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# KAUST Solar Center News

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# Message from the Associate Director

*It is my pleasure to welcome you to the 2nd issue of our biannual KSC Newsletter. With this Newsletter, we aim to provide a glimpse of the Center's recent research activities and to share important updates with you.*

*This issue features the Center's research on solar-thermal clean water production, introduces our new PECVD system for fabrication of high-efficiency silicon solar cells, and discusses new approaches for renewable hydrogen generation.*

*I believe we have exciting times ahead of us. As of July 2018, the Center will evolve further towards more technology-oriented research. This important development is marked by the kick-off of three new CARF (Center Applied Research Fund) projects, dealing with building-integrated organic PV, high-efficiency and stable silicon/perovskite tandem devices, and highly-conductive and transparent interlayer materials for electronic devices. In addition, the Center will support three exciting exploratory CARF projects on solar steam generation, rectennas for energy generation, and impact of defects in metal halide perovskite semiconductors.*

*We continue to strive for new research areas and researchers that complement the Center's existing research and technology development portfolio. With the current lab renovation coming to an end, the acquisition of advanced tools for our Center-supported technology projects, and a now fully-staffed lab operations team, we are all set to fulfill our mission.*

*With this, I would like to close, but not without expressing my sincere thanks to all our Center members and external research partners who are committed to contributing to the Center's success. I hope you enjoy reading the 2nd issue of the KAUST Solar Center Newsletter.*

**Frédéric Laquai,**
Associate Director of KAUST Solar Center
Associate Professor of Material Science and Physics

"...we have exciting times ahead of us. As of July 2018, the Center will evolve further towards more technology-oriented research."

## KSC Research Highlights

# The rejuvenation of solar-thermal based clean water production —By Renyuan Li

Professor Peng Wang (left) and Renyuan Li (right) are working on photothermal materials and their applications in atmospheric water harvesting.

Given the vast abundance and inexhaustibility of sunlight, tapping into solar energy to produce clean water is a viable solution to the current global challenges of fresh water scarcity and clean energy shortage. Solar distillation is an ancient technology but has been rejuvenated in the past 4 years by nano-enabled photothermal materials. In particular, the zero $CO_2$ emission feature of solar distillation for seawater desalination is very appealing and relevant and it has the potential to lead to a zero-liquid-discharge seawater desalination. Categorically, solar water evaporation is an integral part of a solar distillation. In a typical solar distillation apparatus, sunlight is captured and converted to heat by photothermal materials and the heat is used to generate water vapor which is subsequently condensed to produce fresh water.

Renyuan Li, a PhD student in Prof. Peng Wang's group, is working on photothermal materials and their applications in atmospheric water harvesting. Instead of going after new materials, his attention has been attracted by some of the existing materials with low-cost and high abundance. He believes that the full potential of many common materials has not been fully explored. He recently reported the use of common anhydrous salts together with sunlight for effective harvesting of water vapor from very dry air with relative humidity as low as 15%. He is now working on significantly improving the water production capacity of these materials.

The solar spectrum at sea level ranges from 280 to 2500 nm. In order to capture the solar energy to a great extent, a good photothermal material for solar water evaporation and distillation is needed which absorbs widely within the entire solar spectrum. The development of effective photothermal materials has been a very active playground for nanomaterials in the past 4 years. A variety of materials with strong light absorbance in the wide solar spectrum have been investigated and optimized, including carbon-based materials (e.g., carbon black, graphite, graphene, graphene oxide, carbon nanotubes), metals (e.g., gold, silver, aluminum, germanium nanoparticles), black metal oxides (e.g., $Ti_2O_3$, $MoO_3$, $CuCr_2O_4$, $CuFeMnO_4$), polymers (e.g., dopamine, polypyrole), among others. The state-of-the-art photothermal materials are able to harvest the full solar spectrum and convert it to heat with extremely high efficiency. This has effectively shifted much of the research effort to heat management during the water evaporation and condensation processes. Photothermal devices with heat loss management strategy have evolved fast, leading to steady and significantly improved energy efficiency, especially of the solar water evaporation process. In contrast to the vast volume of research activity directed towards solar water evaporation, little research effort has been devoted to water vapor condensation.

Our group only began research into photothermal materials in early 2015 but ever since has worked passionately on photothermal nanomaterial selection and optimization along with photothermal structural designs. Like many others, our attention so far has been on solar evaporation. Our first paper on this topic was in July 2015 in which we reported a solar-to-water-evaporation efficiency of 56%. In our latest work in April 2018, we achieved close to 100% energy efficiency. In parallel, we have paid attention to salt and bio-fouling issues of photothermal materials during practical applications and identified or developed a few photothermal materials which can be thermally or mechanically cleaned once fouled. While making efforts in water condensation and all-in-one solar distillation device fabrication, we have very recently extended our photothermal research into new applications, including harvesting water vapor out of dry air, sunlight-assisted highly viscous oil spill cleanup, smart windows, etc.

Looking forward, in both solar evaporation and distillation applications, we consider device design and fabrication now to be more important than finding new photothermal materials unless the new materials can provide other new perspectives in practical applications, such as easy recycling, thermal stability, robustness, flexibility, longevity, etc. In solar distillation devices, more research efforts are highly warranted on water condensation and collection sides and more effective recovery of the latent heat of water condensation will boost their energy efficiency significantly. The future breadth of applications for both solar evaporation and solar distillation is expected to widen.

