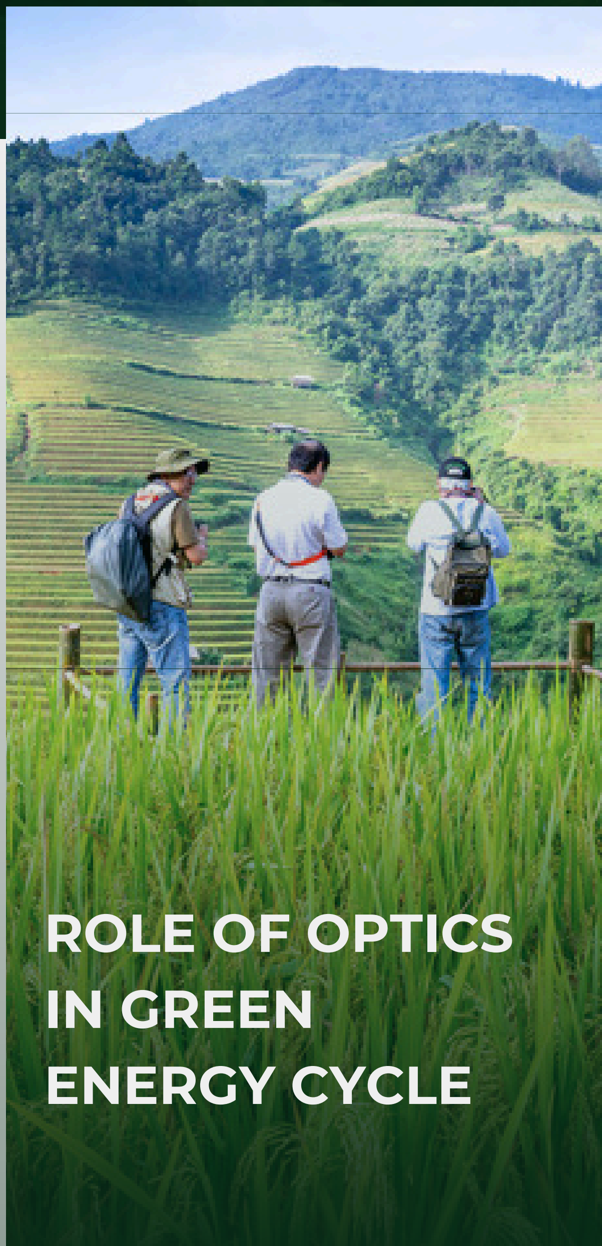
OPTICA
Advancing Optics and Photonics Worldwide

Optics for Energy

NEWSLETTER

CONTENT



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FOREWORD

Mission and Goals

The groups aims is to connect professionals and students in optics and energy through: Technical events ,Educational webinars, Networking activities, Social media engagement.
MUCH MORE would be possible with your contributions!

Meet the team

Chair
Dr. rer. Nat. Banafshe Zakeri
HySON Institute
zakeribanafsheh@yahoo.com

Vice Chair
A/Professor. Georgios Arnaoutakis
Hellenic Mediterranean University
arnaoutakis@hmu.gr

Event Officer
M.Sc. Idris Adeshina Sulaimon
Institut National de la Recherche Scientifique (INRS)
sulaimonidris61@gmail.com

Social media Officer
M.Sc. Rodgers Mutugi Gichuru
Multimedia University of Kenya (NIOL)
roycerodgers2@gmail.com

Webinar Officer
Prof. Ahmed Morshed
Ain Shams University
ahmed_morshed@eng.asu.edu.eg

OPENING MESSAGE

By Banafshe Zakeri

The upward spiral of progress

As I was reviewing some old publications to see where the role of optics began in green energy cycle, I found a very interesting term *"the upward spiral of technological progress",* and I gave it some moments of deep thought . Spiral has some specific elements that make its geometrical structure as it is. It has a center and some turns which render a helical form to it. If the whole scientific journey is like an endless upward spiral stair, what would define its center? The turns are obviously the redirections along the path and we all know it's often the case in scientific and technological developments that the initial assumptions might have needed a change which means inevitably taking a new direction. But I couldn't figure out what this magical center might be that guides all of those turns and redirections! Is it perhaps simply the demands of the world with the problems that need to be solved, or is it something much deeper, like the need of man's soul for perfection? I couldn't totally convince myself with any answer! Then I read the thoughtful "Inspiring story" of this month written by one of our committee members; Maybe, this center that makes man constantly moving upward is a combination of many different things; "An opportunity for thought", "making the most out of our time in this world", perhaps a need for perfection, or to add something meaningful to the world from the jar of our curiosity, but also "to see another version of ourselves that we can be proud of"! Whatever it might be, this magical center keeps us moving upward without even doubting whether there is something at the end!

