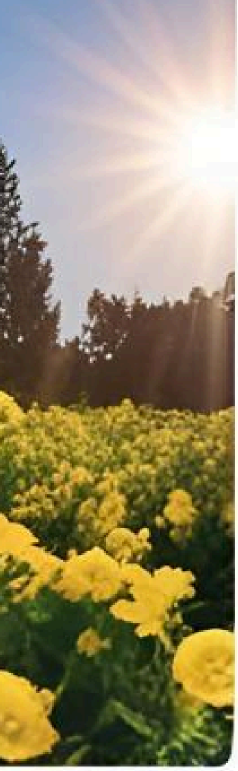
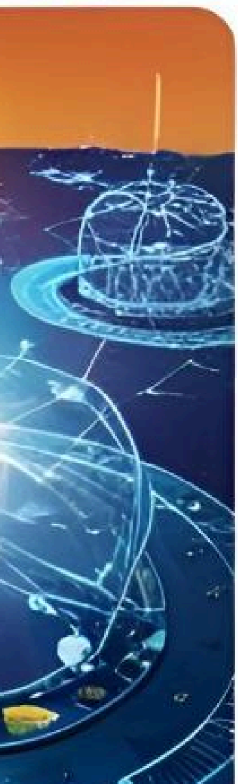
OPTICA

Advancing Optics and Photonics Worldwide

Optics for Energy

NEWSLETTER





FiO
Frontiers in Optics + Laser Science
LS

25-28 October

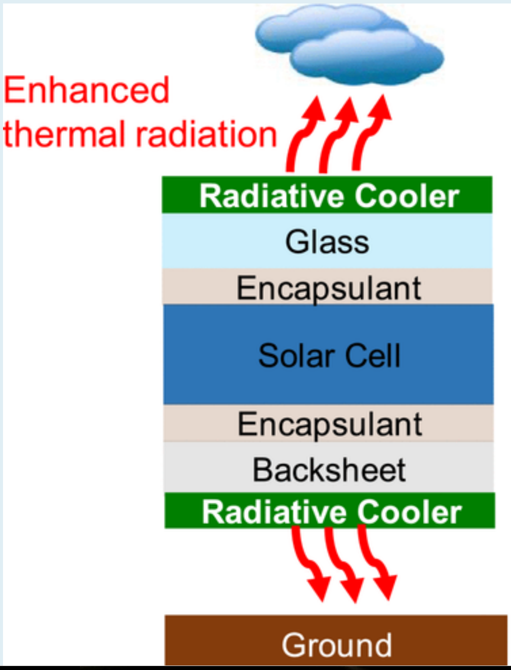
Denver, Colorado, USA

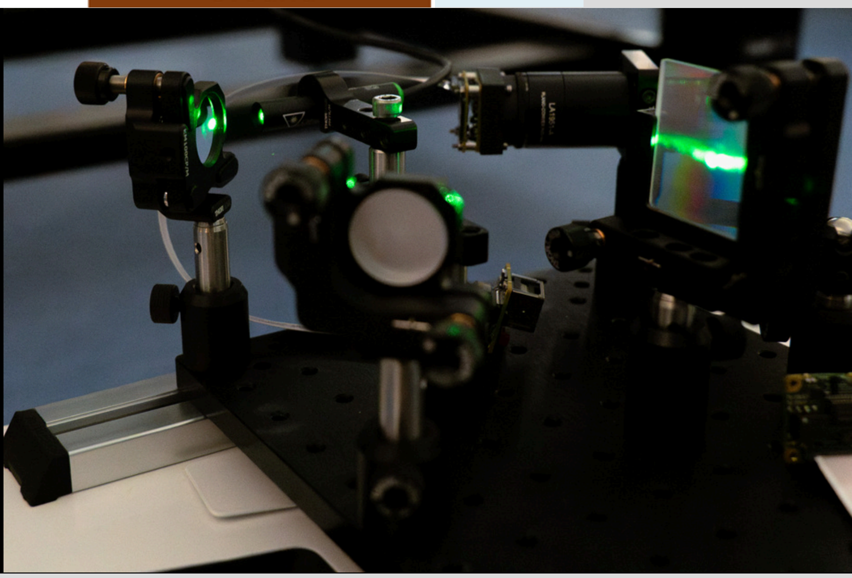
FEATURES

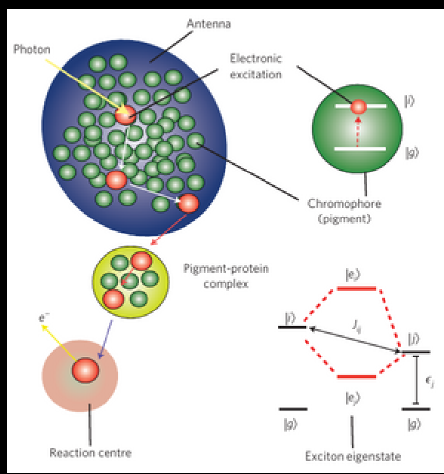
Technology Highlights

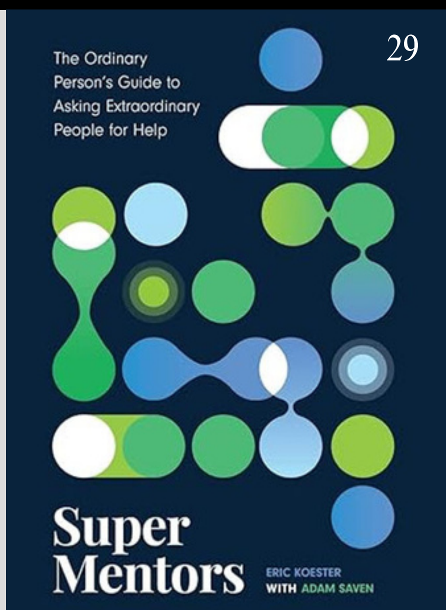
- Introducing spectroscopy and microscopy techniques for solar research
- “BotanyKI”, a CO_2-neutral, optical based minirobot for farming

FEATURES









Career Focus

- Interview with Dr. David Giltner on "Shaping the World"
- A look at "Super Mentors", a book that revolutionize the concept of mentorship

Opening Message

By Banafshe Zakeri

"The most important thing is to never stop questioning." *Albert Einstein*

Discussion, debates, and questioning have been always, and will be, the foundation of science. What we know today as scientific facts is a heritage with a long history achieved by those who embraced the unknown by questioning what was known. The access to this unbelievably rich heritage, however, is what makes this era unique. We are living in a time "where" connections through scientific communities facilitate the knowledge transfer more than ever, while science writing and journalism expanding knowledge beyond scientific boundaries by bridging the gap with the public. Science drives the heartbeat of modern society like never before, via connections to industry and helping solve the problems of the world. In the energy sector alone, following the climate change crisis, the footsteps of science can be clearly seen in rapidly growing industries with solutions based on scientific discoveries.

The burst of infinity, the unlimited access to the world's knowledge, has already began and it is a priviledge to be part of it, to help the expansion of this heritage by any means. But true and real data is always buried in noise, and in an age of endless information, the real task is filtering truth from chaos. Here, our culture of discussion and questioning makes all the difference. Every question counts, and dialogues birthed from disagreements helps us move with a safe pace. Moreover, the responsibility to mind the scientific ethics, in an era where science provides the way for making the most trustworthy decisions, is also huge. Having these goals in mind, let's serve our OPTICA community together. Even the very small steps can make a big difference.

Meet the Team

Dr. rer. Nat. Banafshe Zakeri
Chair

“I’m a scientific researcher at HySON research Institute for hydrogen technology. Sharing my passion for science is one of my favorite hobbies and I’ve been doing it either by science writing and blogging or being involved in OPTICA technical groups activities. Hope to make science more applicable, informative, and fun for everyone.”

“I am A/Professor in HMU, Crete and I enjoy teaching and research on solar energy conversion, optics and photonics. I realized early in my career that optics are a fun way to do science and engineering. What is not widely known is that the more you share and communicate it, the more fun it becomes, with OPTICA technical groups being one of the ways to do so!”

A/Prof. Georgios E. Arnaoutakis PhD
Vice Chair

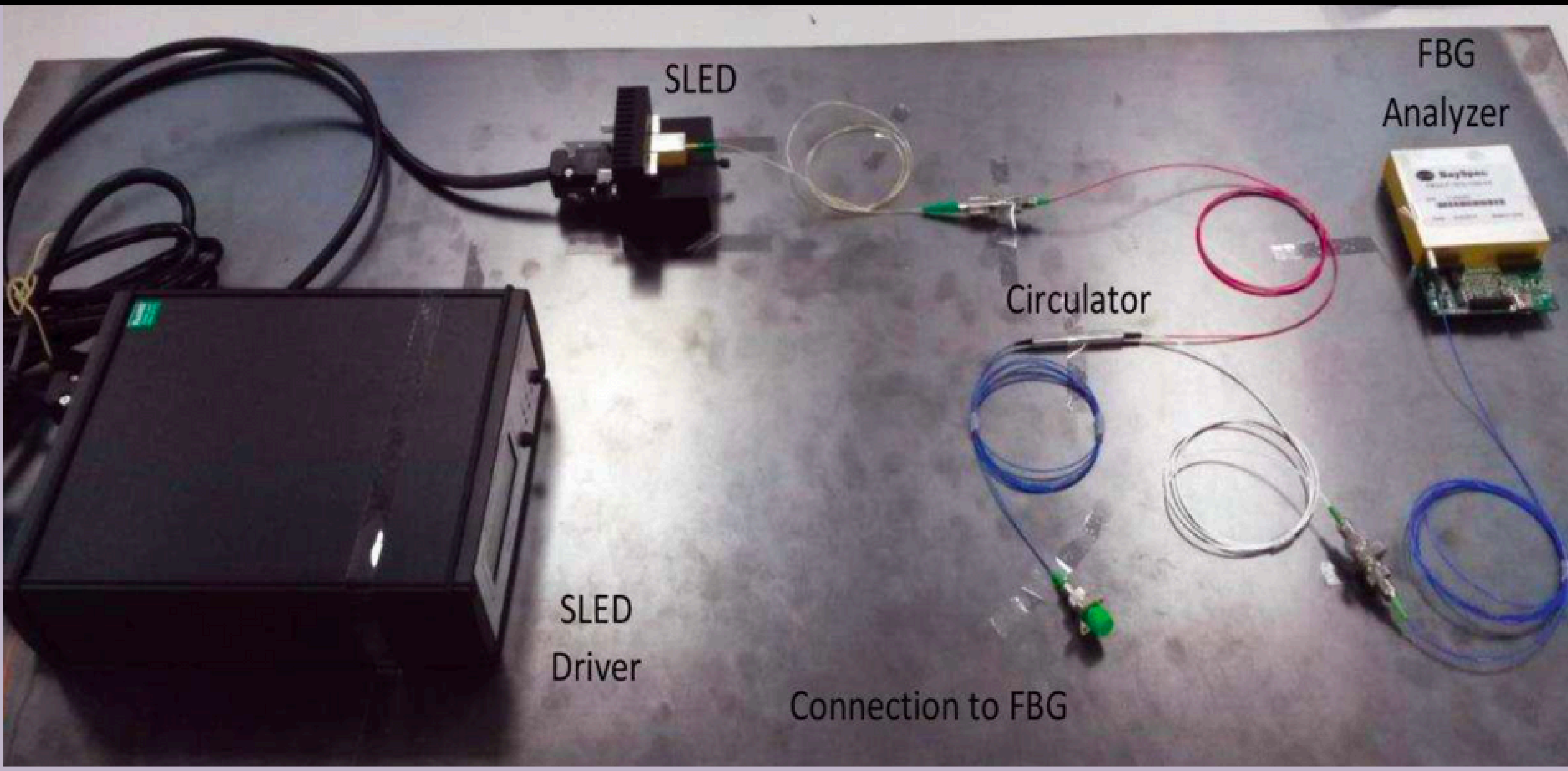
M.Sc. Rodgers Mutugi Gichuru
Social Media Officer

“I’m persuing masters of science in Applied Optics at the National Institute for Optics and Lasers. A conference on Optics and Photonics opened my eyes to the vast possibilities of light from cutting-edge technologies to transformative applications. An highlight was the critical need for greater public awareness of this field. Through my involvement in student chapters and here in OPTICA TG, I have been working to demystify photonics and inspire others to explore its potential.”

"I’m a master’s student in Energy and Materials Sciences at INRS. My research initially focused on graphene for optoelectronic applications, but it soon captured my curiosity in optics. From structured light to quantum optics, I’ve come to admire the power of photonics in probing the quantum world and solving global challenges like energy. Through student chapters and the Optics for Energy Technical Group, I’m passionate about promoting light-based technologies and making their potential more visible and inspiring to others."

M.Sc. Idris Adeshina Sulaimon
Events Officer

Featured Group Event



This is what I do...