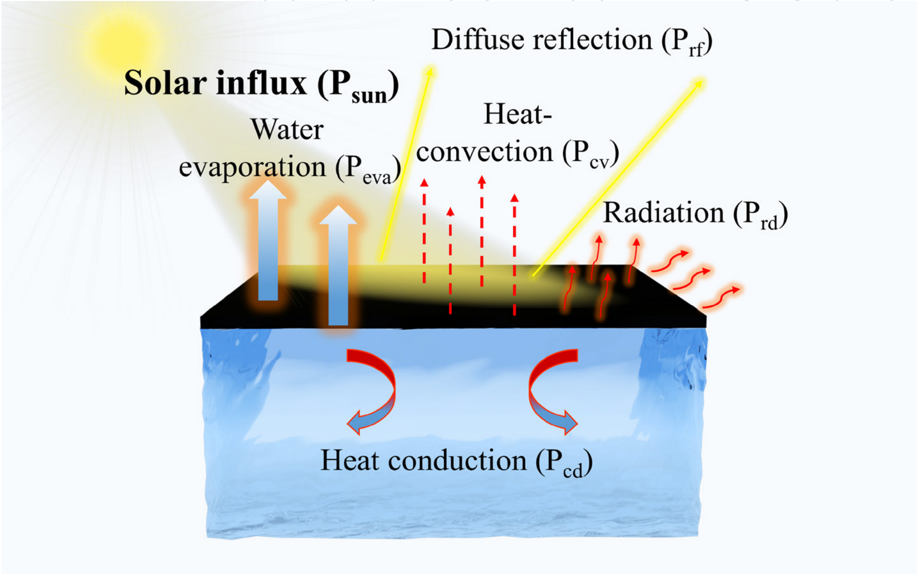



**Figure:** Energy flow diagram of a typical solar-driven water evaporation system

# OCTOPUS II: An Advanced PECVD System for High-Efficiency Silicon Solar Cells

## —By Xinbo Yang

Xinbo Yang joined the KAUST Solar Center in September of 2016 as a Research Scientist in Professor Stefaan De Wolf's group. He obtained his Ph.D. in Materials Science at the Chinese Academy of Sciences in 2010. He was then a JSPS fellow at Tohoku University, Japan. Next, Xinbo spent four and a half years at the Australian National University as an Australian Renewable Energy Agency (ARENA) fellow before joining KAUST. Xinbo's research is focused on high-efficiency silicon solar cells, using novel heterojunctions and contacts, as well as perovskite/silicon tandem solar cells.

High-efficiency silicon heterojunction (SHJ) solar cells (Fig. 1), which use a crystalline silicon (c-Si) wafer as an optical absorber and thin-film layers

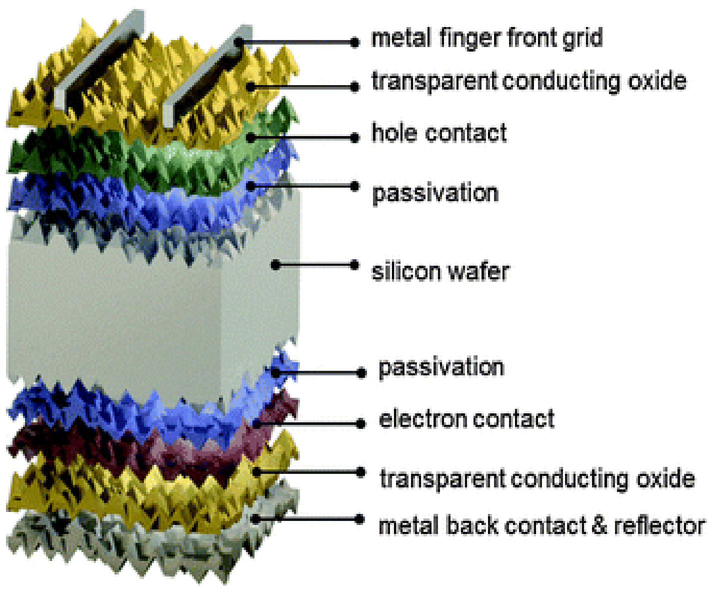
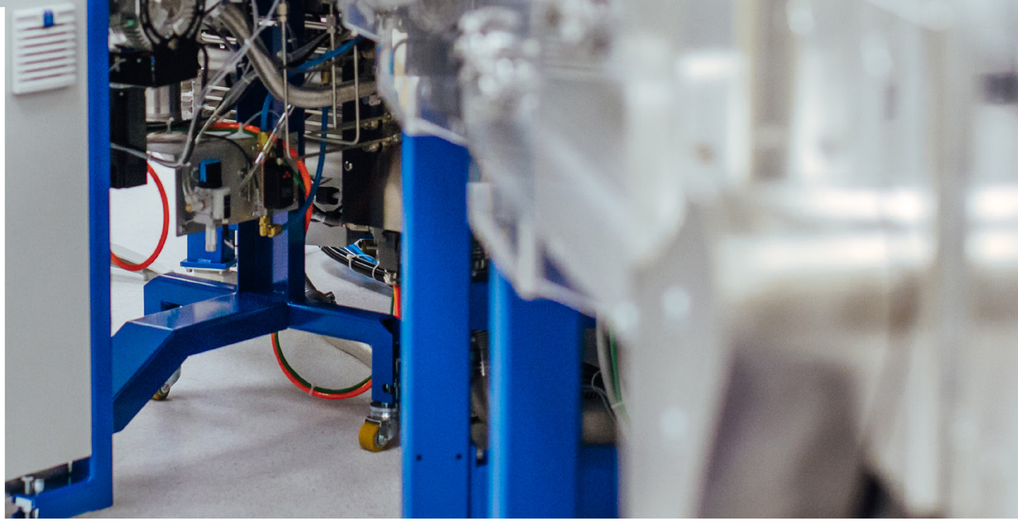



**Figure 1:** Schematic of the components of a silicon heterojunction cell, as published in Energy Environ. Sci., 2016,9, 1552-1576

Dr. Xinbo Yang operating the Octopus II, a multi-chamber plasma-enhanced chemical vapor deposition (PECVD) system, a key tool for silicon heterojunction solar cell fabrication

to form their electrical contacts, have the potential to gain a substantial share in the commercial photovoltaic (PV) market in the future. Currently, the world-record efficiency of 26.7 % is achieved with SHJ technology by placing both contacts in an interdigitated back-contact design. The KAUST Photovoltaics (KPV) Lab, led by Prof. Stefaan De Wolf, which is part of the KAUST Solar Center (KSC), is dedicated to the development of high-efficiency silicon-based solar cells, using SHJ solar cells as a core technology, and to tailoring such solar cells specifically for use in hot and sunny climates.

