Third Workshop on

Thermal radiation to electrical energy conversion

CETHIL

Lyon

May 19th – 21st

Scientific organization by members of the GDR CNRS TREE

Local organization by
P.-Olivier Chapuis

CETHIL (UMR 5008)

Coordination
Rodolphe Vaillon

LAAS-CNRS (UPR 8001)

Program

May 19th

12h30	Lunch	For the participants who registered
13h30 [30 min]	Registration	
14h00 [15 min]: Olivier Chapuis and Rodolphe Vaillon	Introduction to the workshop	**Welcome address and program**
14h15 [60 min]: Jean-Philippe Perez	IES, Univ Montpellier, CNRS, France	**New antimonide TPV cells**
15h15 [30 min]: Thomas Châtelet	CETHIL, INSA Lyon, CNRS, Uni Lyon 1, France	**Thermophotonic cooling**
15h45 [30 min]	Coffee break	
16h15 [30 min]: Bhrigu Rishi Mishra	LAAS-CNRS, France	**Insight into cooling requirements for thermophotovoltaic devices**
16h45 [30 min]: Wissal Sghaier & Mathieu Thomas	CETHIL, INSA Lyon, CNRS, Uni Lyon 1, France	**Near-field radiative transfer experimental setups for energy conversion**

May 20th

9h00 [60 min]: Patrick Bouchon	ONERA, France	**Control of thermal emission with metasurfaces**
10h00 [30 min]: Cédric Blanchard	CEMHTI, CNRS, France	**Disordered photonics: achieving spectral selectivity with random particulate materials**
10h30 [30 min]	Coffee break	
11h00 [30 min]: Karam Choukri	ESYCOM, Univ Eiffel, CNRS, France	**Hybrid silicon metamaterial as a selective emitter for thermophotovoltaic applications**
11h30 [30 min]: All	**Open discussion**	**Challenges in the design, fabrication, and characterization of selective emitters for thermophotovoltaic applications**
12h00	Lunch	For the participants who registered

13h30 [30 min]: Rodolphe Vaillon & Xavier Py	LAAS-CNRS & LTeN, France	**A collaborative platform for the network TREE**
14h00 [30 min]: Mauro Antezza	L2C, Univ Montpellier, CNRS, France	**Effect of top metallic contacts on energy conversion performances for near-field thermophotovoltaics**
14h30 [30 min]: Mohamed Amara	INL, INSA Lyon, CNRS, ECL, Univ Lyon 1, France	**How do symmetries drive optical nonreciprocity in topological semimetal heterostructures?**
15h00 [30 min]	Coffee break	
15h30 [30 min]: Pablo Martin	IES, UPM, Spain	**Impact of bulk and surface recombination in state-of-the-art germanium thermophotovoltaic converters**
16h00 [60 min]: Erwann Fourmond	INL, INSA Lyon, CNRS, ECL, Univ Lyon 1, France	**Materials, structures, and modeling of PV cells at the Institute of Nanotechnology in Lyon**
17h00 [60 min]	**Visit of CETHIL's installations**	

Dinner at 20h00 in the city center

May 21st

9h00 [30 min]: Charles-Alexis Asselineau	UPM, Spain	**Analysis of the optical cavity of a commercial portable thermophotovoltaic system via ray-tracing**
9h30 [30 min]: Xavier Py	LTeN, Univ. Nantes, CNRS, France	**High-temperature Power-to-Heat with thermal energy storage for thermophotovoltaics**
10h00 [30 min]	Coffee break	
10h30 [60 min]: Régis Olivès	PROMES-CNRS, Univ. Perpignan, France	**Solar energy and decarbonizing process heat**
11h30 [30 min]: All	**Concluding remarks and discussion**	
12h00	Lunch	For the participants who registered

The end of the workshop is at 12h00.

New antimonide TPV cells

Jean-Philippe Perez * [1], Basile Roux [1], Matthias Tornay [1], Philippe Christol [1], Rodolphe Vaillon [2]

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This communication focuses on the development of new thermophotovoltaic (TPV) cells based on type-II Gallium-free InAs/InAsSb antimonide superlattices (T2SL) structures. The aim is to optimise the conversion of infrared thermal radiation into electricity, by exploring low-bandgap materials suitable for recovering energy from moderate-temperature thermal sources (700∘C, 1000∘C).
The principles of TPV conversion are first defined on the basis of the essential physical quantities: absorbed radiative power density, generated electrical power, dissipated thermal power and conversion efficiency. Optimising electrical power requires the use of low bandgap materials, in contrast to the conventional approach which favours maximum efficiency with wide bandgap materials.