Modern Fiber Sensors for Monitoring Pressurized Pipe

By Prof Ahmed Hisham Morshed
Ain Shams University
https://eng.asu.edu.eg/staff/ahmed_morshed

REFERENCES:

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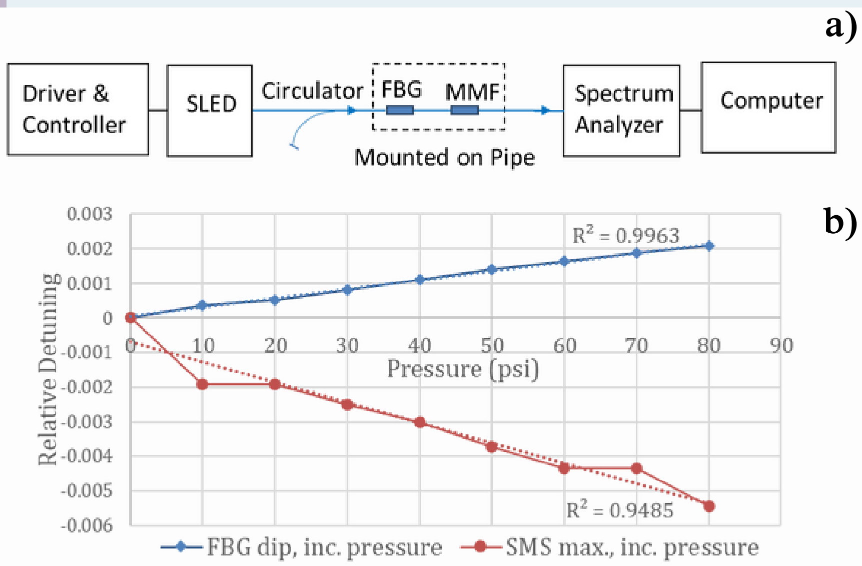
Watch the full webinar

Pipelines are commonly used for fuel and gas transport, vital to the energy sector. Their damage or malfunction is thus very undesirable. Their in-service monitoring to avoid the occurrence of such events is an important task, which requires the installation and networking of sensors along the pipelines to continuously check their status for abnormal operating conditions. Strain measurements at the surface of a pipeline can indicate undesired conditions, such as overpressure, wall thinning, or pipeline leak, providing possible early warnings for the occurrence of failure. The dynamic strains accompanying pipe vibrations can be used to detect tampering events, such as pipeline drilling.

The use of optical fiber sensors for these measurements is advantage over other techniques. Strain measurements using the optical sensors are compared to those obtained using electrical strain gauges, showing better sensor linearity and simplicity of strain measurements. Fiber Bragg gratings (FBG) have been exploited in strain measurements, where the reflected waves in a grating-inscribed fiber section occurs at a specific Bragg wavelength, which is sensitive to the grating section strain. However, the use of spectral measurements in FBG sensors limits their measuring speed to the relatively low speed of tspectral scanning, which is a major challenge for dynamic sensing. A similar and lower cost optical fiber sensor that has been proposed for strain measurement is the multimode interference (MMI) sensor. In this sensor, modal interference is used to probe the strain applied to a multimode fiber section spliced to single-mode fiber (SMF) leads in a single mode-multimode-single mode (SMS) structure. This fiber sensor has been explored for pipeline strain and vibration detection. Its performance is compared to that of a fiber Bragg grating sensor. The detuning of spectral features of the MMI sensor transmission is found to have a larger sensitivity to strain than the Bragg wavelength of an FBG sensor. It further can be used in a simple configuration to detect the dynamic strains of pipeline drilling.

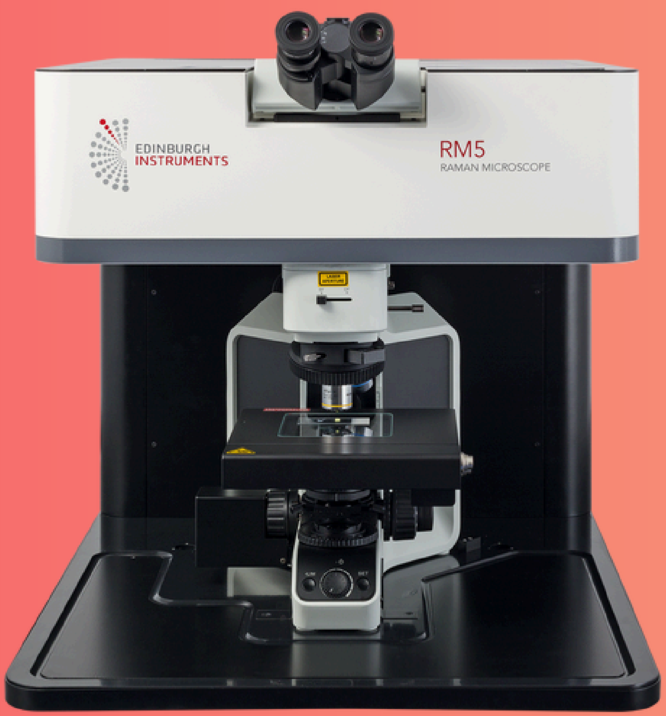


a) Spectral measurement setup b) FBG Bragg wavelength vs. MMI sensor transmission detuning with pipe pressure

Industry Highlight

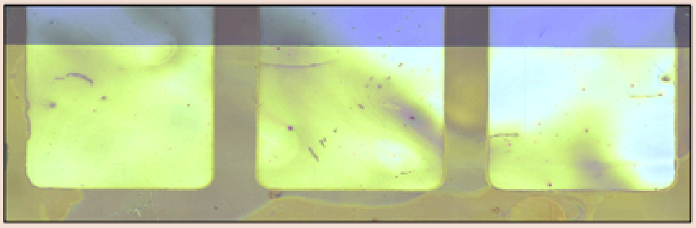
Correlative Confocal Raman, Photoluminescence, and Photocurrent Imaging of an Organic Solar Cell

Understanding the internal structure and charge dynamics of organic solar cells (OSCs) is crucial for enhancing their power conversion efficiency.
In this highlight, a correlative imaging approach is demonstrated using confocal Raman spectroscopy, photoluminescence (PL), and photocurrent mapping to investigate the performance of an OSC.
This combined methodology offers detailed spatial insights into the chemical composition, phase separation, and charge extraction efficiency within the device.

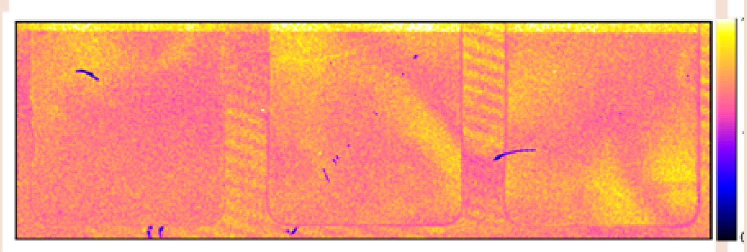


RM5 Confocal Raman Microscope

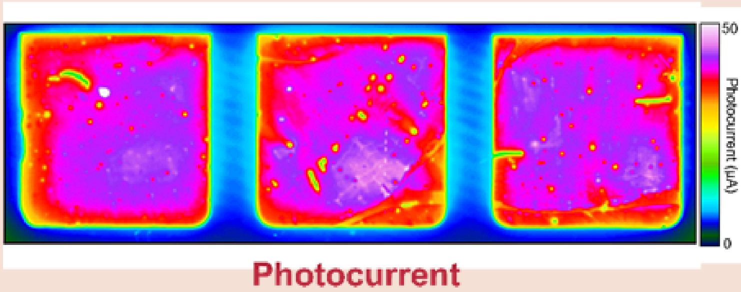
The OSC investigated was fabricated by the TEMD Research Group at London South Bank University and featured a PM6:Y6 active layer. Using the Edinburgh Instruments RM5 Confocal Raman Microscope,
we conducted spatially resolved Raman and PL imaging with a 532 nm laser, alongside simultaneous photocurrent measurements.
Raman imaging enabled mapping of the chemical composition, identifying characteristic vibrational bands of the PM6 polymer. Notably, regions with high Raman intensity correlated with reduced photocurrent output, indicating that local variations in polymer morphology can adversely affect charge extraction.
PL imaging provided further insights into charge carrier behaviour by visualising recombination across the cell. Areas with high PL intensity typically indicate poor charge extraction efficiency due to inhibited electron-hole separation. Spectral features at 677 nm and 883 nm confirmed emission from PM6 and Y6, respectively.
A comparison of PL and photocurrent data revealed areas with significant variation in efficiency, even in the absence of visible physical defects.



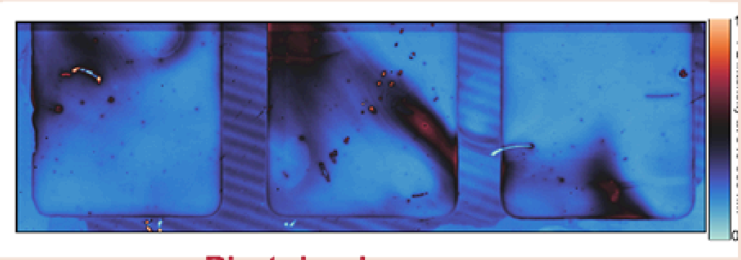
Brightfield



Raman



Photocurrent



Photoluminescence

For instance, differences in donor-acceptor mixing, as inferred from Raman spectral ratios, explained discrepancies in PL and photocurrent responses.Mechanical defects were also detected, with surrounding regions showing increased PL intensity and reduced current generation, further highlighting the sensitivity of these techniques to performance-limiting features.

This study highlights the utility of combining Raman, PL, and photocurrent imaging for correlative analysis of OSCs. These techniques, when used together, enable a comprehensive understanding of how chemical structure and morphology impact electronic performance. This methodology holds promise for guiding improvements in organic photovoltaic fabrication by identifying spatially dependent inefficiencies.

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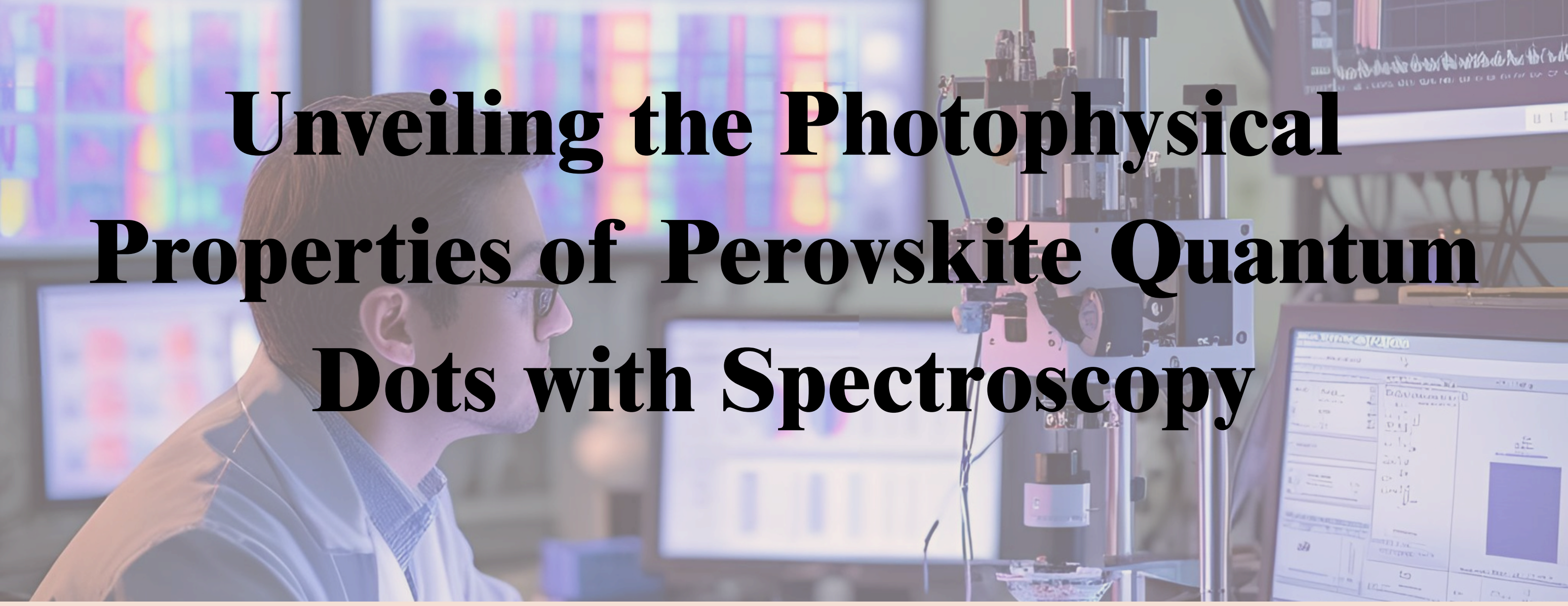
Acknowledgements: We thank Bahattin Bademci and Dr. Tariq Sajjad (TEMD Research Group, LSBU) for providing the OSC device.

More information: To find out more, read our Application Note, available here
https://www.edinst.com/resource/confocal-raman-photoluminescence-and-photocurrent-imaging-of-an-organic-solar-cell/

or

Scan the QR code



Unveiling the Photophysical Properties of Perovskite Quantum Dots with Spectroscopy

Perovskite quantum dots (PQDs) have garnered significant attention in the scientific community due to their promising applications in next-generation optoelectronic devices, including solar cells, LEDs, and lasers.

These nanoscale materials exhibit high photoluminescence quantum yields (PLQYs) and tunable bandgaps depending on their size and composition. Furthermore, they can be synthesised at low cost with few structural defects.

Photoluminescence and absorption spectroscopies characterise the light-matter interactions within PQDs in detail, thereby informing the optimisation of their performance and stability.

In this study, we utilised a spectrofluorometer equipped with an absorption detector (Edinburgh Instruments FS5) for a complete photophysical characterisation of two halide perovskite quantum dot solutions, PQD-A and PQD-B. All experiments were performed in a single spectrofluorometer, reducing measurement time and experimental error.

The absorption and emission spectra (Fig. 1) exhibited distinct peaks that differed significantly between PQD-A and PQD-B, demonstrating the tunability of the bandgap with composition.

A substantial difference was observed in the absolute PLQYs, measured in an integrating sphere accessory: 3.3% for PQD-A and 56.0% for PQD-B (Fig. 2).