Recently, an advanced plasma-enhanced chemical vapor deposition (PECVD) multi-chamber cluster system (OCTOPUS II from INDEOtec in Switzerland, Fig. 2) has been installed in the cleanrooms of KSC. This system is specially designed to deposit thin-film contacting layers onto c-Si wafers

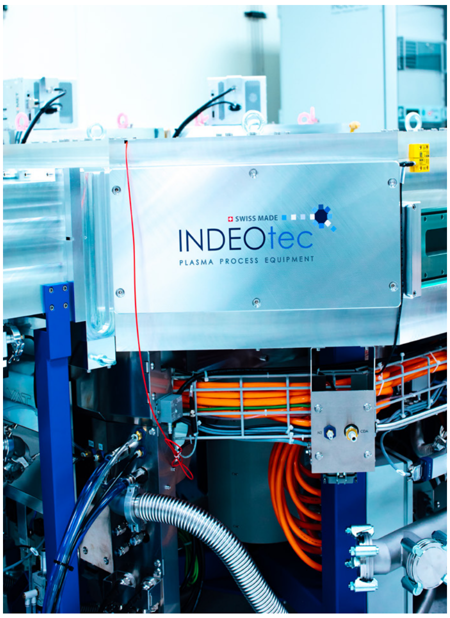



**Figure 2:** The advanced PECVD system: OCTOPUS II

for the purpose of fabricating high-efficiency SHJ solar cells. For this, PECVD amorphous silicon thin films, as well as physical vapor deposited (PVD) thin transparent conducting oxides (TCO) and metals, can be prepared in many dedicated process chambers which are all connected to a central transport chamber in a cluster design. Three low-temperature (≤ 280°C) PECVD deposition chambers are specially designed for amorphous silicon (intrinsic, or p- n-doped) thin film deposition. One high-temperature PECVD chamber (≤ 450°C) is suitable for dielectric thin film deposition (e.g., silicon nitride, silicon oxide, silicon carbide). The linear PVD chamber features many targets on both the top and bottom, designed for TCO (e.g., indium tin oxide, ITO) and metal (e.g., Ag) deposition. The load lock is capable of loading 24 pieces of 6-inch silicon wafers at a time and allows co-deposition of 4 of such industrially-sized wafers. This deposition cluster is capable of sequential deposition of different types of thin films without breaking the vacuum, which is essential for the development of high-efficiency SHJ solar cells. Overall, this system combines excellent flexibility, while being fully compatible with the industrial silicon solar cell standards. It is, therefore, the ideal platform for the research activities targeted by our group, including the development of perovskite-based tandem solar cells. This deposition cluster also acts as a key enabler for industrial collaborations.

Prof. De Wolf believes that with this advanced system, SHJ solar cells with an efficiency of > 25% can be made with a simple fabrication sequence at a low cost.

Silicon solar cell module prices, installed system costs, and the levelized cost of electricity (LCOE) in Saudi Arabia are expected to decrease by introducing this SHJ technology.

Moreover, this technology is the perfect choice for hot-climate countries. Solar energy will be competitive for residential applications in Saudi Arabia without government subsidies.

# A new approach for renewable hydrogen generation —By Jan Kosco

KSC PhD student Jan Kosco preparing organic materials and architectures for photocatalytic applications

Jan Kosco completed his chemistry degree at Imperial College London in May 2016 and joined the McCulloch group at KAUST in August 2016. Here he is designing organic materials and architectures for photocatalytic applications.

Solar energy is booming. As prices have dropped, the number of solar photovoltaic (PV) installations is rising exponentially. This is a good thing as solar energy along with other renewables can decrease the world's dependence on fossil fuels and mitigate many of the problems that come with it. However, it is difficult to use PV to completely replace the electricity that is currently generated from fossil fuels. This is due to a mismatch between the times when solar energy is produced, and when it is needed. In most countries, peak electricity consumption is in the mornings and evenings, but peak production is at mid-day. Similarly, in countries outside of the tropics, peak production is in summer, but peak demand is in winter.

Batteries can balance the daily cycle of supply and demand, and large grid-connected installations are already being deployed in several countries including the US and Australia. However, batteries alone cannot balance the annual swings in supply and demand. For this a higher capacity, longer-term storage solution is required.

One option is to use solar energy to produce a fuel, which can be stored indefinitely and used when needed. The simplest fuel to produce is hydrogen, which can be made by splitting water either thermally, electrochemically, or photoelectrochemically. Upon burning, hydrogen returns to water, providing no direct greenhouse gas emissions.

In photoelectrochemical water splitting, light is harvested by a semiconductor and the generated charges are directly used to split water. If the semiconductor is fabricated into nanoparticles, it can directly be added to water, and produce hydrogen and oxygen whenever it is illuminated (see figure). If efficiencies rise, this technique has the potential to significantly lower renewable hydrogen production costs. Current photoelectrochemical systems have very low efficiencies due in part to poor visible light absorption by the semiconductors used. Addressing this issue is the subject of a joint research effort between the McCulloch group in the KSC and the Takanabe group in the KAUST Catalyst Center, where the visible light absorbing polymer nanoparticles are being developed for photoelectrochemical water splitting. The work involves processing semiconducting polymers synthesized in our group into colloidal nanoparticle suspensions in water. The hydrogen evolution rate of the suspensions is then measured under illumination and in the presence of a suitable catalyst and sacrificial hole scavenger. Polymers with a range of energy levels are being explored to determine the optimal energy level positions for water splitting in these systems. Current work is focused on enhancing the efficiency of the hydrogen evolution reaction using catalyst decorated organic semiconductor nanoparticles.