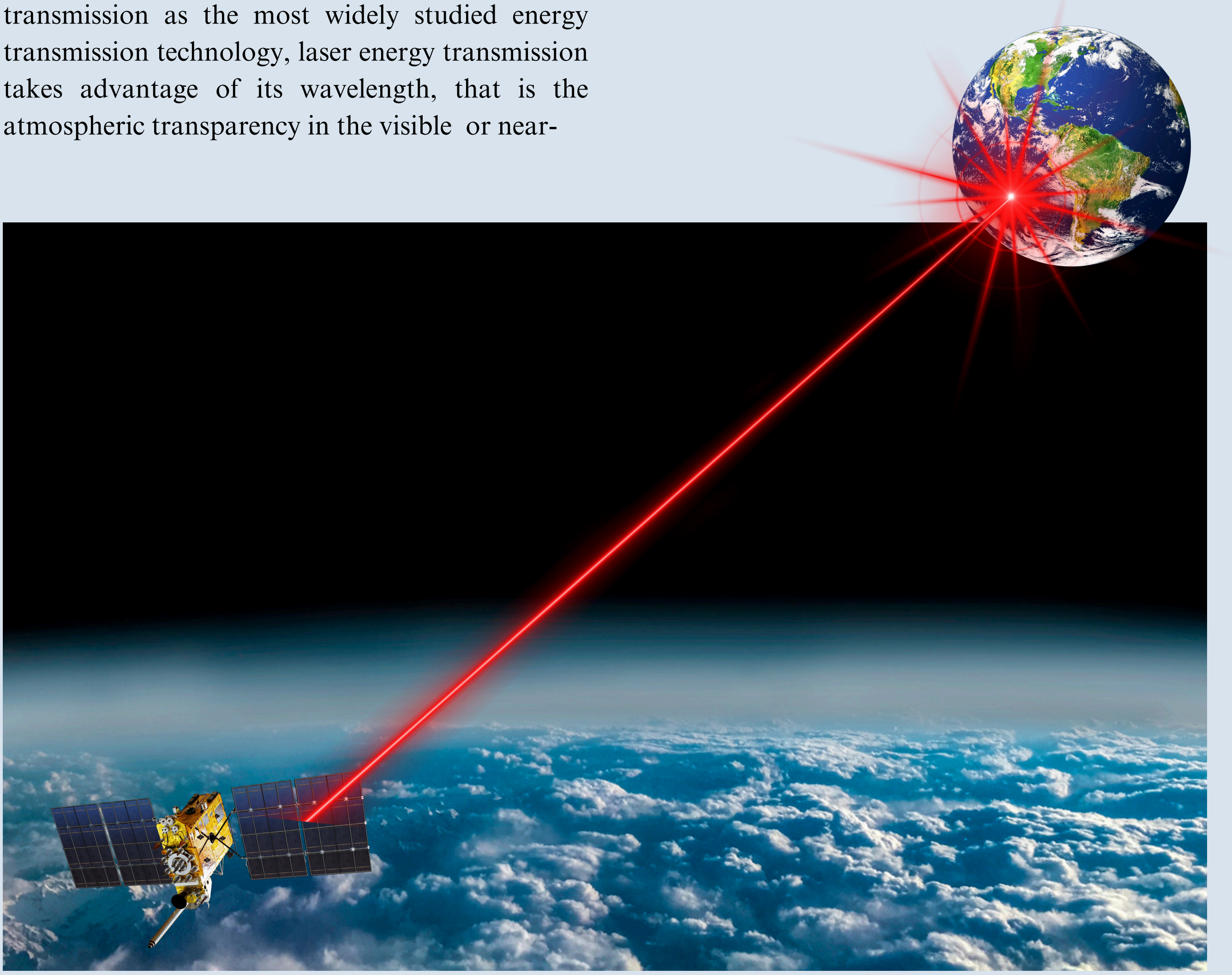
THE ROLE OF OPTICS

in green energy cycle

Energy transfer with laser

Efficient transfer of renewable energies especially over long distance requires technologies that enable less loss and high speed. Just as in renewable energy production, optics plays a vital role also in transferring the produced energy. Laser-based systems, for example, beam energy wirelessly to far locations either on the earth or even the moon. One potential application is space-based solar power. The concept of Solar Power Satellite (SPS) was introduced first by *Glaser* in 1968 as a vision of a sustainable, abundant source of energy to meet the world demands for energy[1]. A space solar power system can use both laser light or microwave produced by solar energy on a satellite orbitting the earth. They transmitt the energy to the ground where it can be used as power. Compared to microwave energy transmission as the most widely studied energy transmission