The strain-balanced InAs/InAsSb superlattice fabricated by molecular beam epitaxy (MBE) on a GaSb substrate is then presented. This quantum object, whose bandgap can be precisely tuned, is particularly effective in absorbing radiation in the 3-5 μm mid-wave infrared (MWIR) range. The fabrication processes, structural characterisation (AFM, photoluminescence, X-ray diffraction) and optical performances are presented, showing a high absorption coefficient for thicknesses of a few microns.

Finally, electrical measurements performed of barrier structures based on the InAs/InAsSb superlattice are presented and discussed. First, they reveal a low dependence of the dark current on the surface of the bariode, highlighting the robustness of the post-growth technological process. Macroscopic and microscopic cells electrical characterisations evidence a photovoltaic effect, more marked on microcells (open circuit voltage of around 200 mV), although the form factor remains low, and the maximum power delivered still needs to be improved.
In conclusion, Gallium-free InAs/InAsSb superlattices appear to be promising candidates for TPV conversion, with experimental evidence of photovoltaic effect on micron-sized structures at low temperatures. However, further progress is still needed to achieve significant performance at ambient temperature, to improve power delivery and form factor, and to consider practical applications in thermal energy harvesting.

Keywords: TPV conversion, InAs/InAsSb type II superlattices, Molecular Beam Epitaxy, Dark current density

*Speaker

Near-Field Thermophotonic Cooling: From Theoretical Limits using the detailed balance approach to Device-Resolved Models using Drift-Diffusion model.

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Thermophotovoltaic (TPV) and/or thermophotonic (TPX) (1) devices are used to convert the radiated energy from a hot source into electric power by means of a photovoltaic converter. TPX devices extend the concept of TPV by replacing the passive hot emitter by an active light-emitting diode (LED), which is expected to improve the radiative exchange or to widen the emitter temperature range towards with lower values. The working principle is based on the fact that LEDs can emit larger radiative power than the supplied electrical power under particular conditions, by extracting heat from the crystalline lattice. This results also in cooling of the LED and its surroundings. This effect is called electroluminescent cooling (2-3) and can be used either to increase power harvesting from the PV cell when the emitter is hot – as discussed above - or to design a radiation-based cooling device when the LED is at a temperature below ambient (3). To increase the cooling power of the TPX device, near-field coupling can be used, which appears when the distance in-between the LED and PV cell is smaller than the wavelength dominating the radiative exchange. Such effect increases the radiative exchange within the device by means of evanescent waves (4). A TPX near-field refrigerator is the focus of the present work, which can be seen as another type of radiative thermal device complementary to TPV/TPX radiative engines.

By means of accurate nanoscale radiative computation (fluctuational electrodynamics), we investigate the potential performances of near-field TPX refrigerators made of GaAs-based materials as a function of temperature and vacuum gap distance. We first identify upper bounds for the cooling power using the detailed-balance approach (6). To move beyond these bounds, we then implement a self-consistent 1D drift-diffusion model that solves the coupled Poisson, continuity, and transport equations (5). This approach captures the influence of device-scale parameters such as doping asymmetry and intrinsic layer thickness. The near-field GaAs heterojunction-based device outperforms far-field designs and can sustain cooling power densities of the order of 1–2 W/cm^2 even though internal quantum efficiency is lower than unity. We identify optimized-junction architectures. These findings demonstrate that well-engineered near-field TPX devices are capable of achieving net cooling powers rivalling other solid-state cooling devices such as

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thermoelectrics.