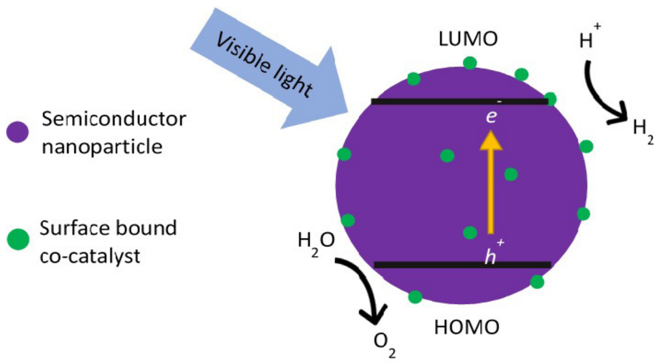


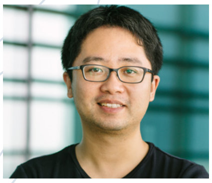

**Figure:** Schematic representation of photoelectrochemical water splitting at a polymer nanoparticle surface.

Recent Ph.D. Graduates

# Federico Cruciani, Ru-Ze Liang, Sara Abbas, Maxime Babics, and Muhammad Rizwan Khan Niazi

*Federico Cruciani*

Dr. Federico Cruciani defended his Ph.D. dissertation entitled, 'Donor and acceptor polymers for bulk heterojunction solar cell and photodetector applications' under the supervision of Prof. Pierre Beaujuge.



*Ru-Ze Liang*

Dr. Ru-Ze Liang defended his Ph.D. dissertation entitled, 'Device Strategies Directed to Improving the Efficiencies of Solution-Processed Organic Solar Cells' under the supervision of Prof. Pierre Beaujuge.

*Sara Abbas*

Dr. Sara Abbas defended her Ph.D. entitled, 'Solution-Processed smart window platform based on plasmonic electrochromics' under the supervision of Prof. Aram Amassian.

*Maxime Babics*

Dr. Maxime Babics defended his Ph.D. entitled, 'Solution-processed molecular organic solar cells: relationship between morphology and device performance.' This work was supervised by Prof. Pierre Beaujuge.

*Muhammad Rizwan Khan Niazi*

Dr. Muhammad Rizwan Khan Niazi defended his Ph.D. entitled, 'Solution Processing of Small molecule Organic Semiconductors: From In-situ Investigation to the Scalable Manufacturing of Thin Film Transistors' under the supervision of Prof. Aram Amassian.

Ph.D. Profile

# Ghada Ahmed

"...KAUST has offered me a great learning experience and exceptional networking opportunities..."

Ghada Ahmed is a fourth-year Ph.D. student working in the Ultrafast Laser Spectroscopy and Four-dimensional Electron Imaging Laboratory under the supervision of Prof. Omar Mohammed. Her current research focuses on the preparation of semiconductor nanocrystals in addition to the characterization of their optical and electronic properties.

Before joining KAUST, Ghada gained her Bachelor's degree in Chemistry and an MSc in Nanoscience & Technology in Egypt. "I was fortunate enough to get the opportunity to work with the hard-working scientist, Prof. Omar. I consider this as a turning point in my research career," Ghada said.

At KSC, Ghada is currently working on the colloidal synthesis of semiconductor quantum dots and nanocrystals with different sizes, shapes and controlled dimensionalities that are successfully conducted through careful manipulation of the surface ligand chemistry and the reaction conditions. The primary goal behind the precision synthesis of the semiconductor nanocrystals is to develop an insightful understanding of the photogenerated charge carrier dynamics, the origin of the defect states, as well as the reaction mechanism at the interface in different donor-acceptor systems. With the latter being the critical step in optimizing the performance of many of the relevant energy-efficient devices. "My research has resulted in many notable publications in highly-reputed journals including, Chemistry of Materials, Chemical Communications, JACS, and JPC-Letters," said Ghada.

## Faculty Focus

# Interview with Prof. Thomas Anthopoulos

Thomas Anthopoulos is a Full Professor of Material Science and Engineering in the University's Physical Science and Engineering (PSC) Division, who joined the University and KAUST Solar Center in January 2017. He obtained his B.Eng. degree in Medical Engineering and a D.Phil. in Physical Electronics from Staffordshire University (UK). He then spent two years at the University of St. Andrews (UK) where he worked on new materials for application in organic light-emitting diodes before joining Philips Research Laboratories (Netherlands) to focus on organic semiconductors for printed microelectronics. From 2006 to 2017 he held faculty positions at Imperial College London (UK), first as an Engineering & Physical Sciences Research Council (EPSRC) Advanced Fellow (2006) and later as a Research Councils UK (RCUK) Fellow (2008), Reader (2009) and Professor of Experimental Physics (2012).

### *What was your motivation to join KAUST and KSC?*

I first heard about KAUST in 2010 and a few years later I had the opportunity to visit the campus for the first time. I recall being impressed by the scale and ambition of this new but highly dynamic university. I remember touring the facilities within the KSC and Core Labs and being impressed by the sophistication of the equipment available within this scientific oasis next to the Red Sea. In the following years, I had the chance to expand my collaborations and to learn more about KAUST and the various research center initiatives focusing on addressing global challenges. The more I learned about KAUST and KSC, the more interested I became in expanding my interactions with faculty members. When the opportunity came, it didn't take much time for me, together with my family, to decide that KAUST would provide an ideal place where I could see my professional dreams materialize while at the same time improving the quality of my family's life.

### *Please tell us about your research interests and how you see them fitting with the Center's mission.*

A significant portion of my research here at KAUST is centered on understanding the properties of novel functional materials (chemical, optical, electrical and magnetic) and to apply this fundamental understanding to develop improved materials and devices for a wide range of applications in energy harvesting & generation, large-area microelectronics, displays, lighting, and sensors. I am also interested in innovative manufacturing technologies for large-area nano-scale opto/electronics where the device, and ultimately system level, performance is determined by the device's physical dimensions rather than strictly by the functional material(s) employed. Examples of my work include printed optoelectronic devices such as solar cells and photodetectors all the way to plastic nanoelectronics for wireless energy harvesting and transparent optoelectronics. Both research strands are nicely aligned with the center's mission as new materials are at the heart of all emerging photovoltaic technologies and innovative manufacturing paradigms may one day help to reduce the production cost of solar cells while enabling the development of new product concepts such as lightweight, deformable & wearable power sources.

