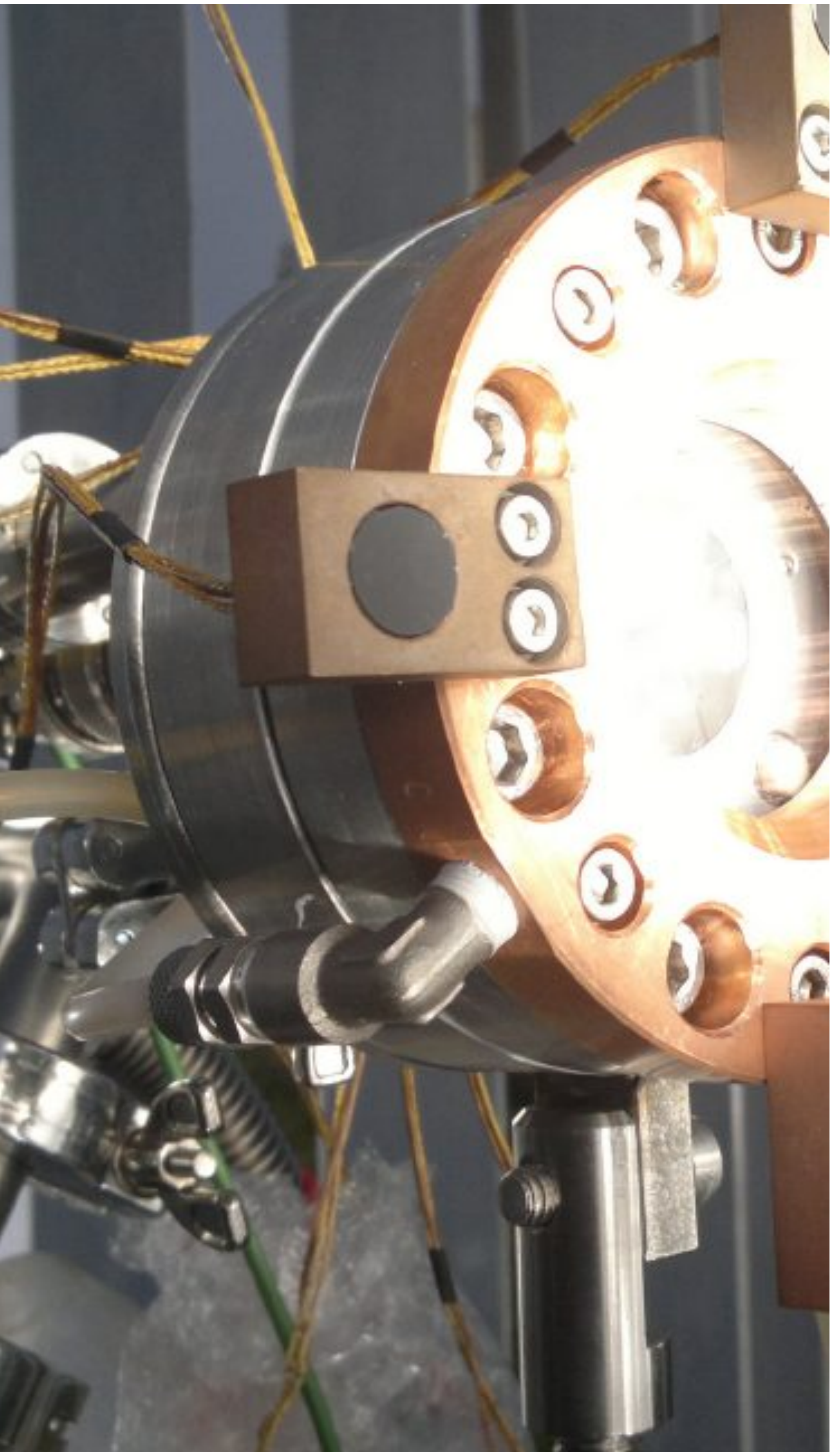
Cogeneration

The advantage of concentrated solar systems is the cogeneration, namely collection of the waste heat as an additional energy product, can increase the effective conversion efficiency and generate an additional revenue stream that improves the plant economics. Cogeneration can provide a range of thermal applications, such absorption cooling and air-conditioning, thermal desalination, and process heat or steam for industry. Cogeneration in CPV can reach temperatures around 100 °C, which provide access to attractive thermal applications but accepting a moderate decrease of cell performance. Conversely, cogeneration in CSP technologically is difficult in the more common Rankine cycle plants since collecting waste heat at useful temperatures requires raising the condenser pressure leading to a significant decline in cycle efficiency, while this effect is less significant in Brayton cycle based plants. But the most limiting aspect is that cogeneration is suitable for distributed generation where the plant is small enough to be close to the end-user, while CSPs tend to be large and remote. CSP access to cogeneration is therefore very limited today.