REFERENCES

(1) N.-P. Harder and M.A Green, Semiconductor Science and Technolology 18 S270 (2003)
(2) P. Santhanam et al., Physical Review Letters 108, 097403 (2012)
(3) T. Sadi et al., Nature Photonics 14, 205 (2020)
(4) J. Legendre and P.-O. Chapuis, Solar Energy Materials and Solar Cells 238, 111594 (2022)
(5) J. Legendre and P.-O. Chapuis, IEEE Transactions on Electron Devices 72, 1211 (2025)
(6) T. Châtelet, J. Legendre, O. Merchiers and P.-O Chapuis. (2025). *Performances of far and near-field thermophotonic refrigeration devices from the detailed-balance approach.* http://arxiv.org/abs/2504.0
Acknowledgements: We thank P. Kivisaari, J. Van Gastel, M. Thomas, W. Sghaier for the constructive discussion. This work has received funding from European Union Horizon 2020 research program through EU projects OPTAGON (GA 964698) and TPX-Power (GA 951976).

Keywords: Thermophotonic, Near, field radiative heat flux, Thermodynamics, Drift, Diffusion, Solid state cooling, LED, Photovoltaic cells, Fluctuational Electrodynamics, Electroluminescent cooling, Electroluminescent refrigeration

Insight into cooling requirements for thermophotovoltaic devices

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Thermophotovoltaic (TPV) devices comprise a high-temperature thermal emitter and specific PV cells, which enable the radiation emitted by the former to be absorbed and converted into electricity. Recent experimental work (1) demonstrated that TPV devices can achieve a 43.8% pairwise efficiency under 14350C illumination using a 0.9eV bandgap TPV cell. The reported power density was limited to 0.91Wcm-2 due to a view factor of 0.33–0.38. A chilled water loop was employed to maintain the TPV cell temperature close to ambient. However, the study did not quantify the input power required to dissipate the heat generated in the TPV cell to achieve this thermal management. In practice, the heat flux generated in the TPV cell is directly proportional to the electrical power output and inversely proportional to the pairwise efficiency (2). This means that approximately 1.15Wcm-2 of heat must had to be removed to get the targeted temperature in the cited setup. This highlights the critical role of thermal management in the TPV device design. In this context, our work investigates and quantifies the effective heat transfer coefficient necessary to maintain optimal TPV cell temperatures under realistic operating conditions.

Our thermal model considers a TPV device with a cooling system, characterized by an effective heat transfer coefficient ($h$eff) and the temperature (Tcold = 250C) of an external body to which heat generated in the TPV cell is dissipated. $h$eff is calculated to operate the TPV cell at temperatures of 300C, 500C, and 800C for various emitter temperatures. To operate the TPV cell at 300C, i.e., near room temperature, low bandgap TPV cells require a cooling system with a very high heat transfer coefficient. For example, for TPV cells with bandgaps below 0.8eV and with only 2% out-of-band absorptance, $h$eff must exceed 11400Wm-2K-1 for an emitter temperature of 1500 0C. Increasing the cell operating temperature to 500C leads to a significant reduction in the required $h$eff. The effect of other parameters - such as view factor, in-band absorptance, and out-of-band absorptance - on power output, pairwise efficiency, and $h$eff are also analyzed. In every case, $h$eff increases significantly for low bandgap TPV cells. Furthermore, the cooling requirements intensify when the TPV cell operates at a fraction of the Shockley–Queisser limit. The findings of this study are helpful in designing TPV devices with optimized cooling strategies to maximize power output and efficiency.

References

(1) Roy-Layinde et al., Joule 8, 2135–2145, 2024.
(2) Roux et al., JPE 14(4), 042403, 2024.

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Keywords: Thermophotovoltaic, cooling system, effective heat transfer coefficient, pairwise efficiency, power density

Near-field radiative transfer experimental setups for energy conversion

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Thermophotovoltaics (TPV) is a promising approach for energy harvesting (1) but is constrained by Planck's law, limiting the effectiveness in delivering high power. Near-field thermal radiation, observed when objects are brought within a few micrometers, has proved to be a promising solution to exceed the bound imposed by Planck's law through intensified radiative heat exchange driven by evanescent waves (2). In addition, the concept of thermophotonics (TPX) was introduced (3), which uses heated light-emitting diodes (LEDs) as active emitter, exploiting the strong intensity of electroluminescence and enabling spectral control to tune the emission profile. Notably, TPX offers the advantage of operating at moderate emitter temperatures, enhancing its interest for energy harvesting. To date, only limited experimental proof of TPX has been reported in spite of its interest for both energy harvesting and for refrigeration. We report on two experimental setups that enable the probing of radiative properties in near field.