### *How does your position support your short and long-term research goals?*

Joining KSC has not only allowed me access to the state-of-the-art facilities, but has also instigated interactions with faculty from different programs, leading to numerous fruitful collaborations. These early interactions eventually culminated in various KSC funded projects which, in some cases, have benefited other work within my group here at KAUST. Thus, I have no doubt that in the long run some of my KSC work will help define the future research directions not only in the field of photovoltaic technologies, but more broadly in large-area opto-electronics.

### *Please tell us about your five year scientific vision.*

We are currently witnessing a digital revolution, often dubbed the 3rd industrial revolution, taking place before our very eyes. During the last decade, this revolution has not only defined how solar energy is harnessed, but also the way we work, shop, learn and entertain ourselves. Right now, we see traditional electronic devices based on silicon, which has been the main instigator of this revolution, being slowly replaced by new materials. This is not necessarily due to their superior electronic properties but because they combine several other attractive characteristics, such as inexpensive processing, tuneable electronic properties, and mechanical flexibility, that are absent from incumbent silicon technologies. I personally see the various emerging technologies (printable solar cells, microelectronics, sensors, etc.) eventually branching out from mainstream electronics, forming their own, initially niche, application space and ultimately leading to the rapid proliferation of large-area optoelectronics.

### *What do you see as significant challenges and how will you address them?*

Although there are still many outstanding technological challenges that need to be addressed in the coming years, I am particularly concerned about the environmental impact of the envisioned rapid proliferation of large-area optoelectronics. Development of low-energy manufacturing methods in combination with environmentally friendly materials (passive & active) could help address part of the problem and for this reason, increasingly research effort in my group is directed towards such technologies. A few representative examples include the use of water-based material synthesis routes, low-energy processing methods and incorporation of paper substrates instead of plastic or glass.

### *What motivates you to do your best?*

From a young age, I was always fascinated by scientific discoveries, but I never imagined that one day I would be contributing to those myself. I think this hardwired fascination with science has always been, and will still be, my driving force. I don't feel like I am trying to do my best; I am merely doing what I enjoy the most.

### What do you like to do beyond research?

I like gardening. While living in northern Europe I never imagined that I would one day be able to grow tomatoes, peppers and other vegetables, next to bananas and papaya trees. So, KAUST truly makes dreams come true!

### What is your advice to the young scientist?

I have more than one piece of advice drawn from my own experience: I will first advise all young scientists always to try and see the big picture in whatever they do and don't allow little things to dominate their time. It is easy to get lost in an endless circle of experiments that yield no clear answers and lead to disappointment. Do not hesitate to step outside your comfort zone, try new things and aim high, but first make sure you identify the little tangible steps that will get you there. If possible, talk to your friends and colleagues about your work. It is often the case that the best ideas emerge during the course of stimulating conversations. And finally, try and enjoy your work as much as possible.

## KSC Highlight Paper

### "Impact of Nonfullerene Acceptor Core Structure on the Photophysics and Efficiency of Polymer Solar Cells"

Non-fullerene acceptors increase the absorbance of the photoactive layer in organic solar cells (OSCs) and thereby can significantly increase their performance. However, a clear picture of which chemical structures should be targeted to optimize the performance is still lacking.

In KSC's recent Letter published in ACS Energy Letters, Maha Alamoudi et al. report how the chemical structure, precisely the core of the non-fullerene acceptor, affects the photophysical processes and thus the power conversion efficiency. One particular structure, namely an IDTT-based acceptor, was identified that outperformed earlier-developed materials by both an increased photovoltage and photocurrent due to optimized energetics and suppression of carrier recombination. Theoretical calculations performed by Denis Andrienko from the Max Planck Institute for Polymer Research in Mainz, Germany, demonstrated that the acceptor's energetic disorder, as well as dipole and quadrupole moments, are the cause of the improved performance. This work allows development of guidelines for the future development of novel acceptor molecules with improved performance.

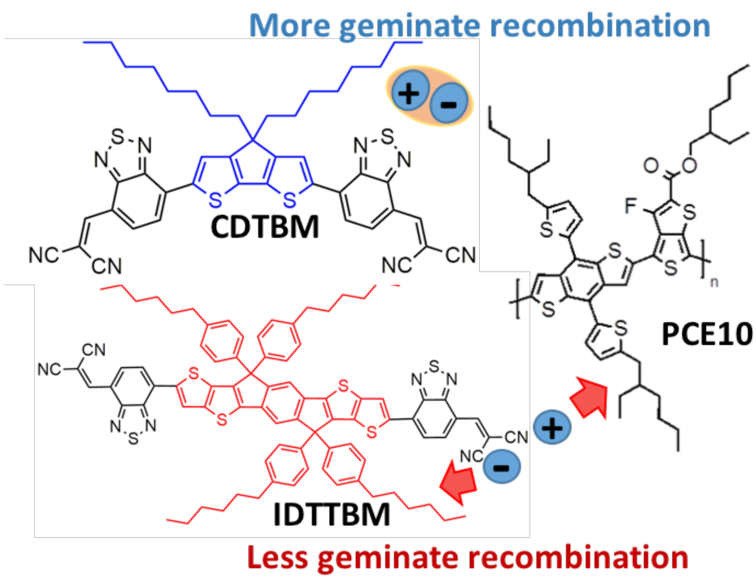



**Figure:** Small-molecule "nonfullerene" acceptors are promising alternatives to fullerene (PC61/71BM) derivatives often used in bulk heterojunction (BHJ) organic solar cells. Reprinted with kind permission from ACS Energy Lett., **2018**, 3 (4), pp 802–811

Recent Events

# KAUST Research Conference: Synergistic Approaches in Solar Energy Conversion

Underpinning KAUST's commitment to solar energy in the region, the KAUST Research Conference: "Synergistic Approaches in Solar Energy Conversion" was held from February 25 to 27. In addition to the 150 KAUST scientists and engineers who attended, faculty and young scientists from across the Kingdom of Saudi Arabia, for example from KACST, Prince Sattam bin Abdulaziz University and Effat University, joined the event, actively contributing to the scientific lectures, poster sessions and general discussions, together with 30 international participants from leading global institutions.