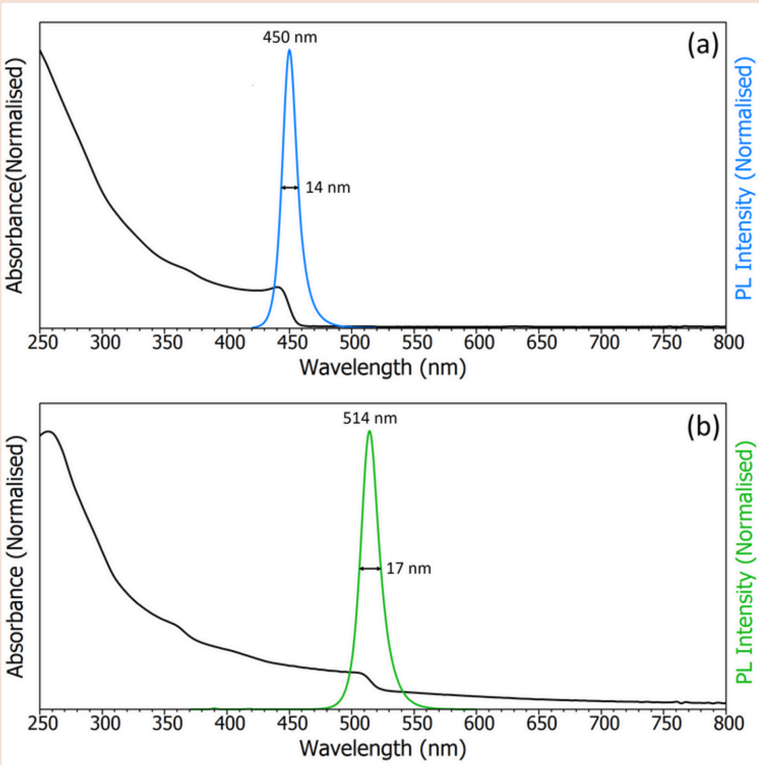


Figure 1. Absorption and emission of (a) PQD-A and (b) PQD-B, both in cyclohexane.

This high PLQY for PQD-B suggests its potential as a more suitable replacement for traditional cadmium-based quantum dots, which are known for their high PLQYs.

A higher PLQY translates directly into brighter output in display applications and greater power conversion efficiency in solar cell applications.

Time-resolved photoluminescence (TRPL) measurements were conducted to study the excited-state dynamics of the PQDs (Fig. 4)

Figure 2.The FS5 Spectrofluorometer

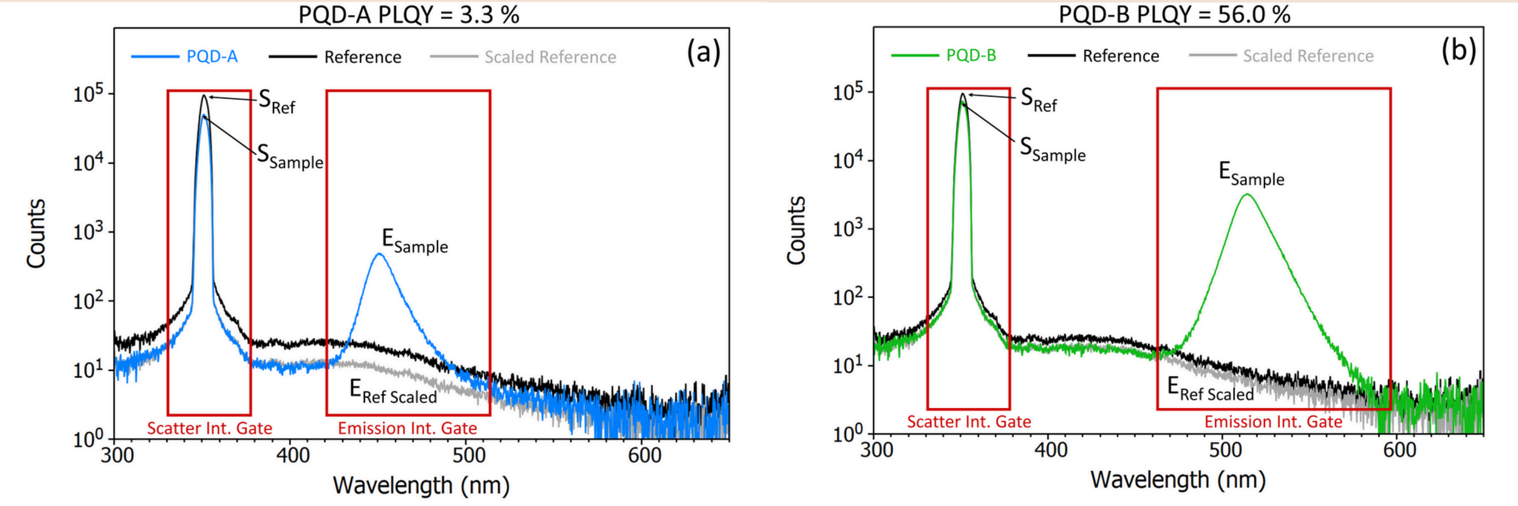


Figure 3. Absolute PLQY measurement for (a) PQD-A and (b) PQD-B in cyclohexane. The scattering and emission integration ranges used for the calculation are shown in red.

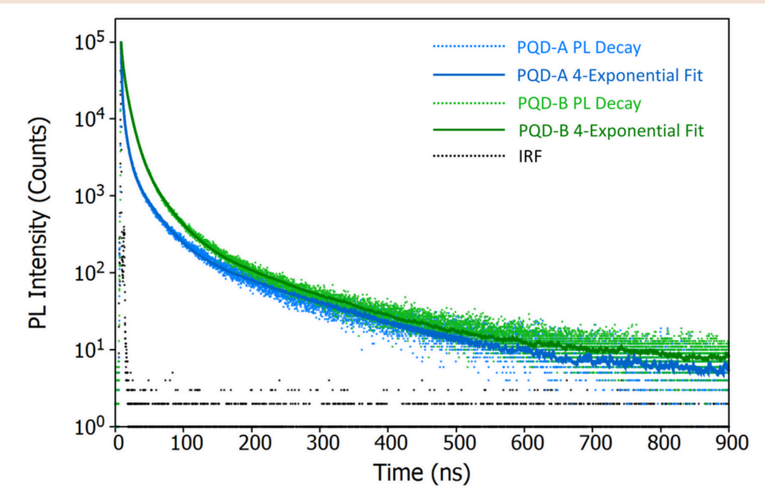


Figure 4. PL decays of PQD-A and PQD-B measured with Time-Correlated Single Photon Counting (excitation at 405 nm). 4-exponential fit results shown in the graph.

The decay profiles were complex, likely due to a combination of radiative and non-radiative recombination processes, as well as a distribution of PQDs each possessing slightly different lifetimes. A 4-exponential decay fit yielded average lifetime values of 16.1 ns and 19.1 ns for PQD-A and PQD-B, respectively.

In conclusion, this study provides a detailed photophysical characterisation of PQDs with tunable emission properties and high quantum yields. The results underscore the significant potential of these nanomaterials for various optoelectronic applications.

More information: To find out more, read our Application Note, available here https://www.edinst.com/resource/application-note-photophysical-characterisation-of-perovskite-quantum-dots/

or

Scan the QR code

Nature's Giant Solar cells

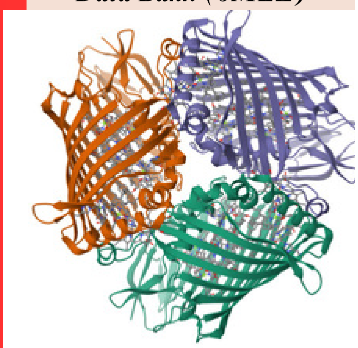
The role of Coherent Excitation dynamics in Light Harvesting

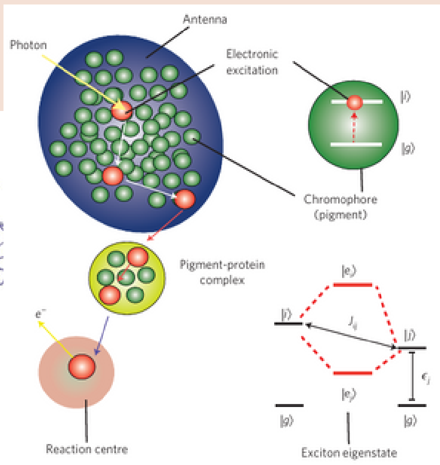
The primary source of energy in nature is provided by photosynthesis. At the heart of this fundamental biological process, where the photoinduced charge-separation reactions take place, are the reaction centers that act as nature's solar cells. The ratio of released electrons during charge-separation reactions to the induced photons defines the qantum efficiency of a solar cell. In photosynthesis, the reaction centers rely on their surrounded protein complexes to absorb the sunlight through their concentrated chromophores. The efficient energy transfer is critical for releasing the electrons in reaction centers. Applying these lessons from nature is the foundation for biomimetic cell design.

In some photosynthesis systems, it has been shown that quantum coherency can efficiently enhance the energy transfer to their reaction centers. This coherency, which has no classical counterpart, occurs when different excited chromophores couple in a superposition of their excited states. While the coherent states are normally short-lived due to the environmental dissipation and dephasing, it surprisingly lasts enough in some photosynthesis complexes to enhance the energy transport. The 2D electronic spectra of Fenna-Mathews-Olson (FMO) complex shows a dynamic quantm coherence for 660 fs. This is more than twice as long as the average population transfer time. This long-lived quantm coherence can play an important role in energy transfer processes whithin the photosynthesis systems.

Two-dimensional spectroscopy is an excellent techniqe to probe the coupling between excited states. The off-diagonal peaks in 2D spectrum displays the coherence with a wave-like behavior which is known as quantum beat, enhancing the energy transer to reaction centers.

FMO complex from Protein Data Bank (6MEZ)





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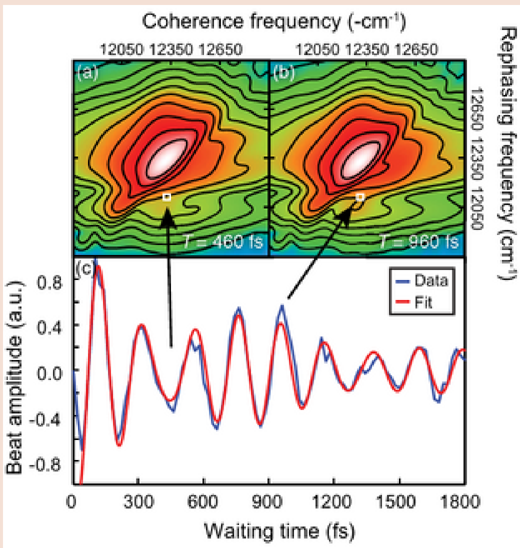

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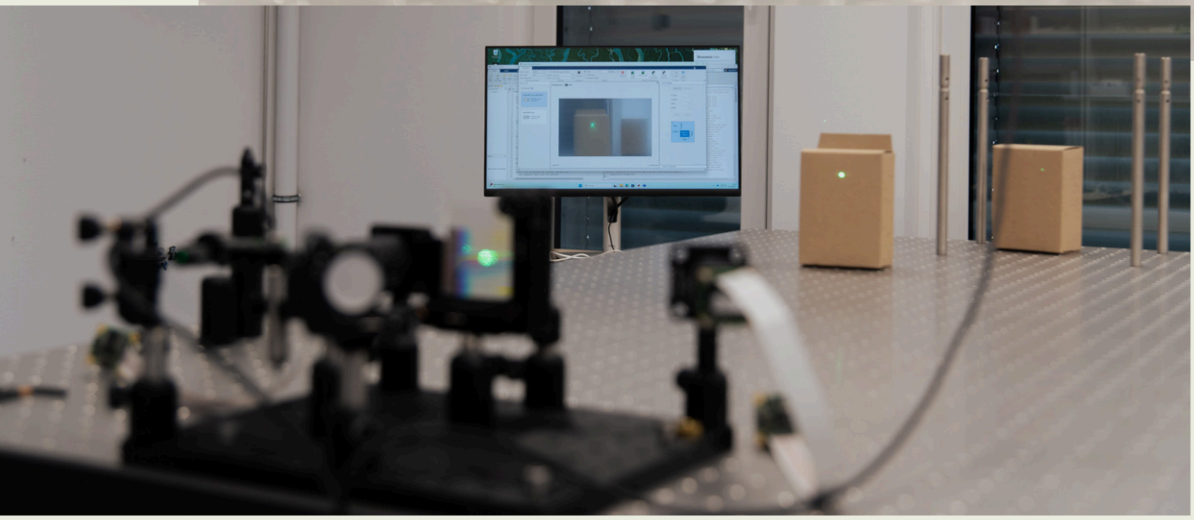
Climate change, the side effect of automation

Automation is not a new concept in agriculture. Digital technologies such as intelligent feeding systems and land machines with GPS have already found their place in farming. Sustainability through fewer pesticides and increased efficiency are the most advantages of automated agriculture. A reliable autonomous robot not only maintains the quality of products, but also relieves the burdens on the workers in special crops such as medicinal and aromatic plants. Nevertheless, although fully automated farming can guarantee the livelihood of our societies in the long term especially with the very high rate of population increase, its side effect of climate change shouldn't be underestimated. Large and heavy land machines compact the soil and release CO2. The development of small agricultural robots that use CO_2-neutral energy sources to efficiently recognize and navigate their environment can offer solutions to the mentioned problems. However, ensuring efficient, accurate autonomous movement and performance in unfamiliar terrain is a major challenge. Obstacles can easily distract a compact robot during its movement. Therefore, in modern agriculture and for the sake of a carbon-free future, efficient use of energy flow resources should go hand in hand with developing high-precision, full-automated techniques.