The first approach involves a heated micrometric 40 μm-in-diameter sphere (graphite or SiO2) glued on a Scanning Thermal Microscopy probe cantilever, which is moved using a piezoelectric actuator towards a flat sample of interest, i.e. a junction. Near-field thermophotovoltaic conversion can be performed (4), with passive-emitter temperatures up to 1000 $\circ$C. In addition near-field electroluminescence measurements can be performed if the junction is polarized in the harmonic regime or if its temperature is higher than that of the sphere. Radiative heat transfer is monitored during the approach by means of resistive thermometry. The emitter-sample distance is further evaluated by combined means of interferometry and optical deflection. Such a control allows us to determine the movements of the emitter at nanometric scale, its stability with respect to vertical oscillations and provides accurate results in the sub-100 nm distance regime. In particular it eliminates issues of parallelisms between flat surfaces. This configuration allows fundamental studies but cannot be scaled up towards applications.

The second approach involves an experimental setup tailored to investigate TPX in a planar geometry down to the near-field distance regime. The experiment is made of two facing flat elements independently connected electrically in order to perform IV characterizations on each side. The hot side is heated by resistive thermometry while the second side is maintained close to room temperature and able to be aligned both linearly and rotationally to the hot side by means of piezoelectric actuators with 6 degrees of freedom (3 translational ones and 3 angular ones). The heat flowing to the ambient heat sink is monitored at the same time. Preliminary results and insights into the experimental challenges and opportunities of NF-TPX will be discussed.

References

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(1) A. LaPotin et al., *Nature*, 604, 7905, (2022)

(2) C. Lucchesi et al., Nanoscale Horizons, 201-208, (2021)

(3) N. P. Harder and M. A. Green, Semiconductor Science and Technology, 18, 5, S270, (2003)

(4) C. Lucchesi et al., Nano Letters, 21, 4524–4529, (2021)

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Keywords: near field radiative heat transfer, thermophotovoltaics, thermophotonics

Control of thermal emission with metasurfaces

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Metasurfaces can be used to tailor the electromagnetic response (phase, polarization, absorption). These metasurfaces can be made of building-blocks, sometimes referred to as a meta-atom, and the interaction of a single meta-atom with light can be described by its various effective cross-section (extinction, scattering, absorption). The local Kirchhoff law states that, in the absence of symmetry breaking, which is the most common case, the absorption cross-section is equal to the emission cross-section.

As a first meta-atom, I will introduce the metal-insulator-metal (MIM) nanoantenna and show how it can be used to modify the absorption of a surface due to a Fabry-Perot resonance. And equivalently, show how it can be used to tailor the infrared emissivity of a metallic surface, and turned a nearly-zero emissivity into a nearly unity emissivity. Such a nanoresonator has a very small geometrical cross-section, and thus several of them can be combined nearly independently in order to design multiband absorbers/emitters with a control on the polarization. This spatial control can even be used to tailor the emissivity at the wavelength scale. In this case, it is interesting to determine the emission behavior of single objects as well as determine their emissivity cross-sections.

Then, I will discuss the possibility to use metasurfaces to conceive converters of light that rely on absorption and emission processes and will show its experimental application to Terahertz to infrared light conversion.

Eventually, I will discuss our latest works on high temperature metasurfaces, which face various technological challenges such as melting temperature, thermal expansion mismatches and oxidation. By using a metasurface made of a unique material, tungsten, and by coupling nano-Fabry-Perot cavities, high-quality factors (in the range 20 to 100) thermal emission at high temperatures ($>$ 1000 K) can be demonstrated. Such devices can be promising for solar thermophotovoltaic applications.

REFERENCES

JJ Greffet, P Bouchon, G Brucoli, F Marquier, "Light emission by nonequilibrium bodies: local Kirchhoff law" Phys. Rev. X, Vol. 8, pp. 021008, 2018

P. Bouchon, C. Koechlin, F. Pardo, R. Haïdar and JL Pelouard "Wideband omnidirectional infrared absorber with a patchwork of plasmonic nanoantennas," *Applied Physics Letters*, Vol. 34, No. 6, 1038-1040, 2012.