The conference goal was to identify synergistic approaches, across the different solar-energy related fields, for the development of low-cost, high-efficiency photovoltaics and solar-driven technologies such as photocatalysis. Chemists, physicists, and engineers discussed emerging technologies and trends, generating new research ideas across classically held borders and creating impetus for potential collaborations. With contributors hailing from four continents and from industry as well as academia, emphasis was given to identifying practical solutions with relevance to actual regional and global challenges. The success of the conference is borne out by a number of follow-up projects that have subsequently been initiated between the KAUST Solar Center and the conference guests.

KSC Director Professor Iain McCulloch opening the conference

Delegates attend the poster session held in KAUST University Library

A further distinguishing feature of the conference was its accessibility to junior scientists. A pre-conference workshop was dedicated to young scientists with technical lectures provided by faculty from EPFL Switzerland, TU Delft, and Hasselt University, complemented by a fascinating session on research ethics provided by KAUST's Researcher Support team and advice on science writing and publishing from an Associate Editor at Nature Energy. Additionally, the young scientists were encouraged to interact and exchange ideas, both formally and informally, throughout the event with prominent scientists attending from the University of Oxford; University of California, Berkeley; Australian National University; Masdar; Purdue; NC State University; IIT Milan; and the University of Toronto amongst others. In the Young Scientist sessions, scheduled within the main program, ten junior researchers were selected to present their research to the distinguished guests and over 40 graduate students and postdocs took the opportunity to present their work during the well-attended poster session. Poster prizes were awarded to Dr. Michele De Bastiani, KAUST and Dr. Marina Gandini, IIT. For their excellent talks, PhD student, Ghada Ahmed, KAUST, and postdoctoral fellow Dr. Yanwei Lum, University of California, Berkeley, received young speaker awards.

Prof. Harald Ade, NC State University; Dr. Nancy Haegel, NREL; and Dr. Elsa Couderc, Nature Energy also kindly agreed to a student initiative to be interviewed and give their views and insights into their specialist field. These video interviews can be viewed on ksc.kaust.edu.sa/Pages/News

Over 250 delegates attend the conference including guests from across the Kingdom and abroad

KAUST Solar Center would like to thank the KAUST Office of Sponsored Research (OSR) for funding the event and KAUST Industry Collaboration Program (KICP), Industry Partnerships Office, for providing additional support. The poster awards were kindly sponsored by the Royal Society of Chemistry's Energy & Environmental Science and Sustainable Energy & Fuels and a young speaker award was generously sponsored by Nature Energy.

# KSC Summer School attracts students from across KSA

Effat University, Qassim University, KAU, Taif University and Aramco students and employees, together with visiting students from Imperial College London and members of KAUST, joined the KSC Summer School 2018 from July 10-12th.

Summer School students gained hands-on laboratory experience

In its mission statement KSC not only lays out its aspirations to create new science and technologies, but also puts training for the benefit of society at the heart of what it does. As part of this drive, a summer school was initiated to bring together both theory and practical aspects of photovoltaic systems, delivered by top academics and practitioners from KAUST and TU Delft. The aim of the program was to give young scientists, engineers, and future leaders the opportunity to experience real aspects of photovoltaic system theory and research; to inspire them to pursue studies and careers in the field of solar energy conversion; and to spark ideas for their future research.

The lectures, delivered by Professors Iain McCulloch (KSC Center Director), Stefaan De Wolf (KSC), Miro Zeman (TU Delft) and Olindo Isabella (TU Delft), together with KSC postdoctoral researchers Yuliar Firdaus, Nicola Gasparini and Julien Gorenflot, were open to all. In addition, 15 talented students from KAUST, Saudi Arabia and Europe attended practical laboratory sessions in the afternoons, covering device fabrication & characterization for both organic and silicon photovoltaic systems, as well as semi-conducting thin films, under the guidance of KSC Laboratory Manager Dr. Michael Salvador and his laboratory operations team.

KSC was delighted to engage the help of Professors Miro Zeman and Olindo Isabella from the Photovoltaic Materials and Devices group at TU Delft where, in addition to their research expertise in light management, modelling and silicon-based solar cells, they have successfully run a photovoltaic systems summer school for a number of years. Furthermore, KSC awarded the visiting Saudi students a copy of Prof. Zeman and Prof. Isabella's highly recommended text book, "Solar Energy: The Physics and Engineering of Photovoltaic Conversion, Technologies and Systems".