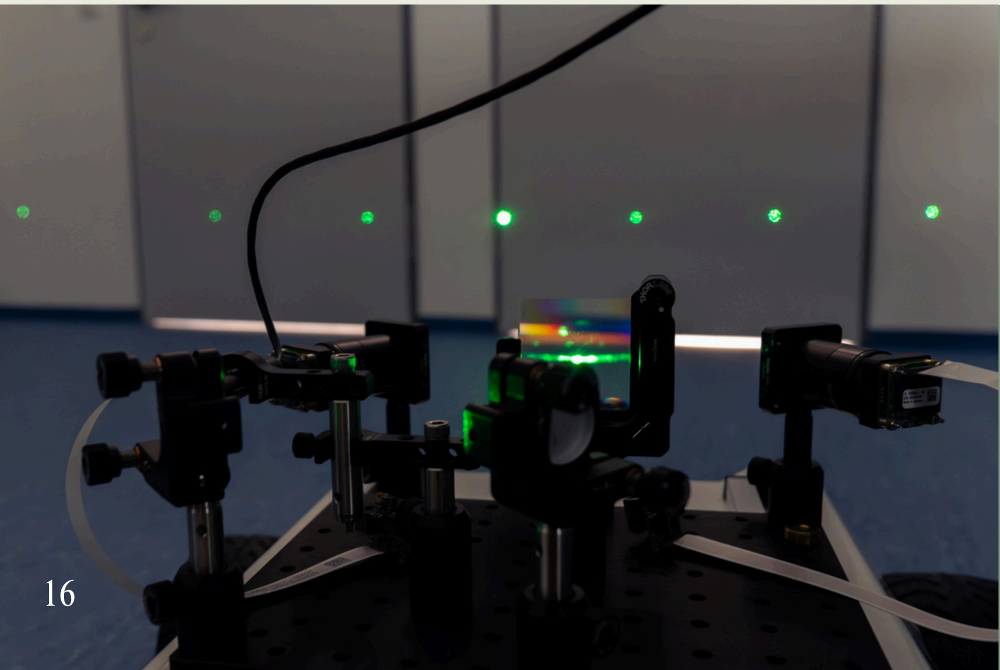
About “BotanyKI”

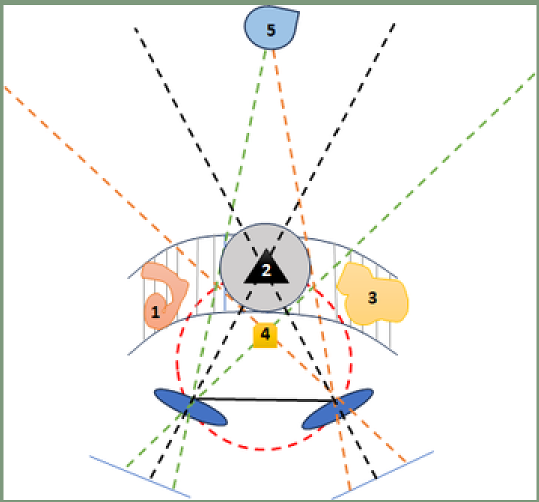
The project “BotanyKI” funded by the *German Federal Ministry for Research and Education (BMBF)* addresses the automation problem in farming with a view to the target of expanding the share of renewables in the final energy consumption. At the heart of the project is the development of an optical navigation system for enabling a robot to recognize its own position in an unknown agricultural field. After being trained with advanced machine learning algorithms, the optical navigation system will provide a general map of the surrounding area via a far-field detection strategy. A near-field investigation, on the other hand, should facilitate the movement of the robot step-by-step towards the target plants while avoiding any obstacle on its path.



“Efficient use of energy flow resources should go hand in hand with developing high-precision, full-automated techniques.”

The initial motivation for starting this project was the expansion of hydrogen energy in the agrigultural industry. HySON, a young research institute in Thuringia state of Germany started doing research on this topic because it was aligned with its mission, to bring and expand the use of hydrogen in different areas of industry. However, as it is the general case in efficient use of renewable energies, the end solution appeared to be more complex than a simple replacement of the fossil resources. The small robots (Hunter SE and Scout Mini) which were chosen to minimize the soil damage needed a compact navigation system for a full-automated movement and localization. The multidisciplinary idea, developing a sensor for recognizing the environment that need to be trained with AI-algorithms for full-automation, and adapting the whole system for the construction of the minirobot became the foundation for a collaboration between three partners. While HySON takes over the research and development for sensor as well as replacing the electricity resources with that of hydrogen, Batix develops the necessary software and deep learning algorithms as an IT-partner. SMB, an industry partner for robotic, is responsible for mechanical adjustment and installation of the whole system on the robot. Although the project is still in the first phase of research and development, the scope of its future is to prototype a compact navigation system equipped with advanced AI-algorithms that can be utilized by any small robots in farming. In addition to the development of each part, sensor and AI, the main chalenge is to optimize the fast and accurate communication between the sensor and the robot. That is to say, the data acquired by the sensor which are mainly images, should be quickly processed with deep-learning algorithms to be timely synchronized with the





Schematic of different zonal distance

current and next position of the robot based on the provided general map of the plants rows. This requires not only high accuracy in the acquisition and processing of the data, but also a very fast communication strategy. The partners, therefore, have planned optimization and testing process after initial development.

Optical Binocular System

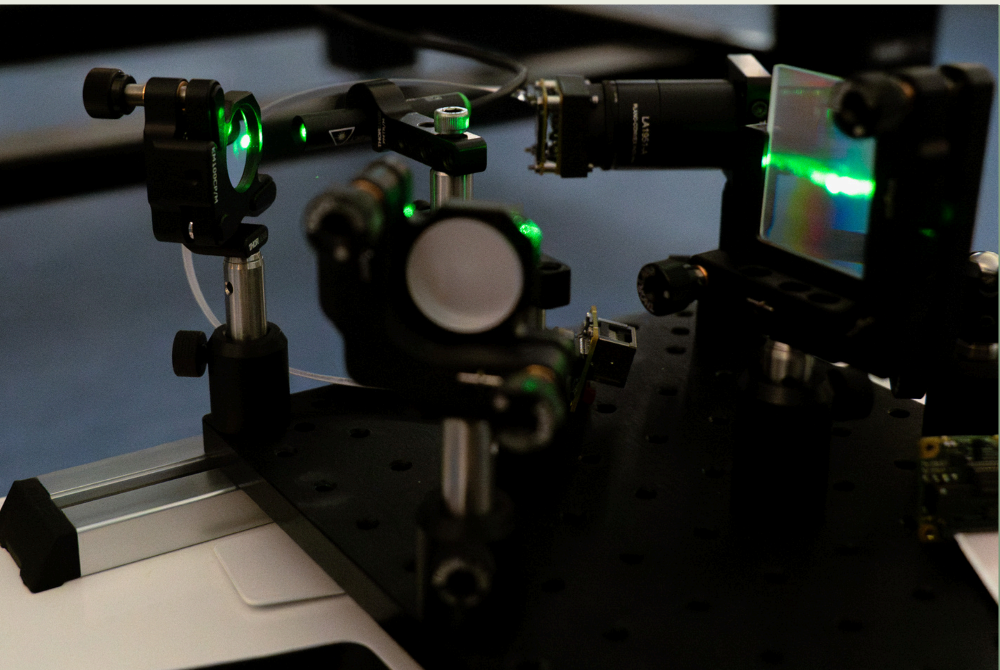
The navigation system for BotanyKI is based on a binocular vision system which works with the same concept as that of human eyes. Two cameras placed in a constant distance in front of the robot produce images of the scence from different perspective. The images are corresponded and processed, and the necessary features will be extracted by deep-learning algorithms to localize the objects based on their position and more importantly their distance to the robot. This is how our brain process the images based on their visual features. A diffracted laser beam illuminate the scene to spot the objects and their positional deviation relative to the center based on the diffracted angles. The robot will be trained with the laser beam together with a special filter which divide the scene in different distance-zones. As a result, there would be a critical zone the objects of which should be considered as priorities and their images should be processed as fast as possible in order to avoid any accident. These objects are shown as numbers 1-3 in the schematic picture.

AI-System

The AI-system includes two main parts of deep-learning algorithms or image processing and commnication algorithms for transferring the processed data to the robot. While the deep-learning algorithms are mainly based on classification and segmentation to extract the features from the image, the commnication algorithms transfer the data from image-cordinate system to the coordinate system of the world and the robot.

Achknowledgment

The assistance and support of the *German Aerospace Center (DLR)* as well as the financial support of the *German Federal Ministry of Research and Education* as the sponsor of the project "BotanyKI" is acknowledged.



Vanadium dioxide-based metasurface for temperature-adaptive radiative cooling

Introduction

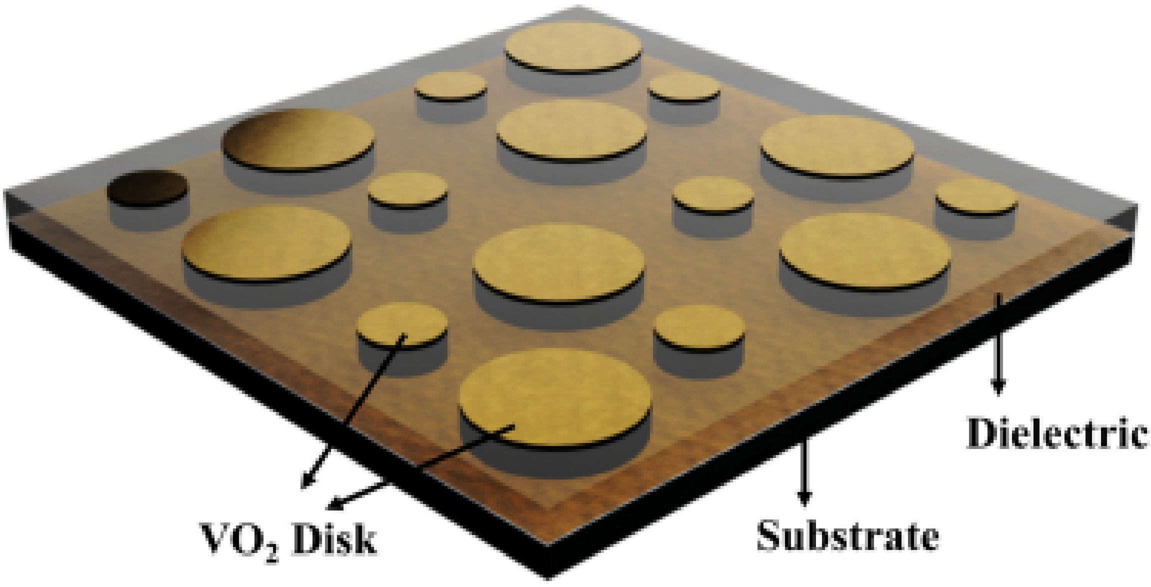
As global temperatures rise, researchers are rapidly advancing cooling technologies that operate without external energy input or carbon emissions. Researchers from Fudan University and the University of Alabama in Huntsville developed a smart metasurface that passively regulates heat emission by adapting to temperature changes

Why it matters

This work adds a new chapter to passive climate control, offering a zero-energy, scalable alternative to traditional cooling.

With applications spanning from smart buildings to wearable tech and even spacecraft, it's a step closer to truly intelligent surfaces that respond to nature—just like living systems. At the heart of their design is vanadium dioxide (VO_2), a well-known phase change material. Below 68 °C, VO_2 behaves like an insulator above that, it flips to a metallic state. This switch changes how it absorbs and emits thermal radiation. The authors design a metal-dielectric-metal (MDM) absorber incorporating two sizes of VO_2 microdisks into a supercell on a layered substrate. This supercell configuration enables broadband absorptivity across the 8–13 µm atmospheric window and realizes a significant cooling power contrast (~100 W/m²) between its "on" (metallic) and "off" (dielectric) states.the team engineered a surface that self-adjusts its cooling performance in real time. The metasurface maintains angular stability (40°) ideal for flat surfaces, reflects sunlight well, and could be improved via tungsten(W) doping and layered reflector

3D modeling of the two-size VO2 metasurface

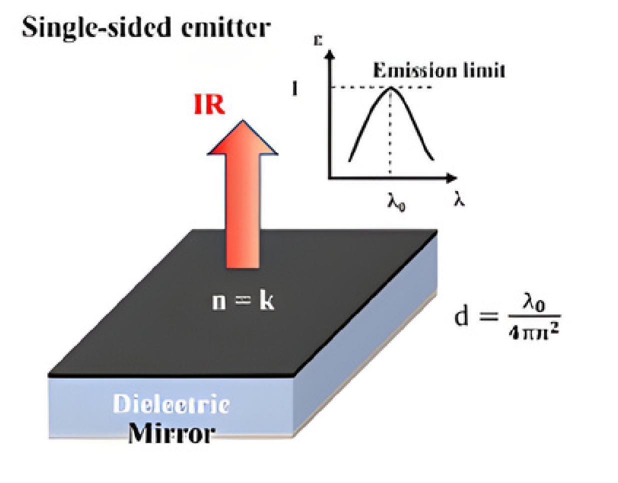


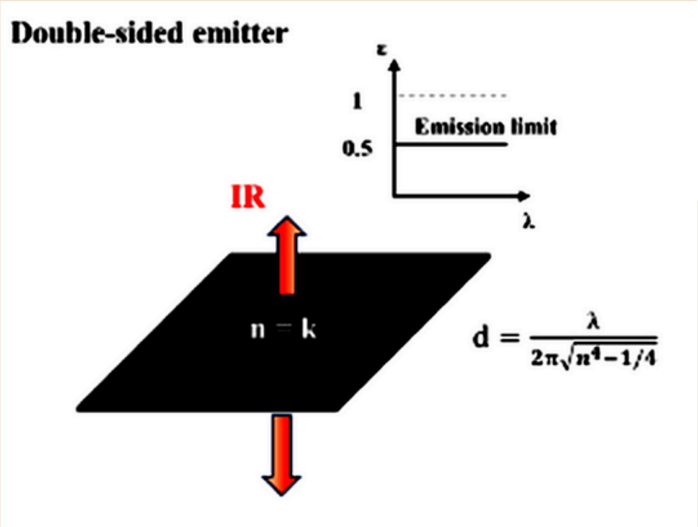
https://doi.org/10.1117/1.OE.64.2.027102

Approaching the Thermal Emissivity Limit with Ultrathin MXene Film

Thermal emissivity measures how effectively a material emits thermal (infrared) radiation, compared to an ideal blackbody. Controlling emissivity is important for thermal management and energy applications. For example, high emissivity can help radiate away heat in cooling and power generation e.g. thermophotovoltaics, while low or tunable emissivity is useful for thermal insulation, infrared camouflage, and efficient heat-steering devices.