*Speaker

M. Makhsiyan, P. Bouchon, J. Jaeck, JL Pelouard and R. Haïdar, "Shaping the spatial and spectral emissivity at the diffraction limit," *Applied Physics Letters*, Vol. 107, 251103, 2015.

C. Li et al., "Near-field and far-field thermal emission of an individual patch nanoantenna", Phys. Rev. Lett., vol. 121, pp. 243901, 2018

L. Abou-Hamdan, "Hybrid modes in a single thermally excited asymmetric dimer antenna", Opt. Lett., vol. 46, pp. 981-984, 2021

D. Langevin et al., "Experimental Investigation of the Thermal Emission Cross Section of Nanoresonators Using Hierarchical Poisson-Disk Distributions", Phys. Rev. Lett., vol. 132, pp. 043801, 2024

J. Lackner et al., in preparation

Keywords: thermal emission, metasurfaces, infrared, absorption cross, section

Disordered photonics : achieving spectral selectivity with random particulate materials

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Achieving optical functionalities typically relies on meticulously ordered media. Some classic examples are structures such as diffraction gratings, photonic crystals with their archetypal periodic arrangements, and thin-film stacks with precisely controlled layer thicknesses. These ordered architectures create predictable interference and diffraction patterns, which dictate the spectral response.
However, an increasingly explored avenue for providing specific optical functionalities lies in the realm of disordered media, particularly those composed of nanoparticles that are randomly dispersed. In these systems, spectral filtering and manipulation do not arise from repeated arrangements that extend over large distances, but rather from the complex interplay of multiple scattering, interference, and resonant effects which occur at the individual particle level and originate from the cooperative scattering of light between the particles.

The core reasons for the growing interest in disordered media for optical applications lies in the potential for simpler and more cost-effective fabrication processes when compared to intricate ordered nanostructures. By playing with constitutive parameters such as size, shape, refractive index, and concentration of the nanoparticles, random particulate materials can be engineered for diverse applications, ranging from structural coloration and enhanced light harvesting to novel optical filters and sensors. This burgeoning field of disordered photonics demonstrates that order is not always a prerequisite for sophisticated control over the electromagnetic spectrum.
In this presentation, the focus will be on nanoparticulate materials exhibiting spectral selectivity in the infrared domain, i.e., near-perfect absorption at a prescribed frequency and weak absorption elsewhere. Most of the talk will be about the strategy we developed for the design of this thermo-optical property which, as will be shown, relies on critical coupling mechanisms, where radiative and non-radiative losses are adjusted by means of the electromagnetic interactions between two populations of particles. The challenges one faces when numerically simulating such complex media will be stressed. In addition to that, preliminary experimental results on the fabrication and Fourier-transform spectroscopy characterization of these selective materials will be presented.

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Keywords: Multiple scattering, light, matter interaction, modeling, spectral selectivity

Hybrid Silicon Metamaterial as a Selective Emitter for Thermophotovoltaic Applications.

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Thermophotovoltaic systems enable the conversion of thermal radiation into electricity. They are mainly composed of an infrared emitter and a photovoltaic cell. The efficiency of the system strongly depends on the spectral matching between the emitted radiation and the bandgap of the cell's semiconductor. To optimize this matching, spectrally selective emitters are used to maximize emission above the bandgap energy and minimize it below. In the literature, various solutions have been proposed including metal-dielectric multilayers (1), resonant cavities, as well as one-dimensional (1D) and two-dimensional (2D) photonic crystals (2, 3).

Disordered structures such as black silicon (BSi), silicon surfaces etched to form microscale conical or needle-like features, exhibit very high broadband absorption (up to 99% for 10μm tall cones) thanks to gradual optical impedance matching, resulting from a gradual depth-dependent Si/air refractive index gradient (4). However BSi lacks spectral selectivity, limiting its direct application as a selective TPV emitter.

In this work, we propose an innovative hybrid structure combining a microstructured surface of doped silicon (similar to BSi) with a multilayer structure made of alternating layers of silicon and silicon dioxide (Si/SiO). This architecture enhances emissivity in the useful spectral range ($\lambda <\ \lambda_$gap) while suppressing unwanted emission ($\lambda >\ \lambda_$gap) across a wide spectral range.