technology, laser energy transmission takes advantage of its wavelength, that is the atmospheric transparency in the visible or near-infrared frequency spectrum[2] though it still needs to overcome the divergence of the beam and turbulence-caused intensity fluctuations. A research including both theoretical and experimental[3] study showed that a turbulence-robust transmission system not only requires laser waveforms that can be uniformly irradiated even under atmospheric turbulences but also a less affected light-receiving panel by variations in the amount of irradiation. Moreover, emerging technologies which decrease the total mass, cost and complexity of the entire system are the potential solutions for the realization of having a practical access to a non-depletable energy source .

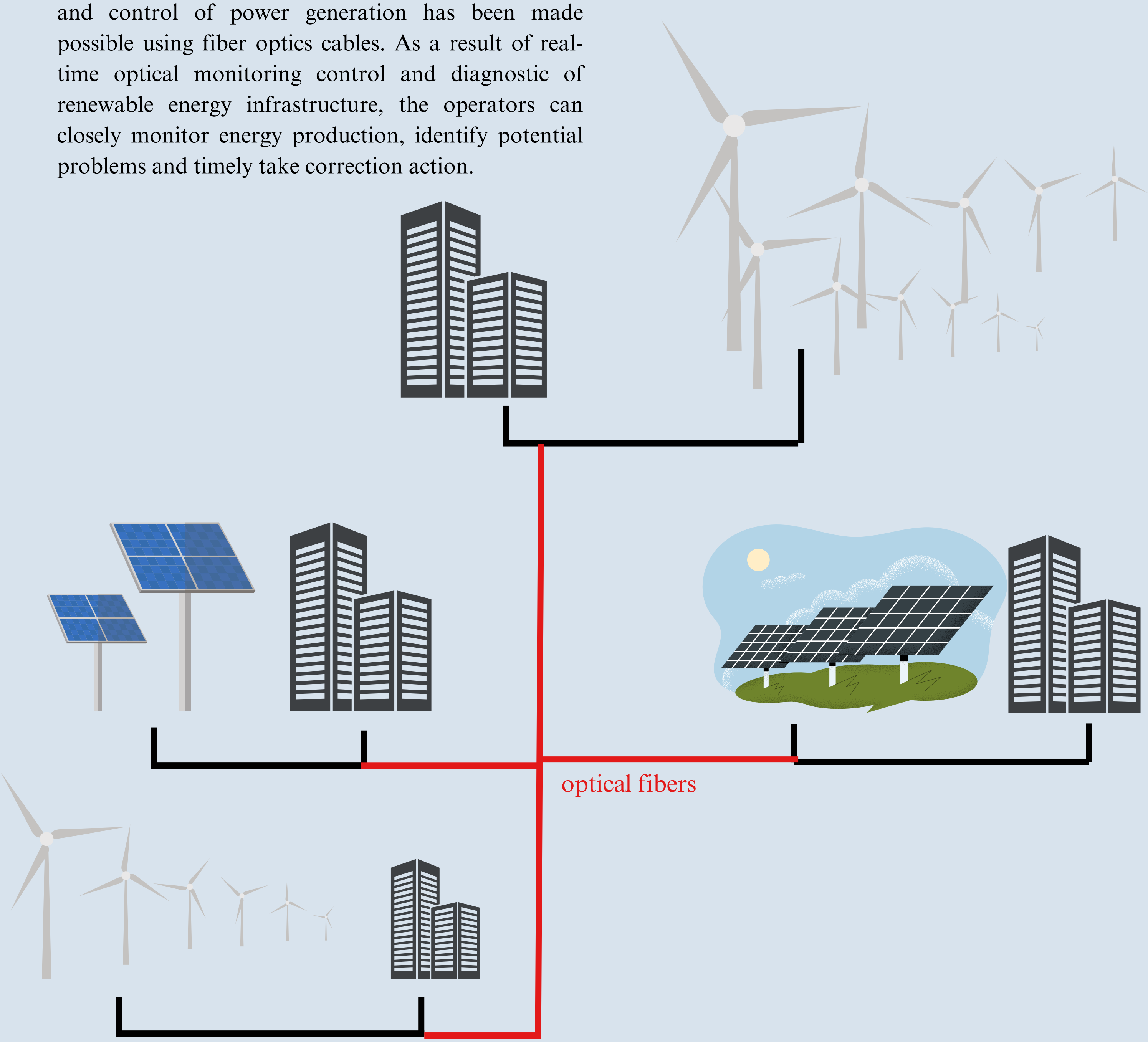
1. Peter. E Glaser, *Science 3859,* 1968
2. Leopold Summerer, Oisin Purcel, *ESA*
3. Natsuha Ochiai, et al., *NTT Technical Review* 22, 2024