Technology Review

# Passivating contacts enabling progress towards the efficiency limits —By Thomas Allen

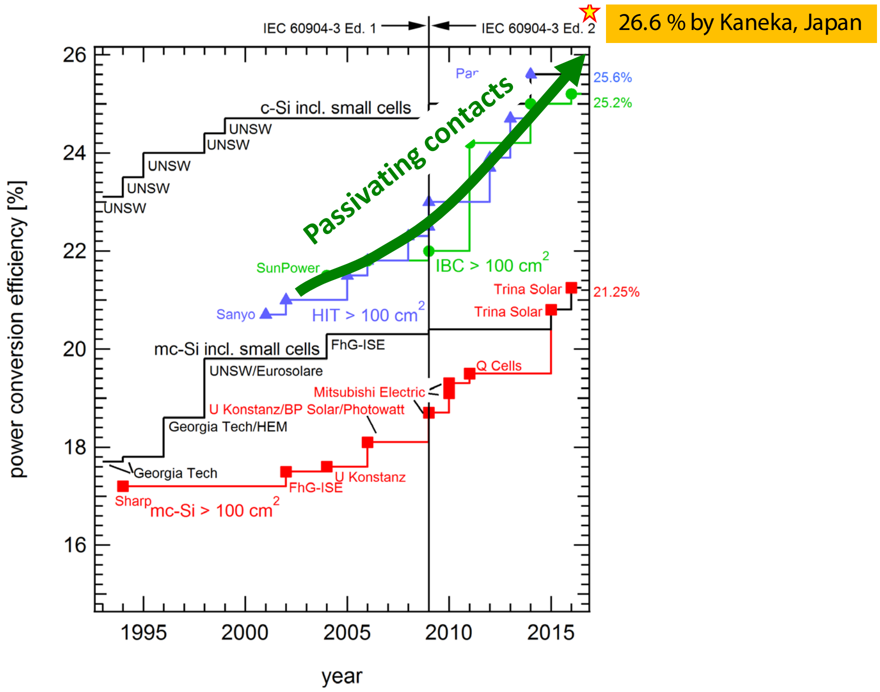



**Figure:** Evolution of the energy conversion efficiencies of silicon photovoltaics. C. Battaglia, A. Cuevas, and S. De Wolf, Energy & Env. Sci. 9, 1552 (2016) published by The Royal Society of Chemistry

Over the past decade, the manufacturing industry for crystalline silicon solar cells significantly expanded, with cumulative module shipments exceeding 400 GW in 2017. Despite this, approximately 70% of the current crystalline silicon photovoltaics (PV) production capacity is still dominated by a low-performance cell design, called the aluminium back surface field cell (or Al-BSF), with a power conversion efficiency (PCE) limited to about 20%. Al-BSF cells are typically fabricated on low quality, p-type, multi-crystalline silicon wafers, in which the front side is thermally diffused with phosphorus dopant atoms (a donor impurity in silicon), and the rear side is fully alloyed with aluminium (an acceptor impurity in silicon), resulting in a heavily Al doped (p+) region, an Al/Si mixed phased region, and finally the Al rear metal contact. An enhancement on this design, called the PERC – passivated emitter and rear cell – design, has the same fabrication process except the rear Al alloying process happens locally, in line or point contacts on the rear side of the cell, with the rest of the rear surface area passivated with aluminium or silicon oxide. This enhanced design enables efficiencies in the production environment of around 22-23%, still falling short of the theoretical limit of 29.4%. These relatively simple cell designs and production processes, combined with the economies of scale in manufacturing witnessed in recent years, are what has led to the low price of this technology, currently only 0.34 US$/Wp.

To further improve on the device efficiency, so-called 'passivating contacts' are being incorporated into the solar cell architecture, as demonstrated by the silicon heterojunction (SHJ) cell technology, pioneered by Panasonic, Japan. Such SHJ solar cells use thin intrinsic amorphous silicon passivation layers that enable remarkably high open-circuit voltages ($V_{oc}$ > 750 mV). These layers are inserted between the silicon wafer and the electron and hole transport layers consisting of thin, doped amorphous silicon. Kaneka currently holds the PCE record (25.1%) for this technology for a large area (>150 cm2) device with both sides contacted, and with the more complex interdigitated back contact (IBC) cell design (26.7%) in which all of the contacting materials are on the rear side of the wafer.

Other passivating contact technologies utilize combinations of silicon oxide buffer layers and doped polycrystalline outer layers. Researchers at ISFH in Germany, for example, recently demonstrated a 26.2% small-area IBC cell featuring polysilicon contacts. Dopant-free ETLs and HTLs are also heavily investigated, though are yet to demonstrate such high efficiencies. However, the use of dopant-free materials (metal oxides, fluorides, carbonates, and nitrides, for example) opens a diverse materials space with a wide range of electrical and optical properties that can potentially further enhance device performance and simplify cell production. In the future, these materials, which are compatible with low temperature processing, can also be utilized to facilitate the integration of a perovskite top cell in a silicon/perovskite tandem configuration.

Through the introduction of passivating contacts, in the past four years crystalline silicon solar cell research has yielded an additional 1.7% absolute improvement in record device efficiency, compared to just 1.8% over the preceding 25 years. The path forward for the PV industry is now clear: increase cell efficiencies through the introduction of passivating contacts. How to do so effectively, reliably, and cheaply, remains an open question that Prof. De Wolf's group in the KAUST Solar Center are aiming to solve.

# New Faces at KSC

*Aniruddha Basu*

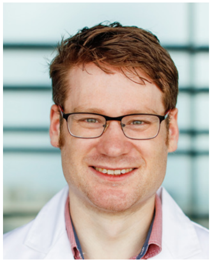
Postdoc with Thomas Anthopoulos

From - CSIR-National Chemical Laboratory, India

*Diego Rosas Villalva*

Ph.D. Student with Derya Baran

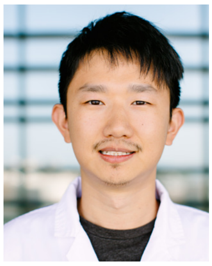
From - Universidad de las Américas Puebla, México



*George Harrison*

Postdoc with Thomas Anthopoulos

From - University College London and London Centre for Nanotechnology, UK



*Lujia Xu*

Postdoc with Stefaan De Wolf

From - National University of Singapore (NUS), Singapore

*Murali Gedda*

Postdoc with Thomas Anthopoulos

From - Jawaharlal Nehru Centre for Advanced Scientific Research, India

*Prashant Kumar*

Postdoc with Thomas Anthopoulos

From - Indian Institute of Technology Bombay, Mumbai, India

*Seyoung Kee*

Postdoc with Derya Baran

From - Gwangju Institute of Science and Technology, South Korea

## Alumni Focus

# Ahmad Kirmani

> "...The freedom I had in attending international conferences was probably one of the most rewarding aspects of my Ph.D. life at KAUST..."

Ahmad Kirmani, a KAUST Material Science and Engineering Ph.D. graduate (2017), recently authored a paper with the supervision of Prof. Aram Amassian focusing on making good QD solar cells in humid air. The paper entitled, 'Overcoming the Ambient Manufacturability-Scalability-Performance Bottleneck in Colloidal Quantum Dot Photovoltaics' was recently accepted in Advanced Materials.