The radiative properties of the emitter are computed using the Transfer Matrix Method (TMM) coupled with Effective Medium Theory (EMT). The cones are approximated as a stack of layers with varying silicon / air volume fractions. The effective permittivity of each layer is calculated using Bruggeman homogenization equation. Using the Transfer Matrix Method (TMM), we compute the spectral reflectance and absorptance of the entire structure, from which the spectral emissivity is derived according to Kirchhoff's law.

The optimization of the dielectric layers thicknesses is performed using the Particle Swarm Optimization algorithm which simulates the collective behavior of a group of particles searching for a global optimum in a parameter space (5).

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Obtained results show that an initial structure composed of 10 μm deep highly doped (5×10^1 cm^3) BSi combined with a standard quarter-wave photonic crystal achieves a spectral efficiency of 41%. After photonic crystal optimization, the spectral efficiency exceeds 60% at 1500 K, demonstrating the potential of this hybrid architecture for high-efficiency TPV applications.

References:

(1) BHATT, Rajendra, KRAVCHENKO, Ivan, GUPTA, Mool. High-efficiency solar thermophotovoltaic system using a nanostructure-based selective emitter. Solar Energy, 2020, vol. 197, p. 538-545.

(2) ZHOU, Zhiguang, YEHIA, Omar, BERMEL, Peter. Integrated photonic crystal selective emitter for thermophotovoltaics. Journal of Nanophotonics, 2016, vol. 10, p. 016014-016014.

(3) SAKAKIBARA, Reyu, STELMAKH, Veronika, CHAN, Walker R., et al. A high-performance, metallodielectric 2D photonic crystal for thermophotovoltaics. Solar Energy Materials and Solar Cells, 2022, vol. 238, p. 111536.

(4) David Abi Saab, Shermila Mostarshedi, Philippe Basset, Stéphane Protat, Dan E. Angelescu,. Effect of black silicon disordered structures distribution on its wideband reduced reflectance. Materials Research Express, 2014, 1, pp.45045 – 45045.

(5) NEFZAOUI, Elyes, DREVILLON, Jérémie, JOULAIN, Karl. Selective emitters design and optimization for thermophotovoltaic applications. Journal of Applied Physics, 2012, vol. 111.

Keywords: Thermophotovoltaic, Selective emitter, Black silicon, Thermal radiation, Particle Swarm Optimization

Effect of top metallic contacts on energy conversion performances for near-field thermophotovoltaics

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The design of metallic contact grids on the front side of thermophotovoltaic cells is critical since it can cause significant optical and electrical resistive losses, particularly in the near field. However, from the theoretical point of view, this effect has been either discarded or studied by means of extremely simplified models like the shadowing methods, that consist in simply ignoring the fraction of the semiconductor surface covered by metal. Our study, based on a rigorous three-body theoretical framework and implemented using the scattering matrix approach with the Fourier modal method augmented with adaptive spatial resolution, provides deeper insight into the influence of the front metal contact grid. This approach allows direct access to the radiative power absorbed by the semiconductor, enabling the proposal of an alternative definition for the thermophotovoltaic cell efficiency. By modeling this grid as a metallic grating, we demonstrate its significant impact on the net radiative power absorbed by the cell and, consequently, on the generated electrical power. Our analysis reveals behaviors differing substantially from those predicted by previous simplistic approaches.

*Speaker

How do symmetries drive optical nonreciprocity in topological semimetal heterostructures?

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Topological materials have emerged as pivotal platforms in photonics, offering unprecedented control over light propagation and confinement due to their robust and unique edge and surface states (1). Within this domain, Weyl semimetal-based photonic structures have recently gained significant attention for enabling phenomena such as bound states in the continuum (BIC) and Fabry-Perot resonances in layered nanostructures (2). Additionally, twisted Weyl systems have demonstrated promising applications in achieving magnet-free, tunable optical isolation, paving the way toward innovative nonreciprocal photonic devices (3). Recent explorations in energy-related applications such as enhanced thermal emission, selective radiative heat transfer, and improved photovoltaic efficiency further demonstrate the growing relevance of topological photonics (4,5,6). Moreover, previous studies have extensively characterized waveguide and plasmonic modes in Weyl semimetal systems, highlighting their tunable nonreciprocity (7,8). In particular, recent theoretical work by Guo et al. has generalized reciprocity conditions by deriving symmetry-based relations between emissivity and absorptivity in photonic structures, emphasizing the critical role of symmetry constraints in nonreciprocal thermal emission (9).
In this context, an important question emerges: beyond time-reversal symmetry breaking, how do additional structural and material symmetries specifically influence the optical nonreciprocity in Weyl-based heterostructures? To address this question, we have rigorously solved Maxwell's equations for a Weyl-dielectric-Weyl slab waveguide heterostructure. By deriving the dispersion relations and corresponding eigenstates of propagating waveguide modes, we explicitly characterize how symmetry constraints-specifically chirality and parity-govern optical nonreciprocity. Furthermore, we investigate the reflectivity of these heterostructures under Voigt and Faraday configurations, providing clear evidence linking nonreciprocal optical responses directly to the underlying symmetry properties of the guided modes.