The research focuses on developing ultrathin emitters that approach the emissivity limit while balancing minimal thickness with optimal free-space impedance matching



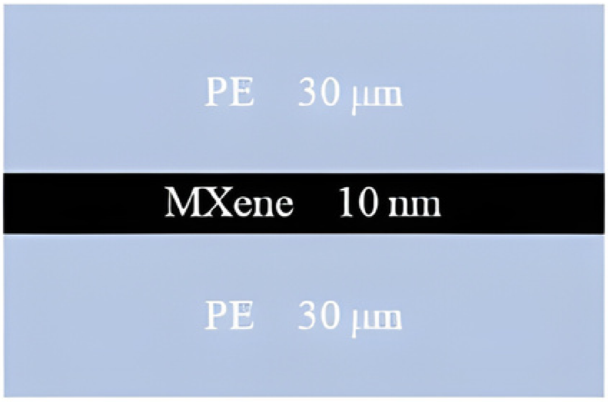


According to Kirchhoff's law of thermal radiation, an object's emissivity at each wavelength equals its absorptivity. However, reaching the theoretical emissivity limit is challenging. Thick materials or multi-layer coatings can approach a blackbody spectrum, but they are bulky. Ultrathin films are lightweight and flexible, but they usually do not absorb enough due to high reflection or transmission to reach high emissivity. In particular, an ultrathin symmetric film in free space is limited to absorbing at most 50% of incoming radiation (emissivity ≤ 0.5).

MXene Films

MXene is a two-dimensional (2D) transition-metal carbides or nitrides and are atomically thin sheet and are electrically conductive like metals and can be processed from solution into thin films. Crucially, MXenes have very low intrinsic mid-infrared emissivity: for example, 2D $Ti_3C_2T_x$ can have emissivity down to approximately 0.10 in the mid-IR, while still strongly absorbing visible light. This unusual spectral selectivity makes them excellent building blocks for engineered emitters. By stacking or resonating ultrathin MXene layers, one can turn the normally low-ε material into a near-perfect emitter at chosen IR wavelengths. Furthermore, MXene flakes can self-assemble into high-quality films and have surface chemistry that allows tuning of their optical conductivity. The combination of metallic conductivity and tunability makes MXenes well suited to approach the thermal emissivity limits in ultrathin form.

Emissivity (ε) ranges from 0 (no emission) to 1 (ideal blackbody). For materials at thermal equilibrium, Kirchhoff's law states that the emissivity equals the absorptivity at each wavelength. Therefore, the structure must be designed to absorb as much radiation as possible to maximize emissivity. A perfect blackbody has ε = 1 because it absorbs all incident light at all wavelengths. By contrast, a freestanding ultrathin film that is much thinner than the wavelength has limited absorption. Theory and prior studies show that such a film can absorb approximately 50% of incident light when its optical impedance is matched to free space. This 50% limit arises because a symmetric thin film splits incoming waves between its two faces, and perfect absorption on each side would require doubling the energy. Impedance matching here means tuning the film's effective conductance so that reflections are minimized. When perfectly matched, any light not transmitted is absorbed, reaching the 50% bound.

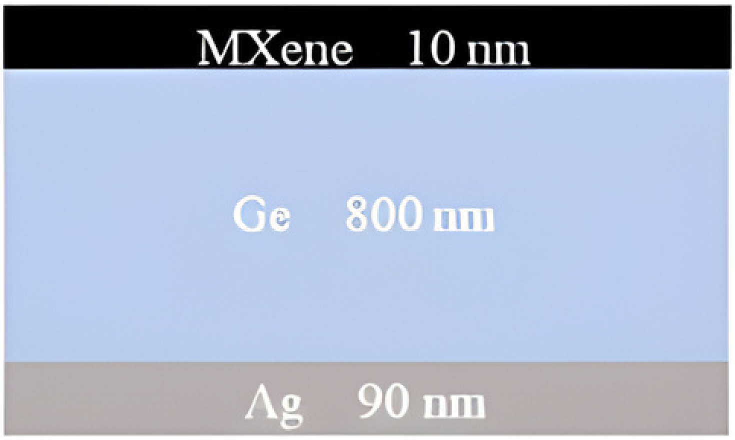


Double-sided MXene emitter film

In a double-sided emitter, i.e., film exposed on both sides to air, the maximum theoretical emissivity is therefore 0.5 across each face. Achieving this requires the film's optical admittance to equal half that of free space. Under that impedance-matched condition, no light is reflected and half is transmitted, and half is absorbed. In contrast, **a single-sided emitter**, i.e., the film backed by a mirror or integrated into a resonator, can reach emissivity up to 1, but typically only over a narrow spectral band. By placing the ultrathin film inside a Fabry–Pérot resonator, for example, between a metal mirror and a dielectric spacer, one can achieve critical coupling, which is the resonant mode that is tuned so that all incident IR light is absorbed by the film, yielding emissivity near unity at the resonant wavelength. In this case, the presence of the mirror means no transmission escapes if the coupling rates are balanced, coherent perfect absorption occurs, and emissivity approaches one at that wavelength. Thus, the theoretical conditions for maximum emissivity are:

1. for a double-sided film, film impedance matched to free space (ideal ε=0.5).
2. for a single-sided resonant emitter, tuning the cavity to critical coupling (ideal ε=1 at resonance).

These principles set the thermal emissivity limits that the study aims to approach with real ultrathin materials.



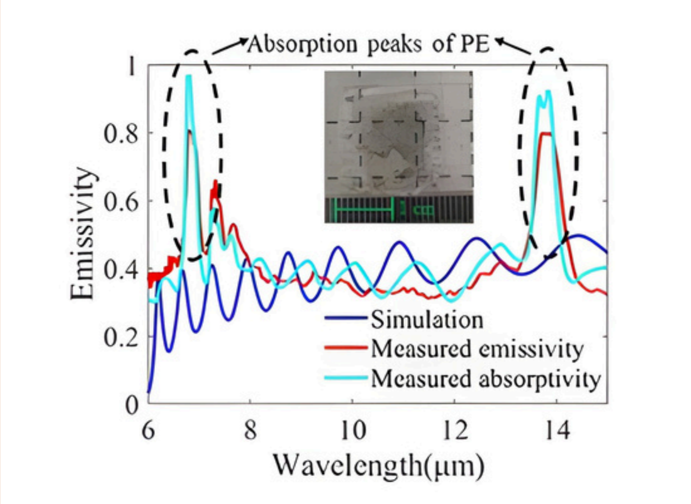
Single-sided MXene emitter film

Practical Implications

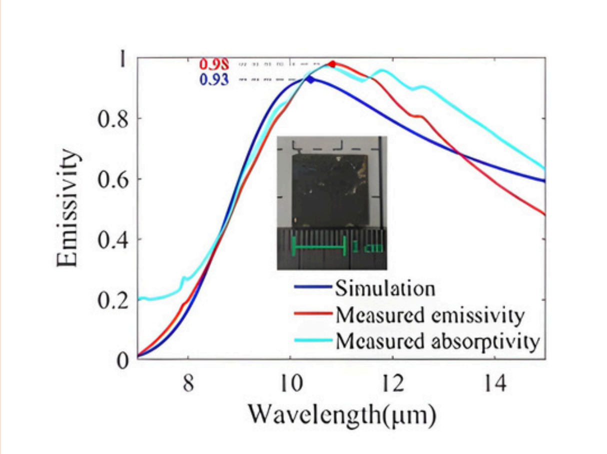
Achieving the maximum possible emissivity in a nanometer-thick film means devices can be made extremely lightweight and compact. Such films could serve as highly efficient thermal emitters in radiative cooling panels. The ability to tune emissivity also benefits infrared imaging and camouflage. MXene's natural properties like high solar absorption but low IR emission already make it attractive for building coatings that heat under sunlight yet stay cool in the IR.

Results

The ultrathin MXene emitters closely approached the ideal emissivity limits. For the double-sided emitter, the suspended 10 nm MXene film achieved an emissivity of about 0.50 over a broad mid-infrared band (approximately 6–15 μm). This matches the theoretical maximum of 0.5 for a symmetric thin film. Both simulation and experiment showed that the film's impedance was tuned so that about half of the incident IR was absorbed (emissivity≈0.5) rather than reflected. For the single-sided resonant emitter, the device showed a sharp peak near ε≈1.0 at a designed wavelength (10.8 μm). At this wavelength, the Fabry–Pérot cavity was critically coupled, i.e, virtually all incident radiation was absorbed by the MXene layer, yielding near-unity emissivity. The experimental emissivity peaked around 0.98 at 10.8 μm, well above what the same film could achieve without the resonator. Both experimental results demonstrate excellent agreement with simulations.



Simulated and experimental emissivity and absorptivity plots of the double-sided emitter



Simulated and experimental emissivity and absorptivity plots of the single-sided emitter

Limitations and Future Directions

The study achieved near-ideal performance, but there are practical limitations. The double-sided emitter's is fundamentally limited to 50%, so it cannot emit more without added structure. The single-sided emitter achieves only over a narrow spectral band, around its resonant wavelength outside that narrow band, emissivity is much lower. For real-world applications, one may need broadband or tunable emissivity. Future work could explore stacking multiple resonators or using patterned MXene arrays to broaden the high-emissivity range.

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Tuning Nanomaterials for Clean Air: Optimized $ZnO–SnO_2$ Sensors for Formaldehyde Detection

Volatile organic compounds (VOCs) are carbon-based gases like benzene, toluene, and formaldehyde, are common indoor pollutants emitted from paints, furniture, and cleaning products. Many VOCs can irritate the eyes, throat, or lungs, and some are even carcinogenic. For example, formaldehyde is a known carcinogen in humans. The U.S. EPA warns that indoor VOC levels can be several times higher than outdoors, so monitoring them is important. However, our noses cannot tell exactly which gas is present or its amount. That's why electronic gas sensors are needed, they provide reliable, continuous measurements of specific VOCs. Among VOCs, formaldehyde is especially important because even low indoor concentrations can harm health. Detecting formaldehyde accurately without confusing it with other VOCs in the air is a major goal to achieve in air quality detection.

Challenges with today's gas sensors

Traditional gas sensors come in various types: metal-oxide (semiconductor) sensors (the most common), electrochemical cells, catalytic combustion sensors, and optical devices. Metal-oxide resistive sensors (like those using SnO_2 alone) are popular because they are cheap and easy to make and can give a big electrical signal when gas is present. But a key limitation is selectivity. A strong sensor response to one gas often means it responds strongly to many gases. In practice, this means a sensor might not distinguish formaldehyde from, say, toluene or other VOCs present simultaneously.In other words, many high-sensitivity sensors suffer from false positives when multiple pollutants mix. Improving both sensitivity and selectivity so the device reacts mainly to formaldehyde is a major challenge in current air-quality monitoring.

Why $ZnO–SnO_2$ Nanocomposites?

Combining two materials can create a nanocomposite with better properties than either part alone. The authors used zinc oxide (ZnO) and tin dioxide (SnO_2), both well-known n-type metal-oxide semiconductors for sensing. Individually, they have very good sensitivity to gases, but together they form a heterojunction (an interface between two different semiconductors) that boosts performance. In such a heterojunction, differences in the electronic energy levels (Fermi levels) create a built-in barrier. When formaldehyde molecules interact with the material's surface, they change how electrons cross that barrier, leading to an amplified change in conductivity.

Moreover, ZnO and SnO_2 nanostructures have very large surface areas, like a sponge-like material made of tiny crystals. Their surfaces have missing oxygen atoms, leaving extra electrons behind. When formaldehyde encounters these surfaces, it reacts with the adsorbed oxygen, and the freed electrons flow back into the semiconductor. This alters the material's conductivity and is detected as the sensor response. In simple terms, formaldehyde "unblocks" trapped electrons, causing a measurable spike in current. By carefully engineering the $ZnO–SnO_2$ mixture at the nanoscale, the sensor can become especially sensitive and even more selective to formaldehyde than to other VOCs.

Fabrication of the ZnO-SnO2 gas sensors.

The ZnO-SnO_2 gas sensors were fabricated using a three-step ultrasonic chemical synthesis method. First, the alumina substrate underwent pre-treatment, where a Pt layer was deposited via electroplating, followed by a Zn layer deposited via sputtering. The substrate was then annealed at 600°C for 1 h to form ZnO seeds. Next, ultrasonic chemical synthesis was performed by immersing the substrate in a solution of zinc acetate, chloride, ethanol, and distilled water under pulsed ultrasonic treatment at varying energy levels. Finally, post-treatment involved washing and annealing at 450°C for 2 h before sensor integration.