Fiber optics: from power to data transfer

The infrastructure that enables the energy generator systems such as wind turbines or solar cells to perform optimally with high efficiency and minimized downtime requires predictive maintenance. Especially for long-distance energy transmission, an efficient communication between various components of the renewable energy system ensures an optimized performance. While wireless power transmission is facilitated by using lasers, optical fibers enable efficient and high-speed data transmission to manage renewable energy systems. The real-time monitoring and control of power generation has been made possible using fiber optics cables. As a result of real-time optical monitoring control and diagnostic of renewable energy infrastructure, the operators can closely monitor energy production, identify potential problems and timely take correction action.

Instead of having a central datacenter network which transfer power, a distributed network of datacenters can transfer data using optical fibers.



https://effectphotonics.com/insights/photonics-for-the-energy-transition/

Publications from TG members

The publications for this review were selected from the research of Optics for Energy Technical Group member, Dr. Dick de Boer, the principle scientist at Soluminous in Netherland.

Introduction

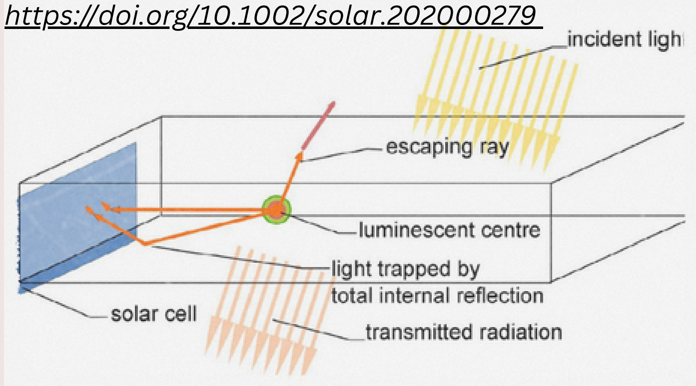
Luminescent solar concentrators (LSCs) are devices designed to collect and concentrate sunlight onto smaller and more efficient solar cells. LSCs offer a promising, cost-effective alternative to traditional solar panels, particularly for building-integrated solutions. As shown in the figures, they consist of a transparent light guide, typically glass or plastic, embedded with luminescent nanoparticles known as luminophores. The sunlight (1) that hits a LSC can have different fates; It can be absorbed and re-emitted at longer wavelengths by the luminophores (2), which is then guided to the edges of the device with total internal reflection (3) where photovoltaic (PV) cells convert it to electricity. It might be also lost through escape cone (4) in which photons emitted outside the critical angle escape the device leading to power loss. Another type of loss in LSCs arises from reabsorption of emitted light by other luminophores before reaching PV cells. Efforts to optimize LSCs have focused on the properties of luminophores including their emission patterns and absorption characteristics.