References:
(1) Ozawa et al., Rev. Mod. Phys. 91, 015006 (2019). (2) Zhao et al., Photonics Res. 10, 1828-1838 (2022). (3) Chistyakov et al., Nanophotonics 12, 3333-3340 (2023). (4) Park, Y. et al. Nano Lett. 22, 448–452 (2022) (5) Shayegan K. J. et al. Nature Photonic 2023 (6) Liu et al. *ELight*, *2*(1), 25, 2022 (7) Kotov and Lozovik, Phys. Rev. B 98, 195446 (2018). (8) Hofmann and Das Sarma, Phys. Rev. B 93, 241402 (2016). (9) Guo et al., Phys. Rev. X 13, 021041 (2023).

Keywords: Thermal radiation, reciprocity, Kirchhoff Law

*Speaker

Impact of bulk and surface recombination in state-of-the-art germanium thermophotovoltaic converters

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Germanium thermophotovoltaic (TPV) converters could become a cost-effective alternative to III-Vs for the deployment of the first generation of commercial TPV thermal batteries. However, due to the high irradiances expected in TPV systems, it is usually considered that the efficiency of any indirect band-gap semiconductor (such as germanium) will be heavily limited by Auger recombination, as already reported for silicon concentration solar cells (1). Nevertheless, the truth is that the literature analysing the impact that the different recombination mechanisms have on germanium devices is far more limited. Therefore, in this work we challenge this idea and revisit the relative weight of radiative, Auger, Shockley-Read-Hall (SRH) and surface recombination in state-of-the-art germanium devices. To this end, SILVACO TCAD is used to conduct a steep-by-steep analysis discussing 1) the impact that the different recombination mechanism have on the experimental lifetimes reported in the literature; 2) the contribution of each recombination mechanism to the dark saturation current (*J0*) on manufactured Ge-based TPV converters with varying substrate dopant concentrations (i.e.: *NB*=3×1017 cm-3, *NB*=1×1016 cm-3, *NB*=1×1015 cm-3) when working under high irradiances resulting in photogenerated currents over 5 A/cm2; and 3) the impact that reducing the extrinsic recombination mechanism (i.e.: SRH and surface recombination) have on the efficiency of record performing TPV converters (2). The analysis concludes that bulk recombination plays a secondary role in current germanium devices, even for substrate dopant concentrations as high as *NB*=3×1017 cm-3. Furthermore, it also shows that the role of intrinsic recombination mechanisms (i.e.: radiative and Auger) is limited, with SRH being the main contribution to recombination in the bulk, and Auger being only dominant in the most highly-doped substrates. Moreover, the final part of the analysis confirms that the TPV performance of the converters barely increases after improving SRH lifetimes in the bulk. Instead, achieving highly passivated surfaces is still critical, especially as substrate recombination decreases. In fact, reducing the surface recombination rates in both the front and rear contacts leads to an outstanding performance increase up to +8% and +10% in the converters with *NB*=1×1016 cm-3 and *NB*=1×1015 cm-3, respectively. Under this conditions, the more lightly-doped converters achieve TPV efficiencies over 25% under a blackbody thermal emitter at molten silicon temperature (1687 K) and over 30% for a selective AlN coated W emitter at 2073 K, values high enough to enable the commercial deployment of the technology.

(1) M.J. Kerr, A. Cuevas, P. Campbell, Progress in Photovoltaics: Research and Applications 11, 97–104 (2003).