Measurement of the gas sensor response

Controlled amounts of gas mixtures were introduced. In each test, the sensor was exposed to a known concentration of formaldehyde: 20 parts per million (ppm), 1 ppm, and 0.1 ppm, and the electrical signal was recorded over time. For comparison, the same concentrations of VOC were also tested under identical conditions. The response is defined as the percent change in conductivity when the target gas is present, and the recovery is how fast the signal returns to baseline when the gas is removed.

Conclusion

The amount of ultrasound energy used in synthesis had a big impact on sensor performance. In every test concentration, the sensor made with 100,000 J stood out as the best

Highest Sensitivity: At 20 ppm formaldehyde, the 100,000 J sensor gave about a 92% response, higher than any other condition. By comparison, the 50,000 J sensor responded~ 80%, the 150,000 J one ~50%, and the 200,000 J one ~70%.

Strong Low-Level Detection: Even at just 1 ppm (near levels relevant for indoor air), the 100,000 J device showed a ~56% response, far above the 10% seen with the 50,000 J sensor. The 150,000 J and 200,000 J sensors gave only ~13% and 24% at 1 ppm, respectively. This means the 100,000 J sensor could detect lower concentrations more reliably.

Selectivity to Formaldehyde: Critically, the 100,000 J sensor responded much more strongly to formaldehyde than to toluene. In tests with 20 ppm of each gas, the signal for formaldehyde was far larger than for toluene. In practical terms, this means the sensor can distinguish formaldehyde in a VOC mix.

Fast Response and Recovery: The 100,000 J sensor not only gave the largest signal, but it also had the fastest recovery back to baseline after exposure. For example, while most recovery times were on the order of minutes, the 100,000 J device consistently returned to idle roughly as quickly or quicker than the others.

Implications for Air Quality Monitoring

A low-cost metal-oxide sensor that is both sensitive and selective to formaldehyde could enable better indoor air monitors and early-warning devices. For example, built into a smart home sensor, it could reliably track formaldehyde from new furniture or air fresheners and alert occupants if levels get unhealthy. The fact that this sensor operates with a relatively simple fabrication no rare elements needed, makes it promising for mass production.

Sensor	Characteristic	20 ppm	1 ppm	0.1 ppm
ZnO-SnO_2 (50,000 J)	Response	80	10	5
	Response time (s)	80	125	145
	Recovery time (s)	450	210	150
ZnO-SnO_2 (100,000 J)	Response	92	56	20
	Response time (s)	65	110	105
	Recovery time (s)	565	245	185
ZnO-SnO_2 (150,000 J)	Response	50	13	3
	Response time (s)	235	110	160
	Recovery time (s)	210	130	170
ZnO-SnO_2 (200,000 J)	Response	70	24	5
	Response time (s)	60	130	110
	Recovery time (s)	225	210	100

Table 1: Response, response time, and recovery time for ZnO-SnO2 gas sensors in response to formaldehyde gas

Sensor	20 ppm		1 ppm		0.1 ppm	
	Formaldehyde	Toluene	Formaldehyde	Toluene	Formaldehyde	Toluene
50,000 J	80	25	10	6	5	3
100,000 J	92	80	56	45	20	18
150,000 J	50	30	13	3	3	1
200,000 J	70	40	24	18	5	5

Table 2: Response of ZnO-SnO2 gas sensors to formaldehyde and toluene gas

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Career Focus

Shaping the World with David Giltner

David Giltner is a scientist, storyteller, and entrepreneur. He is the founder of Turning Science, and the author of three books: “Turning Science to Things People Need”, “It’s a Game Not a Formula”, and the very recent one “Shaping the World; The Vital Role of Scientists in Industry”. His mission is to help scientists to build their careers outside academia.

”The more facts you learn, the less you really know what the right decision is. It’s the Heisenberg uncertainty principle applied to business.”

***Q.* You wrote the first book, "Turning Science to Things People Need". It was the stories of scientists who made the transition from academia to industry and built their careers in the private sector. By your own words, they were stories of struggle and persistence! But why struggle? As you interviewed those scientists, what was the main reason for their struggle and the need for their persistence?**

Giltner: The main reason they struggled is that the environment is very different than the academic research environment we were prepared for. I wanted to create a book that would help them, the same way it would have helped me, because I struggled for the same reason. During our PhD, that is the time we learn how to be a scientist, and we learn how to work as scientist. An undergraduate degree is just about learning information. But during PhD, you learn how to be an independent scientist.You acquire lots of habits, and many of those have great value in industry. However, in the working environment, some of the required habits and the mindset are different.The mindset shift is the biggest challenge that I faced, and so as the scientists that I have interviewed.

***Q.* We know scientists are mostly smart people. On the other hand, as most people usually think, the industry doesn't need a high level of IQ. Could it also be a conflict that causes that struggle, smart people being in places that don't need a high IQ?**

Giltner: I have not found that to be true. I'm aware people think that some people think industry is boring and monotonous, but that hasn't been my experience at all. There are elements of it that are repetitive. When you are developing a product, once the product is released for production, yes, the idea is to build the same thing over and over and over. But that's not usually where we work. There are plenty of challenging problems to solve, and being intelligent and having all these skills has lots of value. That's why when you don't have the right mindset, it can be challenging to perform at a high level that gets you respected, gets you promoted, and allows you to move into positions of influence where we are making a difference.

The problem is that most scientists who are graduating don't understand anything about industry because our advisors don't know anything about it. It's not their fault. They're academics. But I'd seen a lot of scientists struggle in my 25 years in industry. Often our managers don't understand why we are slow to adopt the business mindset. If they don't have a PhD, they likely don't understand the academic research mindset we were trained in. I thought "I can do something to make a difference here". So I wrote my 1st book in 2010, and I went out and I started speaking at universities around the world. *"Can a scientist find a rewarding career in industry?"* was the one hour talk I would give.

***Q.* Then, after those interviews in your first book, you realized that the stories of those scientists were probably personal, but the challenges that they had gone through during this transition were somehow following a similar pattern. And you came up with the metaphor of a game, which was the foundation of your second book, "It's a Game, Not a Formula". But why the game metaphor?**

Giltner: Yes, the game metaphor I describe in the book became a very powerful mnemonic, or memory device for me. It's how I reminded myself to switch to the industry mindset. I realized, in an academic mindset, in a research mindset, we are looking for the right answer, right? And this is something we do really from the time that we are very young; Education is about finding the right answer. Even in your PhD research project, while there are a lot of things we don't know and it's a process of discovery, it's still a matter of finding the right answer that we can publish. We need to be able to say, "I know this is to be true because I have collected the data and analyzed it and several of us have looked at it." And I realized, the academic and research mentalities that we take into industry are often still looking for that right answer, that perfect solution, the best solution. But industry is not about that at all. It's about moving quickly. It's not about finding the right answer, it's about finding something that works, and there may be lots of ways to do it, and it doesn't have to be perfect. It just has to work well enough to satisfy a customer's needs. And it turns out that's a very different approach. I realized that's the way games work; there are many ways to win. That's why you have competition. It's not about finding the right answer, it's about finding a way to win quickly. You can't overthink it, you have to decide quickly, and you have to take risks. Let's take the sport of football, or in the US we call it soccer, a sport which most people around the world know. Any physicist would love to analyze kicking a goal in football, because if know all the parameters, you ought to be able to get the perfect shot. And sure, in principle, that's true, but that's research thinking. But to win the game, you don't have time to do that. You have to take a risk and take a shot when you see the opportunity, and you might miss, right?. But you are not going to die or be kicked off the team. What do you do? You learn from it, and you try something else. That's the way industry works, because it needs to be fast-moving. You have to be more comfortable making decisions, taking risks when you might be wrong, because we need to move fast. It's just a new environment. If embrace that fact and adapt the right mindset, we do very well.

***Q.* As you mentioned in your books, scientists are equipped with many valuable skills that can help them to win in this new environment. Let's go through some of them;**

Flexibility in learning new skills and working principles!

Giltner: Yes, you are absolutely right. We have lots of useful skills for industry. Success is all about having the right mindset. Flexibility of learning and ability to learn on one's own, that's really valuable. The hallmark of a PhD is that we have accomplished something on our own. When you move to industry, that's also very valuable. But unlike academia, when you work for years to learn something new all on your own and demonstrate it, industry doesn't have the time to do that. So, it's great for us to be flexible learners, flexible thinkers, and to learn on our own. But we have to apply those strengths in a team environment.

A part of the mindset shift is, if I don't know something and we have a deadline, I need to back up and say, okay, I could learn this on my own, but it's not fast enough. I need to go find somebody who already understands it. We can move together faster, and I can learn it along the way. That's an example of that shift to the game mindset, where we have to move quickly as opposed to the research mindset that we learnt as PhD.

***Q.* And perhaps regarding one of the main differences that you mentioned in your book between academia and industry, that one in industry needs to pursue results and not understanding, right? The word understanding follows the learning process. So the question is, what is the difference between learning in academia and learning in the private sector? Perhaps, it's just a matter of time that you spend! In academia, you can learn as much as you want, but in the private sector, you just want to learn what is important and not be involved in many different details, right?**

Giltner: The way I think of it is, in academia, learning for learning's sake is OK. If you study any kind of project problem or concept, the idea is to learn everything about it because that's generating new knowledge, and you can publish it, and other people will learn. That's understanding, that's what research is for, and that is valuable. But as you pointed out, learning in industry is great, but we have to stop and think, what do I need to learn to get to the result that we need, and what would just be interesting but actually doesn't move us forward towards a solution for a customer. And that is the difference. Learning is great, and being an independent learner is great, but in industry we don't have the luxury of learning every little thing about the problem we are solving. We have to be disciplined and say, "This is not important for me right now, and I will set it aside." And that can be tough for those of us who are curious. I like to think about it as "what matters and what won't matter". Focusing on the problem at hand is a good guideline, and that turns out to be even more exciting than endless learning. I experienced it when I was working in the industry. There were problems to solve that could help our customers, and that was exciting.

***Q.* Another valuable skill that scientists have could be clear oral and written communication skills; Writing a thesis, publications, and reports, presenting in conferences in front of many audiences. With all of these experiences, scientists shouldn't have any problem in industry regarding their communication skills. But it turns out, as we read the interviews in your book, that almost all of those scientists had communication problems, at least in the first phase of**

their career! But why is that?

Giltner: The nature of communication in industry is often very different. It becomes less a matter of conveying facts, data, analysis, and conclusion, and more a matter of persuasion. The communication we are used to in academia is communicating with people with the same expertise as us. So, I can lay out the facts and analysis, and frankly, it should speak for itself. If I do a good job of laying down the facts clearly, those who listen to my talk or read the paper, ideally say, "That makes sense, and that's consistent with what I know", you have moved things forward.

In industry, however, we are on teams with people who often have very different backgrounds, experiences, skill sets, and knowledge than ours. Now, we might be experts on something, either because we came in with that knowledge or because we are the ones who studied the problem. And we have to help them see what we understand. That becomes more about persuading them to see what we see.

Q. **For persuasion, you mentioned that we don't have enough time to gather enough data, and that's why need to persuade people to accept our idea. But does it mean there is always a trade-off between accuracy and speed in industry? How we should find a balance, because the analysis can also be effective and important!**

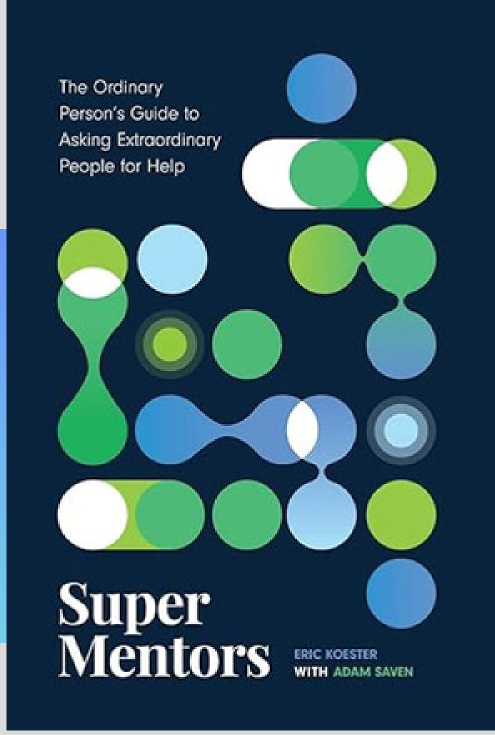
"Don't look for the "right way" to do things. Look for the way that allows you to win the game with the strengths and constraints that you have."

Giltner: Right! Industry does need to move fast. That does not mean that we ship products that may not work well, that are sloppy in some way, and aren't accurate. What it really means is that we have to make decisions early in the development process, and we test them as we go, and we will verify the accuracy that we need. But that's down the road. Right now, we have to pick a path forward without knowing the "perfect" answer. There are certain industries, like the medical industry, that in the end need a high level of accuracy. But speed is very important early on, we have to take a path forward. Many questions simply don't have the right answer. So, don't go looking for a perfect answer. Pick something you think is a good answer, make a decision, and then work to make that the right decision.