Kirmani joined KAUST in the fall of 2011 after completing undergraduate studies in Condensed Matter Physics in India. "It was the time when quantum materials were beginning to emerge in real earnest, and innumerable opportunities in their applications and fundamental science were on the rise", Kirmani recalled. "Backed by my training in physics, I was interested in pursuing this research field at a top-notch university", he added.

During his Ph.D. at the KAUST Solar Center, his research focus was advancing thin film photovoltaic technology by employing nanosized semiconductors, called 'quantum dots,' as the active component of flexible solar cells. "I was lucky to have a surface characterization ultra-high vacuum (UHV) facility in my research lab headed by Prof. Amassian. Surface characterization of quantum dots enabled me to answer a few fundamental questions on charge transport in these novel semiconductors. Thanks to the wide array of characterization tools housed in KSC, I was able to demonstrate scalable printed quantum dot solar cells by the time of my graduation in 2017", said Kirmani.

When asked about his rewarding experience at KAUST, he answered, "The freedom I had in attending international conferences was probably one of the most rewarding aspects of my Ph.D. life at KAUST. Networking is the cornerstone of efficient, high-throughput research. Attending the best conferences in my field allowed me to disseminate my research findings and forge collaborations and networks actively."

Besides this, Kirmani found the KSC peer-led seminars to be very rewarding as these peer-led seminars give the young researchers (students and postdocs) an opportunity to present their work to the KSC cohort, mirroring an international conference setting.

Ahmad is currently working as a postdoc at the National Institute of Standards and Technology (NIST) Maryland, USA, with Dean DeLongchamp and co-workers. The group is amongst the world leaders in soft matter characterization. At NIST he explores the fundamental science of additive manufacturing.

# International Partners

*Establishing new and maintaining fruitful international collaborations is of utmost importance to KSC and at the core of our center's mission. We benefit greatly from the scientific expertise of other research groups outside KAUST (as do they from ours) and, in addition, these collaborations create valuable channels for student exchange, postdoc recruitment, and placement of our own graduates and postdoctoral associates after their auspicious time at KAUST.*

One of our distinguished collaborators is Prof. James Durrant, University Professor in the Department of Chemistry at Imperial College London. James was elected a Fellow of the Royal Society (FRS) in 2017 for his research contributions in photochemistry of new materials for use in solar energy conversion. His group's primary research interest is the development of new chemical approaches to solar energy conversion – harnessing solar energy either to produce electricity (photovoltaics) or molecular fuels (e.g.: hydrogen). We talked with James to gather his views about KSC and KAUST.

### *Can you briefly describe the subject of your Ph.D. research?*

I started my PhD in the late 1980's, when oil was cheap. There were very few opportunities to work directly on solar cells. However, I was lucky enough to find a PhD in the related area of plant photosynthesis. The PhD involved building lasers to measure the primary reactions in photosynthetic reaction centers, working under the fantastic guidance of George Porter and Jim Barber. At the time, building and running ultrafast lasers was challenging, and often messy – typically involving firing laser beams at high pressure dye jets, which had an unfortunate habit of spraying dye over much of the lab (and its users). Laser technologies today are far more advanced, so that ultrafast laser spectrometers can now be run routinely, allowing researchers to focus much more on the materials and devices they are studying in their experiments.

### *When and how did you first become involved with KAUST and the Solar Center?*

KAUST Solar Center has been doing world class science on new materials for solar energy conversion for several years. I became strongly involved following the move of my colleague Iain McCulloch to the Solar Center. Iain and I have worked for many years on the development of organic semiconductors for solar energy conversion – and it was natural to continue these collaborations after Iain had moved to KAUST.

### *You are currently collaborating with the KSC on a project entitled, 'Organic bulk heterojunction photo-cathodes for solar driven hydrogen generation from water'. What is the role of your research group in this project?*

My group had been, and indeed still is, working on inorganic materials for solar driven hydrogen generation for several years. This project, and partnership with Iain McCulloch, has enabled us to move into a new direction, exploring the potential for organic semiconductors to be used to drive this reaction.

Direct solar driven water reduction to molecular hydrogen is challenging. Rapid progress is being made to improve the efficiency and stability of materials and devices driving this reaction, and lower the costs, but substantial advances are still required to enable this to compete cost effectively with fossil fuel derived hydrogen synthesis.

### *Finally, what would you still like to accomplish?*

Going beyond solar driven hydrogen reduction, one of the next big challenges is solar driven carbon dioxide reduction. Achieving this efficiently at low cost would have a major impact on our global transition to more sustainable energy technologies.

News

# Maha Alamoudi wins ICSM poster prize

Maha Alamoudi, PhD student in Prof. Frédéric Laquai's research group, was recently awarded the "ICSM Best Poster Prize" at the International Conference on Science and Technology of Synthetic Metals 2018 (ICSM 2018), in Busan, Korea, for her poster entitled "Impact of IDT-based structures on photophysics and performance of polymer solar cells". In her work, Maha studies novel non-fullerene acceptor molecules synthesized in Prof. Iain McCulloch's group at KSC. By using advanced spectroscopic techniques, Maha aims to understand how the chemical structure of the acceptor molecules influences the performance of organic solar cells.

"We could demonstrate that tuning the acceptor's energy levels by modifying the chemical structure not only changes the solar cell's voltage, but also has a large effect on the efficiency and physics of charge generation and recombination", Maha explains.

Non-fullerene acceptors have recently attracted a lot of attention in the PV community and the development of novel materials has propelled the efficiency of organic solar cells beyond 14%.

KSC had a strong presence at this year's ICSM 2018 with a number of faculty, researchers, and PhD students contributing talks and posters to the lively sessions.

## KAUST Research Conference: 3rd Generation photovoltaic technologies and beyond

February 10 - 12 2019

The main program on February 11-12 will focus on three major themes:

- Novel materials and devices for 3rd generation PVs
- Manufacturing, upscaling and commercialization of PV technologies
- Technologies and concepts beyond PV

On 10 February there will be a workshop for young scientists addressing the fundamentals of solar energy conversion, including the associated economics.

ksc.kaust.edu.sa/Conference-2019

## KAUST Solar Center

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