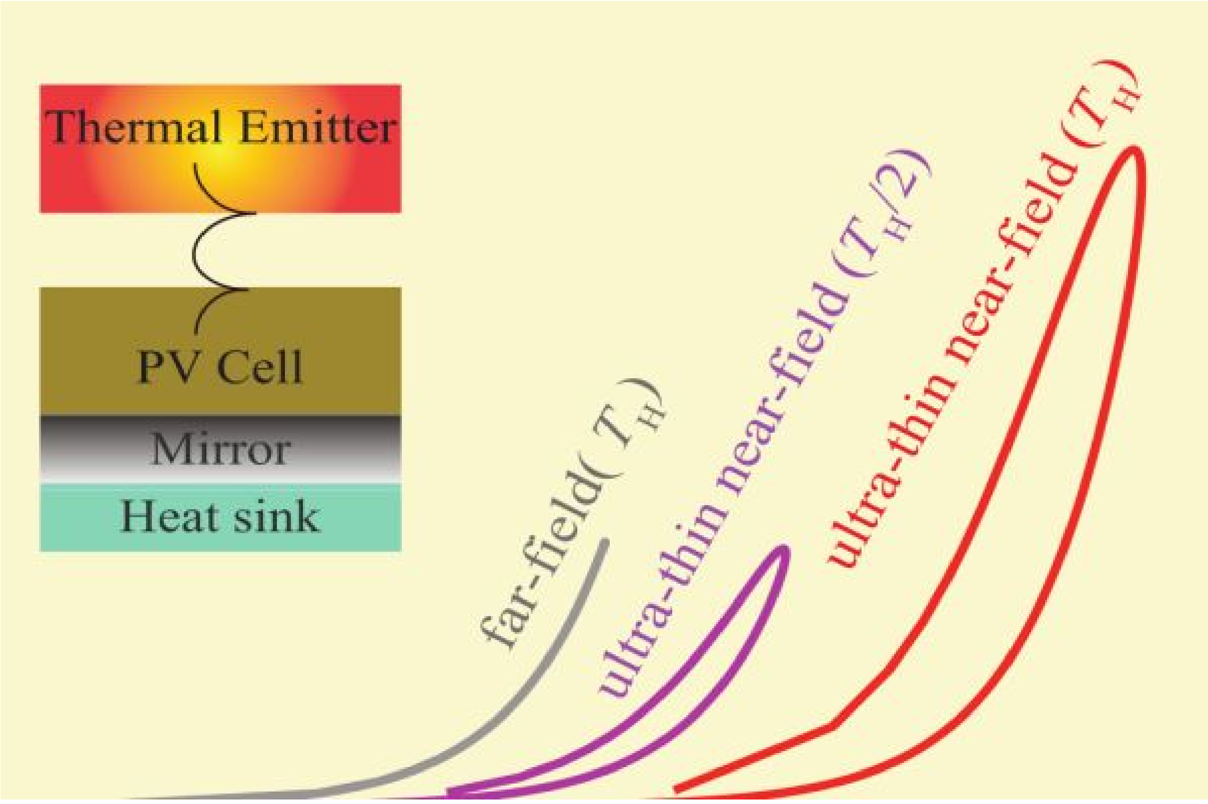

Near-field thermophotovoltaics: a thermodynamic analysis and analytical description

An international team of scientists led by ICFO researchers carries out a thermodynamic analysis of near-field thermophotovoltaic systems to study high heat-to-electricity conversion efficiency performances.

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Solar photovoltaics (PVs) and thermophotovoltaics (TPVs) are both light-based energy generation systems. While classic solar photovoltaic systems convert sunlight into electricity, thermophotovoltaic systems can actually convert heat into electricity. A near-field operating thermophotovoltaic system is based on a hot thermal emitter which is separated from a photovoltaic cell by a nanometric vacuum gap. The emitter can be heated by sunlight or a local heat source such as waste heat, which is the result of industrial processes and is expelled into the environment leading to greenhouse emissions.

While TPV systems seem to be efficient at generating energy from high temperature heat sources, more than 50% of waste heat lies at lower temperature. Thermodynamically, the lower the temperature of the local heat source, the lower the efficiency, which poses a key challenge for thermophotovoltaics systems. Moreover, the PV materials that are relevant for thermophotovoltaic energy conversion suffer from large non-radiative losses, which also compromises efficiency.

To better understand the performance of TPV systems, ICFO researcher Nest Prof. Georgia T, Papadakis, together with Prof Meir Orenstein from Technion-Israel Institute of Technology (Israel), Prof. Eli Yablonovictch from University of California Berkeley (USA) and Prof. Shanhui Fan, from Stanford University (USA), have developed a new analytical model which can accurately predict near-field TPV performance metrics. The new model has been presented in a study recently published in Physical Review Applied, and selected to appear as an invited article in the Collection "Photovoltaic Energy Conversion", which includes contributions that describe advanced approaches to solar energy harvesting.

The developed model allows one to describe analytically the performance of near-field TPVs without complex numerical and optoelectronic calculations, and uses only three input parameters: the spectral bandwidth of thermal emission, the bandgap of the photovoltaic cell, and the cutoff wavenumber. The model accurately estimates the current, voltage, and conversion efficiency of the analyzed systems. It also demonstrates that the luminescence efficiency of a PV cell naturally increases when it operates in the near-field. Additionally, unlike traditional solar PVs where maximizing absorption inevitably requires a thick PV cell, near-field TPV cells can be only few tens of nanometers thick. Finally, the study demonstrates that near-field TPVs can operate with good performance at relevant temperatures, within the waste heat range.

"So far, modelling near-field thermophotovoltaic systems involved numerical simulations that combine fluctuational electrodynamics that describe the near-field radiative transfer of the cell emitter interaction, as well as optoelectronic calculations that model the photovoltaic cell. The model we introduced is analytic and can be used to estimate performance metrics without the need of complicated numerical packages", said Georgia Papadakis. **"It also allows a fundamental understanding of the physics of near-field photovoltaics".**

By using their model, the authors of the study have been able to identify two key opportunities to enhance the performance of TPVs operating in the near-field.

The researchers have showed that "**fundamentally, near-field thermophotovoltaic systems**

can approach thermodynamic limits in terms of their open-circuit voltage, which means that they can operate at relevant low-grade waste-heat temperatures without compromising performance", Papadakis notes. The researchers observed that, although nonradiative losses increase in near-field systems, the luminescence efficiency improves significantly in this range, a key factor to rate a photovoltaic system as a ï¿½good PVï¿½.

Furthermore, the authors demonstrated in their theoretical approximation that, in the case of near-field thermophotovoltaic systems, owing to photon recycling, one can relax the requirement of a thick cell to maximize absorption of photons without penalty in efficiency, in contrast to solar photovoltaic systems where thick cells are typically required. As the authors of the study comment, "**by properly designing a thinner cell, it is possible to reduce non-radiative losses, which are volumetric, and this enhances the open-circuit voltage".**

According to the study, as the vacuum gap of thermophotovoltaic systems decreases, the open-circuit voltage increases due to the combinations of these two identified opportunities.

"In this work, we learned how to model analytically near-field photovoltaic systems beyond standard numerical simulations", said Papadakis. ï¿½**These findings are relevant for estimating the performance of near-field TPVs for the low-grade waste heat. However, in order to reach good performance metrics in practice, key challenges need to be addressed, such as learning to mechanically separate the thermal emitter from the photovoltaic cell only a few tens of nanometers while maintaining their planarity over areas that cover tens of cm2 .ï¿½**