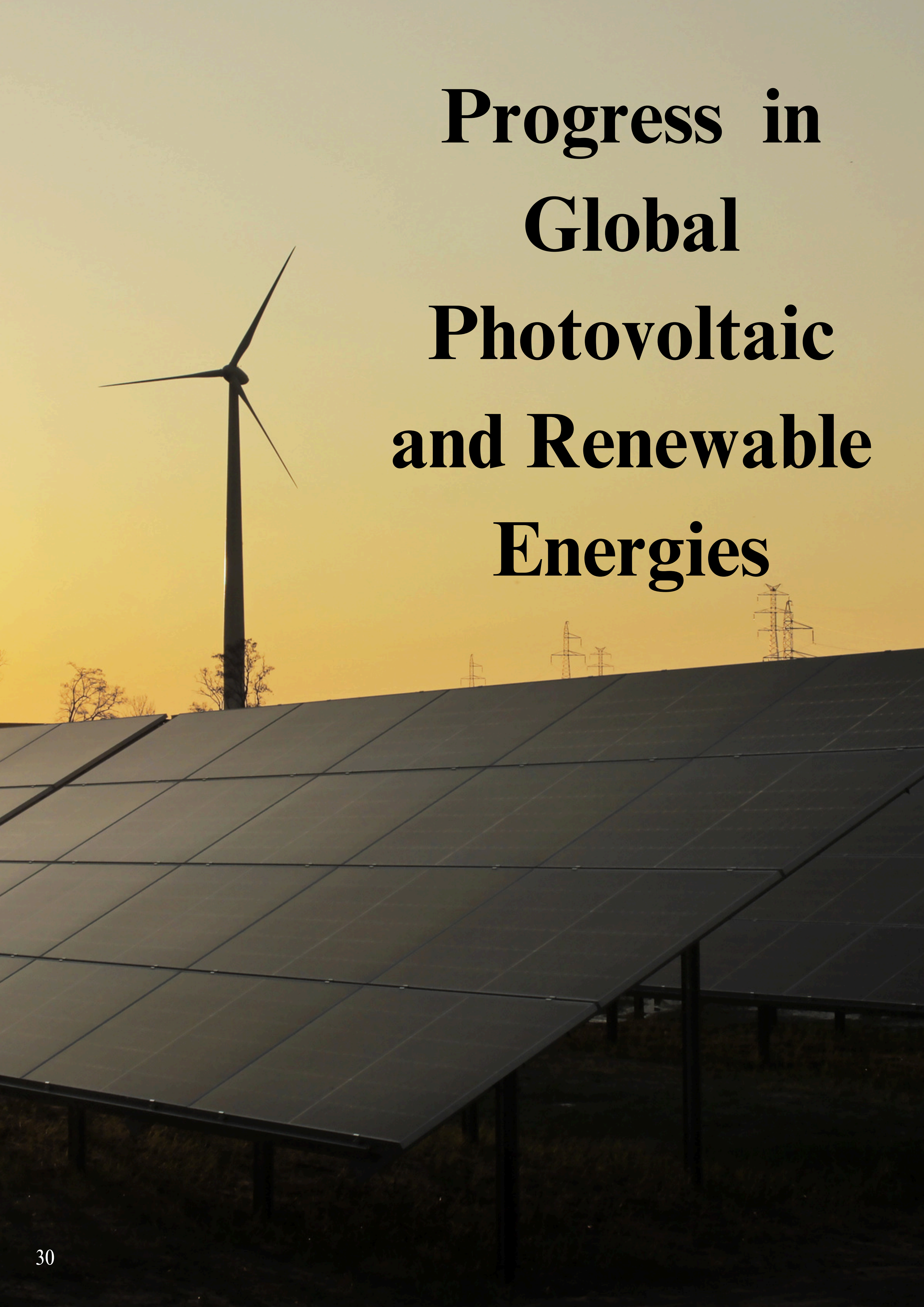
Watch the full interview in our technical group webpage:
https://www.optica.org/get_involved/technical_groups/poe/optics_for_energy_(ps)/

Modern Mentorship

"Aim higher, ask smaller, and do it again."



We all have some names in our mind, of people who helped us at some point in our career or life to go through a challenge by giving us advices or encouraging us. Can we call them "our mentors"? Yes, of course. Modern mentorship, however, which is compatible with a world where our challenges are getting more complex, is much more than that. We need beyond just advice and inspiration from a mentor, according to what the author describes in the book *Super Mentors*. "People usually describe a mentor as a single wise, experienced person in their life who takes them under their wing and guides them with advice and wisdom toward their success ... Modern Mentorship is different. We need mentors who help us solve our biggest challenges, problems, and struggles." What he calls 'Super Mentors', are problem solvers who can help us solve our greatest challenges. "The best mentors are super not because of what they say or what story they might tell but because of their actions. We spend so much of our time hunting for a person to be our mentor rather than finding the right person who will actively help solve our problem. Our job is to identify the right problem and then make it easy for them to help." The role of mentee, as described in the book, in the process of modern mentorship is also different "Mentees drive mentorship." How? "[By being] more ambitious in who you want to help you and less ambitious about what you need from them." Another words, "Aim higher, ask smaller." Modern mentorship, the author says, is about providing opportunities not advice which you can easily get in internet. Opportunities, whatever the person might need, such as a job, a project, or a connection to someone should be asked by mentee. Here is the problem; For many of us asking for an opportunity might be difficult! However, the book outlines four laws of super mentors, an easy to follow guidance for leveraging mentors differently. First, the law of right ask; "Make it specific. Make it simple. Make it schedulable. Explain the opportunity. Acknowledge their capacity." Second, the law of right people; "Find the people who have the power to transform your trajectory." Third, the law of right start; "Begin mentor relationships small. Take steps to make it super. Last law is about the right time; "Mentorship has seasons, so engage the ideal mentor at the right time in your life. Learn how to identify stages and mentors that can support you through them."



Progress in Global Photovoltaic and Renewable Energies

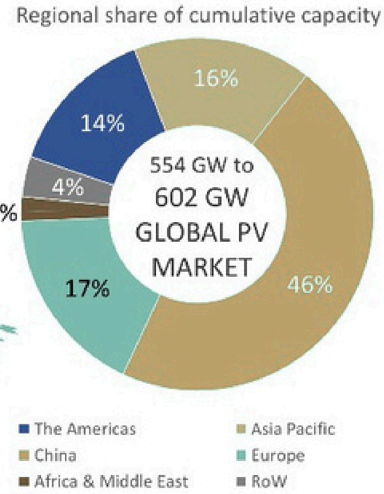
A Snapshot of Global PV Markets

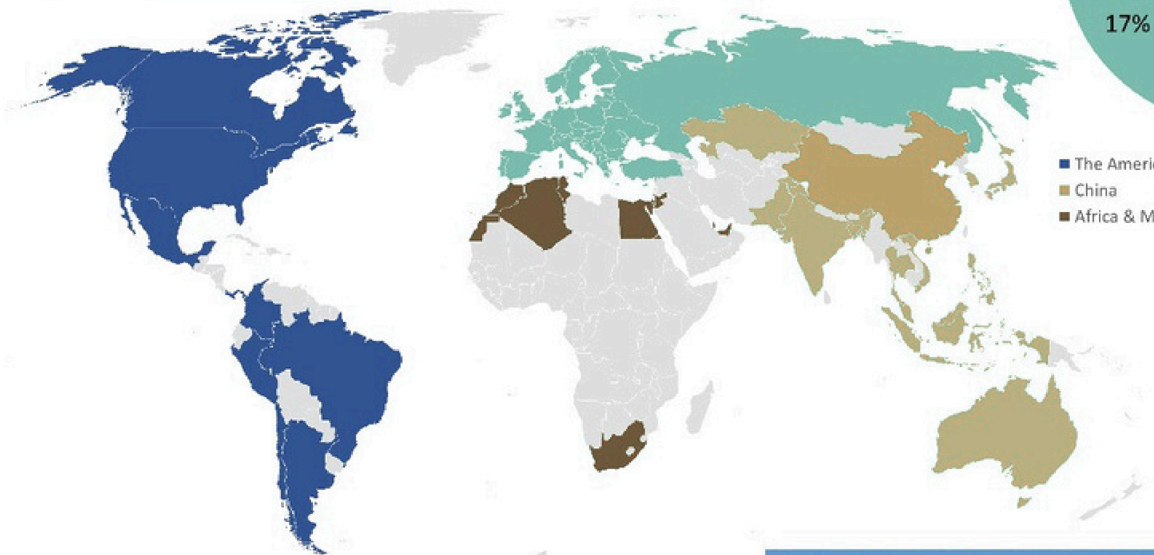
TOP PV MARKETS 2024

CHINA 309 GW to 357 GW

EU 63 GW

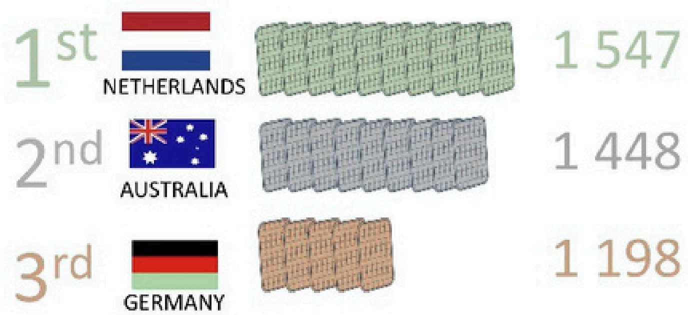
USA 47 GW



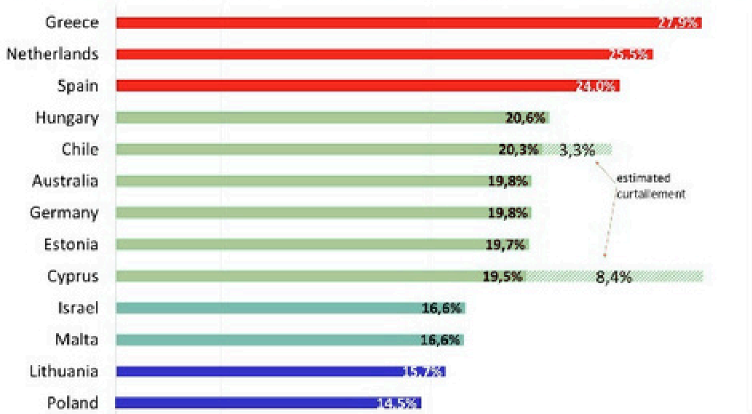


- **2 246 GW** were installed all over the world by the end of 2024
- **China** is the world's **#1** PV market
- **34** countries installed at least **1 GW** of PV in 2024
- **23** countries have installed at least **10 GW** of cumulative capacity at the end of 2024

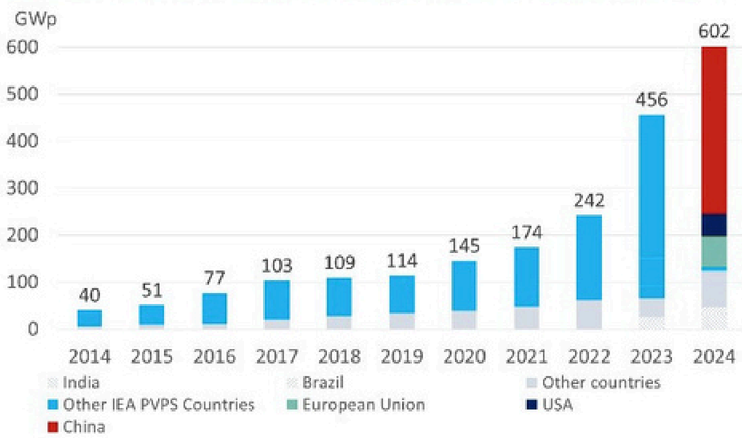
SOLAR PV PER CAPITA 2024 Watt/capita



COUNTRIES WITH HIGHEST PV PENETRATION



EVOLUTION OF ANNUAL PV INSTALLATIONS



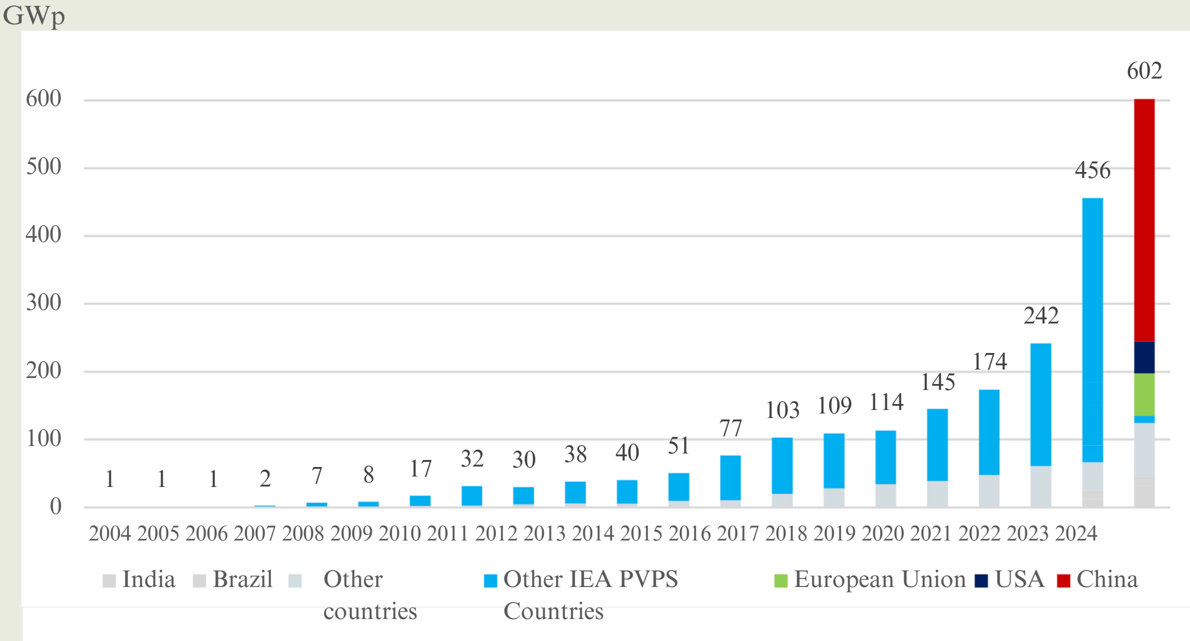


Figure 1: Evolution of Annual PV Installations. Source:https://iea-pvps.org/

Growth rates in individual countries remain subject to local policies and international market prices and considerable variations can be seen between countries and year to year. Whilst growth rates have slowed (but remain positive) in many markets, others have stabilised or contracted. The EU had low growth as continued expansion in Germany and France was balanced by slow-downs in Spain and the Netherlands. **The global cumulative installed** capacity reached 2.25 TW. It took more than 40 years to reach a cumulative capacity of 1.18 TW (in 2022), but just 2 years to double this. China now has nearly 50% of cumulative worldwide capacity.