The Project

ProME^{3}ThE^{2}US^2 project - Production Method of Electrical Energy by Enhanced Thermal Electron Emission by the Use of Superior Semiconductors- aims at developing, validating and implementing a novel solid-state conversion mechanism able to transform concentrated solar radiation into electric energy, at very high efficiency (potentially exceeding 50%) and characterized

Conversion module under concentrated solar irradiation. It was developed by the CNR group with the contribution of Tel Aviv University group during the recent EU project E2PHEST2US - GA 241270. The conversion module operated according different physical mechanisms, but some technological elements may be common with the one to be developed within Pro3ME2ThEUS2.



by a direct solar energy conversion. The primary conversion is obtained by an enhanced electron emission, derived by thermionic coupled to photo-emission, from advanced semiconductor structures. The system may be also cogenerative to possibly supply the needs of future end-users.
ProME^{3}ThE^{2}US^2 (Grant Agreement n. 308975) is an European collaborative project within the Energy FP7 framework of Future Emerging Technologies (FET). FET projects represent an incubator and pathfinder for new ideas and themes for long-term research, whose mission is to promote high risk research, offset by potential breakthrough with very high technological impact. FET is a tool that will be strengthened during the next Horizon 2020 European Framework for research & development.

The project consortium is coordinated by the Italian National Research Council (CNR) and is composed by the Tel Aviv University and Technion Institute of Technology (Israel), the Fraunhofer Institute (Germany), whose activity will be managed mainly by the Institute for Solar Energy. Three high-tech SMEs were involved for their excellence in specific technology sectors: Ionvac Process Srl (Italy), Exergy Ltd and Solaris Photonics Ltd (United Kingdom).

The consortium was assembled to be highly multinational with the aim to provide excellence in the energy and materials science fields. The consortium approach is multi-disciplinary since its expertise ranges from materials science to chemistry, from electronic and electrical to mechanical engineering. Tel Aviv University has a long experience in electro-optical simulation, surface science, and mechanical and thermal design applied to solar energy; CNR group involved is specialized in scientific activities concerning materials science, electronic engineering and surface treatments; Technion's expertise is in materialsscience under a chemical point of view; Fraunhofer Institute's background is focused on semiconductors engineering for solar energy technology; Exergy Ltd has a solid know-how in design and analysis of industrial engineering systems; Solaris Photonics' expertise lies in innovations on alkaline photovoltaic technology and carbon-based devices; Ionvac Process Srl is highly experienced in developing deposition systems and vacuum technology. The consortium is well-balanced from the basic to the applied science and technology, with two Universities (Tel Aviv University and Technion), an applied science research centre (CNR) and a research centre devoted to technological transfer to industry (Fraunhofer Institute). The three high-tech SMEs share their experience to solve specific technological issues which can be exploited to conquer future high-tech markets. Moreover, Abengoa Research S.L. (Spain) - a company with a clear mission aimed at experimenting novel pre-competitive technologies for solar market controlled by a leader industry (Abengoa) - expressed a formal request for joining the consortium which is presently under consideration by the European Commission.

Project details

The objective of ProME^{3}ThE^{2}US^2 project is the development of a third approach alternative to the described CPV and CSP technologies. The principle was first proposed by a research group of the Stanford University [Nature Materials 9, 762 (2010) and Nature Communications 4, 1576 (2013)]. They named the device PETE (Photon-Enhanced Thermionic Emission), consisting of an innovative solid-state converter, whose application is in high-flux concentrating solar systems. ProME^{3}ThE^{2}US^2 aims at developing advanced semiconductors and related structures to maximize the electrical efficiency of the converter by a stage able to employ the solar infrared (IR) radiation to provide a temperature increase, a semiconductor cathode properly deposited on it, and a work-function-matched anode, separated from the cathode by an inter-electrode spacing. The energy conversion exploits the high radiation flux by combining an efficient thermionic emission to an enhanced photo-electron emission from a cathode structure, obtained by tailoring the physical properties of advanced semiconductors able to work at temperatures as high as 800 °C. The high operating temperatures are also connected to the possibility to exploit the residual thermal energy into electric energy by thermo-mechanical conversion. The concept novelty bases on the use of both bandgap and over-bandgap energy to generate electrical current; on the additional use of sub-bandgap IR radiation, with a spectral energy not able to excite photo-emitters, for augmenting the thermionic emission from cathode, on engineered semiconductors, able to emit electrons at lower temperatures than standard refractory metals; on the experimentation of a hetero-structured cathode for emission enhancement by an internal field; on the recovery of exhaust heat from the anode by thermal conversion. It is estimated that the proposed technology could achieve 40% efficiency at the converter level, and possibly even above 50% with the addition of a bottoming converter that captures waste heat to produce additional electricity [G. Segev, A. Kribus, Y. Rosenwaks, Solar Energy Materials & Solar Cells 107, 125 (2012) and 113, 114 (2013)].

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