Recent advances in nanotechnology have introduced nanocrystal, often called quantum dots (QDs), with nonspherical shapes such as nanorods which emit light anisotropically. That is, their emission intensity varies with direction. This directional emission potentially reduces scape cone losses when nanorods are properly aligned. In reality, a high lost estimation of 45-55% of all absorbed energy should be considered for the loss through scape cone for a luminophore that emits light isotropically. Some research groups in Netherland are working on theoretical and experimental design of various nanocrystals for improving LSCs efficiency.

Simulation

In a theoretical analysis conducted by Monte Carlo ray-tracing simulation, different nanoparticles as luminophores were compared regarding the effect of their anisotropic emission and alignment on LSC performance. In the simulation, the anisotropy defined by nonspherical shape of the NRs and the effect of

https://doi.org/10.1002/solar.202000279



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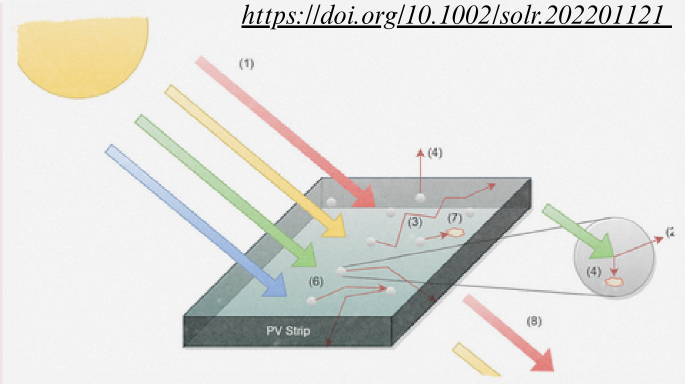
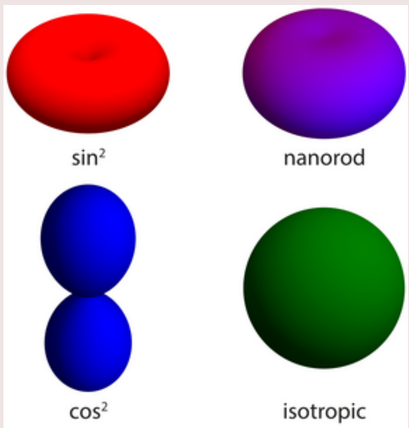


NRs alignment based on the experimental demonstration of their alignment on the efficiency of LSCs was investigated. Experimentally, NRs lie flat on a surface after solvent evaporation. Vertical alignment is also possible only in solution and under high electric field. Different emission patterns of $\sin^2$, $\cos^2$, along with isotropic and realistic NR emitters each corresponding to a particular alignment were examined by the simulation. Comparing to the



https://doi.org/10.1002/solar.202000279

constant emission of an isotropic emitter, the emission for the rod-shaped emitter perpendicular to the plate has a $\sin^2$ pattern with the dipole transition parallel to the long axis and a $\cos^2$ pattern when the dipole transition is perpendicular to the long axis. A real NR emitter will emit with a combination of $\sin^2$ and $\cos^2$ patterns. The escape fraction, defined as the fraction of emitted intensity by the luminophore that escape from the total internal reflection and therefore not capable of reaching to the edges of LSC, was calculated for different alignment of the NRs. “Compared to the isotropic emitter case, the escape fraction for rods aligned perpendicular to the plate is lower, but it is higher than for the $\sin^2$ emitter case. For rods aligned parallel to the plane this is reversed, but with lower relative difference”, showed the result of the calculation.

Three types of nanocrystals were examined in this theoretical study to compare the effects of reabsorption and anisotropy; Core-only CdSe QDs with high reabsorption and nearly isotropic emission, CdSe/CdS Dot-in-Rod NRs with anisotropic emission and small reabsorption, and Mn^{+2} -doped ZnSe QDs with no reabsorption. The finding indicates that while proper nanorod alignment enhances photon retention, reabsorption remains a critical limiting factors. While aligning nanorods can reduce escape cone losses, the main challenge is reabsorption, which can drastically lower useful light emission—sometimes by over 50%.

The study emphasizes that improving material properties, such as increasing the Stokes shift (the gap between absorption and emission wavelengths), is more effective than merely optimizing alignment. Employing coating techniques and wavelength-tunable materials further minimize reabsorption.