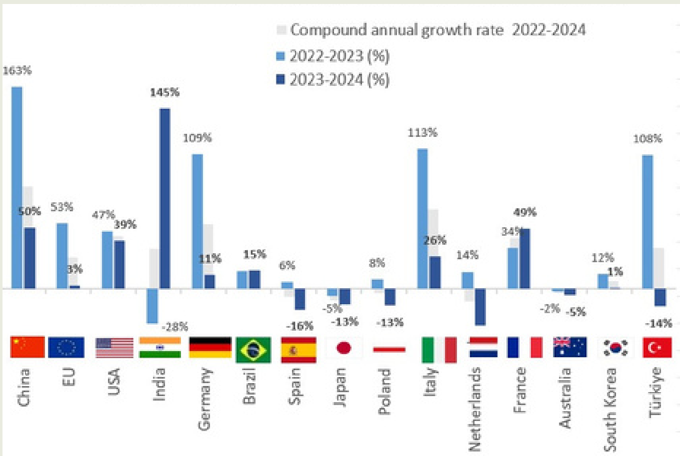


Figure 2: Evolution of New Annual Capacity in Major Markets. Source:https://iea-pvps.org/

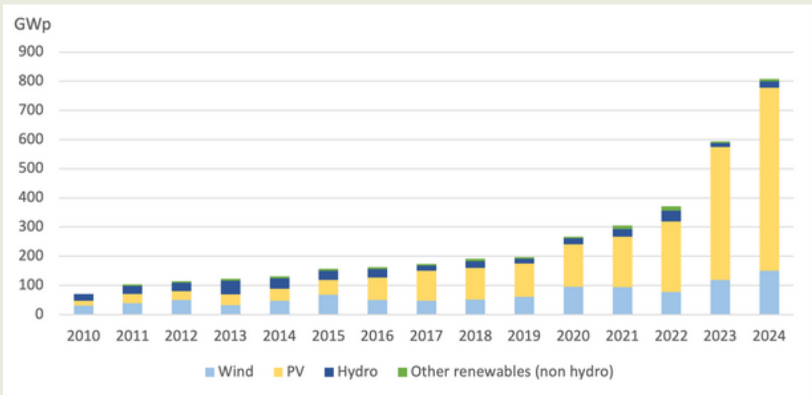


Figure 3: Evolution of Annaul Renewable Energy Installations: Source:https://iea-pvps.org/

References:

The report is from IEA PVPS Snapshot of Global PV Markets 2025 which is available at https://iea-pvps.org/snapshot-reports/snapshot-2025/

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Optical Strategies for Thermal Management in Photovoltaics

Photovoltaic (PV) technology continues to evolve rapidly, driven by the need for higher efficiency, longer lifespan, and cost-effective deployment. A persistent challenge in this domain is the self-heating of solar panels due to parasitic absorption of sub-bandgap (sub-BG) photons and inadequate thermal radiation. Elevated temperatures impair device performance, reduce energy yield, and accelerate aging processes.

Recent advances highlight the significant role of optical engineering in mitigating these effects. In particular, innovative strategies such as selective-spectral cooling and radiative cooling leverage electromagnetic principles to enhance thermal management. The work by Sun et al. (2017) provides a comprehensive exploration of these techniques, emphasizing their potential to improve PV operation without extensive modifications to existing modules.

PV Self-Heating

Under typical conditions, PV modules absorb approximately 80% of incident sunligh,however, 20% of incident sunlight is converted to electricity . A significant share, mainly due to free carrier absorption, defect states, and material imperfections, occurs at sub-BG wavelengths, are absorbed and converted into heat.

Furthermore, the thermal radiation emitted by the module surfaces is often limited by their optical properties. Many cover glasses and backsheet materials display less-than-ideal IR emissivity. As a result, these surfaces cannot effectively radiate away heat, exacerbating the temperature rise.

This combination of parasitic absorption and limited IR emission creates a thermal trap where the modules get hotter, which leads to a decrease in efficiency (since their semiconductor bandgaps decrease with temperature), and accelerates degradation mechanisms.

Optical-Based Cooling Methods

Addressing these issues requires control over the optical interactions within the module. The two main approaches are:

Selective-Spectral Cooling: This method aims to reflect sub-BG photons; those with energies below the semiconductor bandgap preventing them from being absorbed as heat. Using optical filters or wavelength-selective mirrors, modules can be designed to transmit the useful solar spectrum while reflecting the parasitic wavelengths into the environment. This approach capitalizes on the wavelength dependence of material absorption, just as quantum optical systems exploit spectral control to manipulate photon interactions.

Radiative Cooling: This technique enhances thermal emission by engineering the spectral and angular emissivity profile of the module surfaces, often via nanostructured coatings or photonic structures. Specifically, surfaces can be designed to exhibit high IR emissivity within the atmospheric transparency window, thereby radiating heat into the cold expanse of space. This process relies on principles like those mastered in quantum optics, where, unlike traditional blackbody emitters, engineered structures can produce spectral and directional emission profiles tailored for maximum radiative loss.

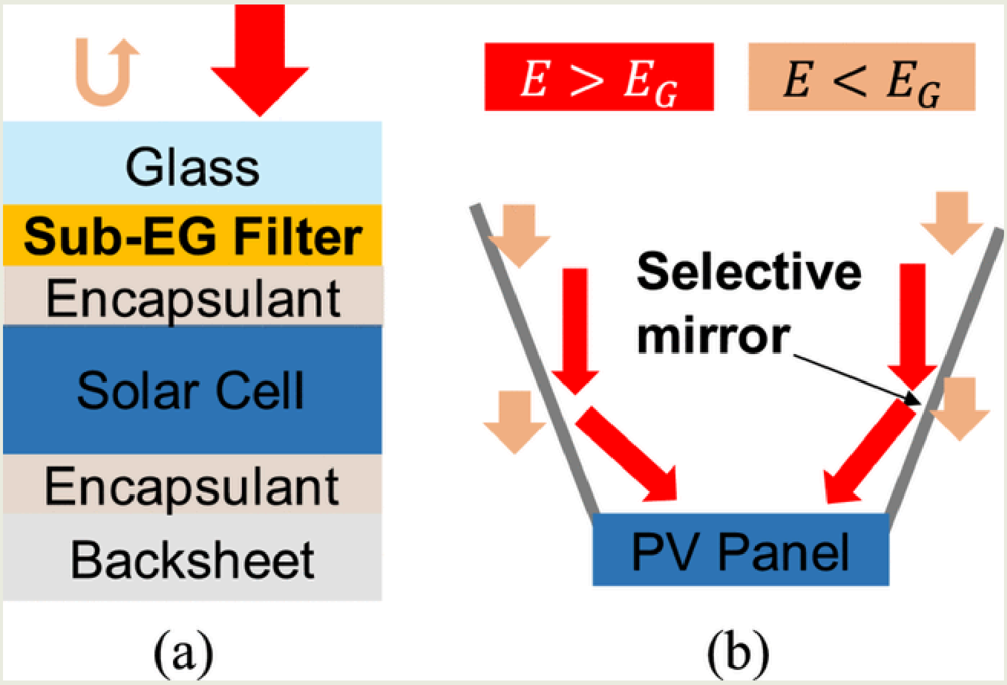

Figure 1. Possible implementations of selective-spectral cooling by using a reflective optical filter or wavelength-selective mirror reflector for LCPV. (a) Optical Filter. (b) Selective-Concentration.

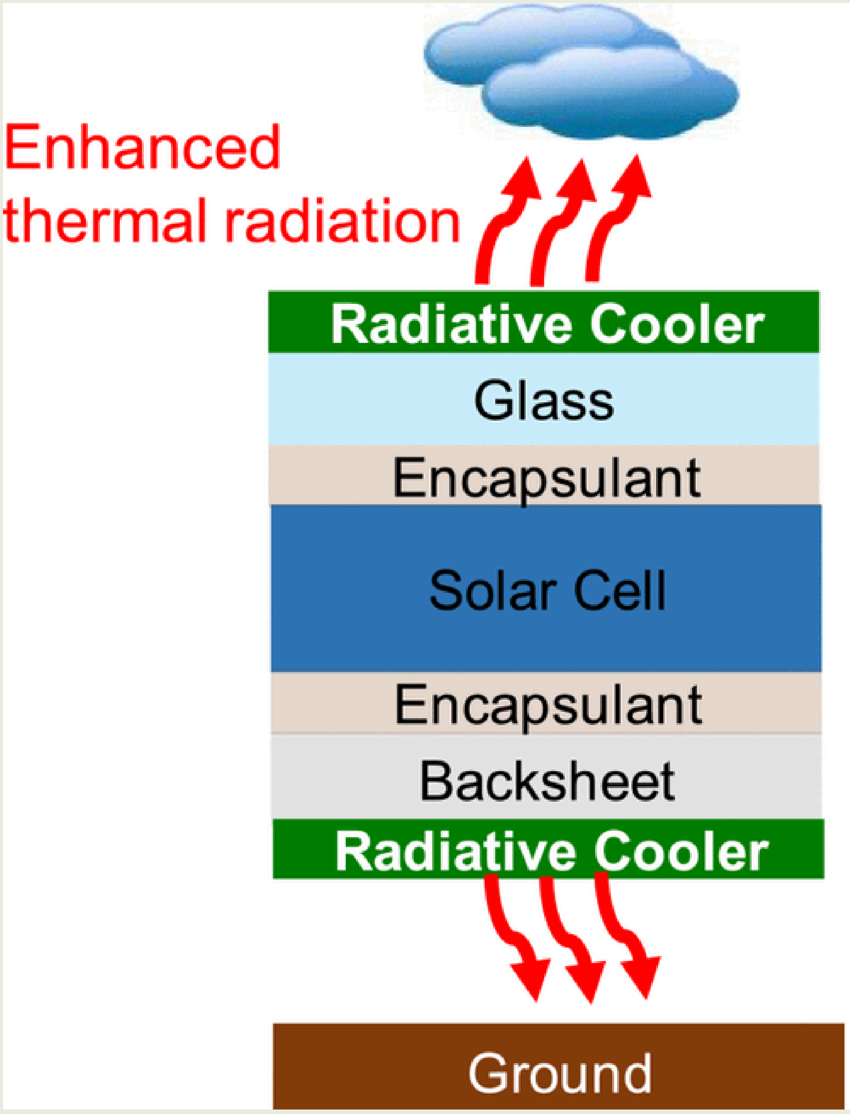

Figure 2. Schematic of a solar module with enhanced radiative cooling.

Results

Sun et al. (2017) highlight that both strategies can produce meaningful temperature reductions up to 10°C translating into a 0.5% increase in efficiency and extending the lifespan of PV modules. Such improvements are attainable through relatively straightforward modifications, such as adding optical filters or applying nanostructured coatings, thus offering a cost-effective pathway for existing PV installations.

Among these, selective-spectral cooling presents a promising route for terrestrial modules, given its compatibility with current manufacturing processes. Wavelength-selective filters can be implemented as thin-film coatings or multilayer dielectric stacks, designed to reflect sub-BG photons while transmitting the useful solar spectrum. This selective reflection reduces parasitic absorption and consequent heating without impeding light absorption in the active layers.Radiative cooling finds relevance in space applications or concentrated PV systems, where the absence of atmospheric convection favours IR emission.

Engineered surfaces with high IR emissivity in the atmospheric window can effectively radiate away excess heat into the cold universe, achieving passive cooling of the modules. Designing such surfaces necessitates a fine-tuned understanding of optical properties spectral emissivity, angular dependence, and nanostructure resonances that directly draw on electromagnetic resonances and interference effects. Photonic crystals, plasmonic structures, or multilayer coatings can be utilized to shape the spectral emissivity profile, echoing how quantum optical phenomena can control emitted spectra and angular distributions.

Potential Research Areas

The integration of these optical strategies opens exciting avenues for further research:

- **Developing tunable or dynamic coatings that adapt to environmental conditions, optimizing heat dissipation in real-time.**
- **Exploring nanophotonic structures that simultaneously serve as filters and emitters, exploiting resonances and coherence effects to maximize cooling.**
- **Extending these concepts to multi-junction and advanced PV technologies, where temperature effects are even more critical.**

For researchers in quantum optics, these strategies exemplify the profound potential of spectral and angular control of light, principles fundamental to our field, to solve pressing energy challenges.

Harnessing optics for thermal management of photovoltaic systems exemplifies the power of electromagnetic control in applied energy science. The techniques of selective-spectral and radiative cooling demonstrate how fundamental principlesnsuch as spectral selectivity, resonance, and directional emission can be harnessed for significant practical gains. As the field progresses, continued innovation at the intersection of nanophotonics, quantum optics, and energy conversion promises to unlock even more efficient and sustainable solar technologies.

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