(2) P. Martín, V. Orejuela, A. Cano, I. García, A. Luque, I. Rey-Stolle, Cell Rep Phys Sci 5 (2024).

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Keywords: Germanium, Radiative, Auger, Shockley, Read, Hall (SRH), Surface Recombination

Materials, structures, and modeling of PV cells at the Institute of Nanotechnology in Lyon

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Members of the i-Lum team at INL work in the field of photovoltaics at the cell level. They specialize in the development and optimization of new absorber materials, as well as innovative structures implementing selective contacts. They are particularly involved in the field of tandem cells on Silicon, with an interest in interface layers and structures. They also work on the thermal/optical/electronic coupling, developing numerical models based on characterization techniques that consider these different parameters.

Keywords: Photovoltaic, Silicon, Tandem cells

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Analysis of the optical cavity of a commercial portable thermophotovoltaic system via ray-tracing

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Thermophotovoltaic (TPV) systems performance depends on the efficient spectral radiative exchange between the thermal emitter and the photovoltaic converter. Recent progress show high potential conversion efficiencies but tend to oversimplify the modelling of the optical cavity of TPV systems1,2. View-Factor (VF) approximations that assume perfect diffuse behaviour in both the in-band and out-of-band spectral regions of a TPV system are commonly used to estimate the performance of theoretical and experimental systems. It is not rare for VFs to be only considered between the source and the PV array, to be used to estimate TPV efficiency potential or indirect experimental results analysis. Yet, VF values are often arbitrarily set to an optimistic value (1 or 95%) common. Real-world materials used in TPV devices are not Lambertian (perfect diffuse behaviour) and the geometrical configuration of TPV systems do not always allow for high VF values, resulting in overlooked inefficiencies such as:
- Radiation absorbed by passive surfaces, not directly participating in the TPV conversion, and thus lost to the PV converter.

- Overestimation of the in-band radiation available to the PV converter leading to efficiency overestimation.

- Underestimation of the cooling needs of the system.

Ray-tracing is an optical simulation technique well-suited to model radiation propagation in complex geometrical systems composed of materials with non-trivial spectro-directional radiative properties. In this work we present a ray-tracing-based TPV cavity model for a commercial TPV system, the LightCell from Mesodyne Inc. The LightCell design is based on the use of a tungsten photonic crystal emitter coupled to a 0.74 eV bandgap PV array as converter. The model exploits the open-source software *Tracer* and adopts a two-band spectral approximation. The optical cavity of the LightCell is simulated using geometrical approximations able to efficiently obtain important operation variables and parameters.

We evaluate the impact of spectro-directional radiative properties assumptions when compared to VF-based estimations and highlight the usefulness of ray-tracing in estimating operational parameters that are otherwise very difficult to accurately measure. Examples include the radiative flux incident on parts of the system or in-band and out-of-band exchange factors. The modelling in this work is a first step into the complex task of developing accurate TPV optical

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cavity simulations suitable to establish improved and optimized designs.

References

1. LaPotin, A. *et al.* Thermophotovoltaic efficiency of 40%. *Nature* 604, 287–291 (2022).

2. Datas, A., Francoeur, M., Shimizu, M. & Vaillon, R. Advances in thermophotovoltaics: Materials, devices, and systems. *Solar Energy Materials and Solar Cells* 240, 111711 (2022).

Keywords: ray, tracing, optical cavity, spectro, directional radiative properties, view factors

Solar energy and decarbonizing process heat

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Decarbonizing process heat is a major challenge that can be tackled in several ways. These include developing the electrification of thermal uses, or deploying thermal renewable energy systems. In the field of possibilities, we can distinguish between electrical RE (hydroelectricity, wind power and photovoltaics), combustion RE (biomass) and thermal RE (solar thermal and geothermal). Solar energy, in all its diversity, is a real lever for decarbonizing the heat used in industry. The potential for energy savings and decarbonization is extremely high. Concrete examples exist, but are still few and far between. Deploying these medium- and high-temperature solar technologies requires R&D efforts. This means reconsidering both the supply of heat to industrial processes and the processes themselves. The case of TPV is proving to be a particularly interesting solution for a number of reasons, which we propose to explore.

Keywords: decarbonizing process heat, solar energy

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