Balancing anisotropy and reabsorption

Anisotropic emission from nanorods offers promising avenues for increasing efficiency, but it must be combined with strategies to minimize reabsorption. A holistic approach will maximize LSC performance. A combination of nanocrystal shape control and material engineering with low reabsorption characteristics holds the key to developing high-efficiency LSCs. Optimizing luminescent nanoparticles for solar cell concentrators requires balancing reabsorption and anisotropic emission. While minimizing reabsorption offers the greatest potential for efficiency gains, leveraging anisotropic emission patterns can further enhance device performance. The path forward lies in a comprehensive approach that integrates advanced material design with strategic nanopareticle orientation. Moreover, in a real-life daily scenario, many other factors and conditions should be taken into account for an efficient outdoor perfomance of LSCs.

Test setup for outdoor 1-year performance of LSCs based on QDs, *https://doi.org/10.1002/solr.202201121*

Publication Review

Advanced Functional Optical Fiber Sensors for Smart Battery Monitoring

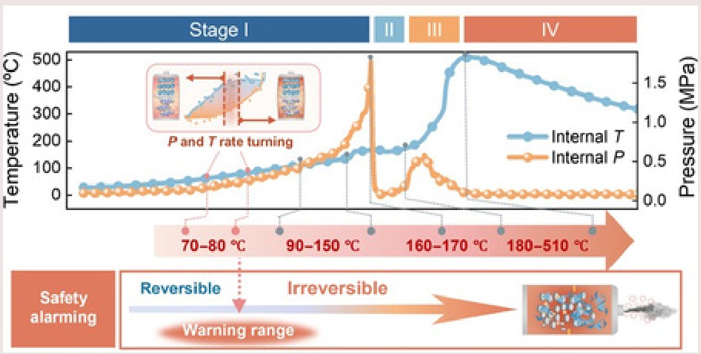
Authors: Z. Liu, et al.

Introduction

With the increasing dependence on batteries as essential components for renewable energy systems, portable consumer devices and electrical vehicles, techniques to improve their performance and ensure their safety operation are becoming more important than ever. The wide spread of Lithium-ion batteries (LIBs) and the reported events of battery thermal run-away events push hard towards the development of innovative methods suitable to probe the states of batteries and predict their future behaviour. As such, the real-time in situ monitoring of the physical/chemical state within the battery "black box" is critical to improving battery performance and safety. This article summarizes the recent advances in optical fiber sensing technology for battery temperature and mechanical stress/strain monitoring with an outlook on the future challenges and development of smart batteries.

Temperature Monitoring

As the operating temperature of a battery has a direct impact on its performance, lifespan, and safety, monitoring of battery temperature is a vital role in battery management systems (BMS). Temperature changes at the surfaces of LIBs have been precisely detected using optical fiber Bragg gratings (FBGs) which were found to provide a much more accurate response compared to standard commercial thermocouples (TCs). In addition to monitoring the surface temperature of batteries, the inert nature of optical fiber sensors has successfully enabled their embedding into the structure of batteries, without affecting battery performance, to probe their internal temperature as well.



Fiber-optic sensor decoding the thermal runaway of a battery from reversible to irreversible stages.

A comparison of the external and internal temperatures of a battery would then reflect its true condition of operation. Both FBGs and Rayleigh scattering-based distributed fiber-optic sensors were used to achieve accurate temperature distribution probing and evolution mapping, without compromising the electrochemical performance of cells.

Stress/Strain Monitoring

Monitoring of the strain in batteries revealed the repeated expansion and contraction of the battery over charging – discharging cycling. Both the external and internal strain and corresponding stress or pressure were detectable using optical fiber sensors. A hybrid sensor consisting of FBG and Fabry-Perot (FP) cavity was embedded into a lithium-ion cell in a non-invasive manner, enabling in situ measurements of internal strains and temperature fluctuations at different locations of the battery.

Monitoring Different Systems

Battery systems other than LIBs, have also been probed with optical fiber sensors. The results validate the importance of optical fiber sensors in monitoring the structural changes and working mechanism of different cell structures.

Outlook

Optical fiber sensors offer unique advantages over traditional BMS in the field of battery safety monitoring. In addition to capturing the characteristic information at the external battery surface, optical sensors can also be non-destructively embedded inside the battery for real-time monitoring of electrochemical reaction processes. The research results demonstrate the important role played by optical sensors in the field of battery monitoring and provide a valuable tool for the in-depth exploration of the electrochemical evolution mechanisms inside batteries. With the utility of optical fiber sensors in detecting battery temperature and stress/strain parameters, encompassing both internal and external metrics, fiber sensors bring new opportunities in optimizing battery operation and safety detection of different energy systems.

https://doi.org/10.34133/energymatadv.0142

Inspiring story: A voice from the future

By Georgios E. Arnaoutakis

Alex was a curious and studious 1st class student in Science, Technology, Education, Art and Mathematics. From his first years in school was easily achieving top grades and was well known by his peers and teachers for his out of the box thinking. He was easily accepted to study his major at the university, but after leaving high school, he slowly started losing interest in the subject. The classes, however, were mandatory to get his cherished degree, so indeed he had to make an effort and joined the class each day. Sometimes he thought he didn't have to go through this, maybe there was an escape route to do something different.

One night he couldn't sleep. All the thoughts were buzzing inside his head. He decided to go out for a stroll to his favorite place, the beach. He was walking and kicking stones in the water, while trying to get rid of these bloody heavy thoughts. Suddenly, a flash of light appeared in front of him. The light was so intense he couldn't see past his feet. Then a voice started calling: "Alex, Alex", the person called and a familiar face appeared.
"I know you" Alex said, "You look like me, but your hair is white"
"Follow me" the person said, "I have to show you".
The person took him back to school. He saw himself going to the class.
Alex asked him: "What am I doing there?"
The person said: "These years, the student years, are some of the best moments in your life. They were surely some of the best years of my life. I had the opportunity to learn something new, to dedicate some years of my life into extending my understanding by delving into a specialized field of science. What was more fun was that I was not alone, I could do so with several other like-minded people of my age. We had good fun studying with these friends and we are still in touch. I was definitely privileged with this opportunity, while many peers quit early and did not have the chance of getting, or did not choose to take, this education train.
I was saying to myself, how can I miss this opportunity? How can I waste my time and not make the most out of it, to make the most of my time in the class, in each assignment or exam, an opportunity for thought, in each coffee meeting with colleagues. Every single case, every single piece of work and piece of interaction was adding to my thinking, adding to my future professional, but mainly, mature self. How can I not strive to make the most out of it, squeezing every little moment of these years?"
He paused for a moment, as if he was watching those years as a movie in far distance!
“This is really what an investment for the future is, you dedicate some of the young years instead of wasting it to endless instant gratification. I say endless, but that means there should be time in these years to enjoy yourself as well, to spend time with family or just take a break from focused attention and studying something intensely. There would be time for this, there always is, for two beers after doing the important things, the crucial, the familiar and friendly things in your everyday life. And if you do this, you will see another version of you that I bet you can be proud of! You would be amazed at where you started, what you went through and what you achieved!”

Alex suddenly woke up to the sound of the crashing waves. He was back home not far from the beach. But his mind could not forget what the person said, what the voice of the future was...

What about your story? Share it with us with a Click & drop

Coming soon

Industrial Webinar

on

“Advanced Photoluminescence Spectroscopy & Microscopy for Solar Cell Materials”

by Dr Stuart Thomson

Dr Stuart Thomson is Head of Product & Applications at Edinburgh Instruments. He received his PhD from the University of St Andrews in Organic Optoelectronics. Dr. Stuart joined Edinburgh Instruments in 2017 as an Applications Scientist, specializing in photoluminescence spectroscopy of semiconductors. In his current role, he leads the product management and applications team for Edinburgh Instruments' optical spectrometers and microscopes.

The race to develop efficient, stable, and cost-effective solar cells depends on understanding materials at the microscopic and molecular levels. In this webinar, Dr. Stuart will explore how photoluminescence spectroscopy and microscopy can be applied to analyze and screen potential solar cell materials. He will discuss techniques such as time-resolved photoluminescence, quantum yield measurements, and fluorescence lifetime imaging microscopy (FLIM) - each offering unique insights into material quality, defect states, and charge carrier behavior. Join us to learn more on the advanced characterization of solar cell materials

The registration link and time will be shared later

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