Lloyd's Register Foundation

UNIVERSITY OF Southampton

ICON
International Consortium of Nanotechnologies

ANNUAL Review 2018

01.

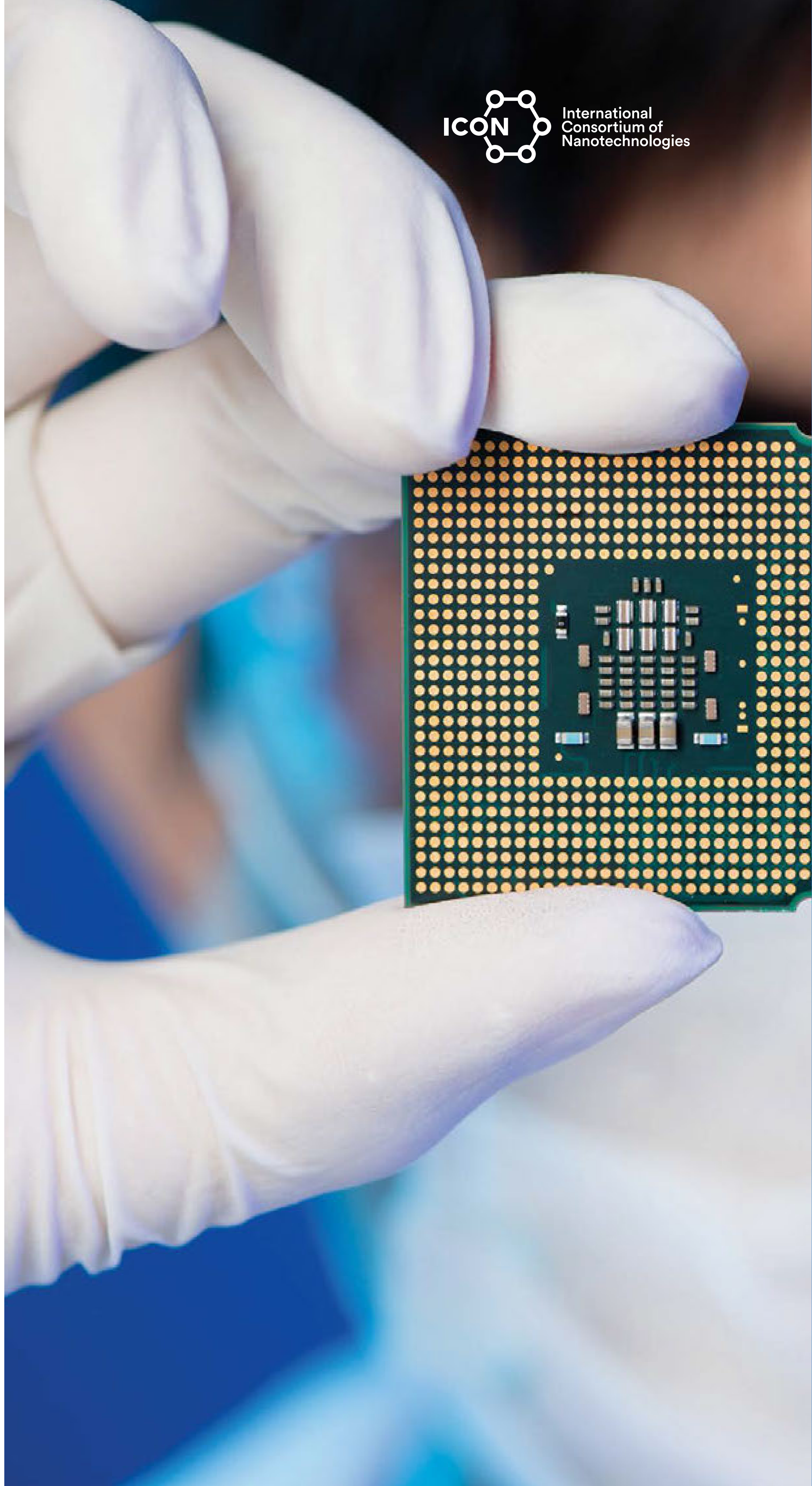
About us

Building a safer world with Nanotechnology

The International Consortium of Nanotechnologies (ICON), led by the University of Southampton and funded by the Lloyd's Register Foundation, is building capacity and knowledge in the application of nanotechnologies to support safety of life and property.

ICON is developing a network of nanotechnology experts from academia and industry to address the 'Grand Challenges in Nanotechnology'. ICON also supports the development of more than 50 new international nanotechnology experts, 47 of whom have started or are about to start specific research projects, who will spend their training considering safety issues and advancing knowledge within a specific field related to the themes identified in the Foresight Review of Nanotechnology (2014).

The Lloyd's Register Foundation is a charity that helps to protect life and property and support education, engineering-related research and public engagement.



Professor Themis Prodromakis
ICON Project Director, University of Southampton

How would the world be without the invention of integrated circuits or smart nanomaterials? Many would argue that nanotechnologies have had a tremendous impact in shaping modern societies towards being healthier and more connected. At the same time, new technologies, if not used responsibly, can have an adverse impact. The generous support from the Lloyd's Register Foundation came at a timely point for allowing the responsible innovation in this new application space that is required for making the world a safer place.

We are delighted to see that during this year, ICON has evolved into a truly unique international action, spearheaded by our PhD students distributed across global institutions. We are immensely proud for all of our students that excel in their research and are recognised by awards, impactful publications and engagements with world-leading industry and societies – as highlighted in this report. Our commitment for enhancing their skills and experiences was reinforced through the establishment of a Distinguished Lecture series that are broadcast online and bring to our students exemplar role models for Nanosciences and Engineering. Building on our previous successes with Nanotechnology outreach, we partnered with the Royal Academy of Engineering that empowered us to promote our approach in a more diverse and broad manner (e.g. engaging secondary students for introducing "nano-concepts" to primary students). And we are particularly thankful to Dr Hayaatun Sillem, RAEng CEO, for sharing our vision and delivering the inaugural ICON distinguished lecture and motivating our ICON members via raising the importance of diversity in research.

As we move forward, our students lead on translating their research and disseminate its impact. We are thrilled to see the enthusiasm of all recipients of our ICON playing cards that described our students' research and excited about our collaboration with The Conversation that provided support to our students for describing their research in layman's language. We look forward to another year as an international hub of collaboration and innovation in Nanotechnologies.

Professor Richard Clegg
Foundation Chief Executive, Lloyd's Register Foundation

We're living in a complex and interconnected world. Technology development is accelerating fast aided by developments in many disciplines, especially the nano-sciences. From the angle of the Lloyd's Register Foundation, we want to make sure that the safety applications and benefits promised by nanotechnology can be realised, but without there being any unintended or unforeseen adverse impacts. That's why we established the global ICON Project in collaboration with the University of Southampton. It's making great strides in training the next generation of professionals and undertaking research that will ensure the future safety of nanotechnology. We're particularly indebted to Professor Themis Prodromakis who as ICON Project Director has built up such an amazing, impactful and internationally recognised team.

02.

Project map

Projects Funded

47

Project Locations

48

Countries Involved

16

Australia
Canada
China
France
Germany
Greece
Italy
Japan
Malaysia
Portugal
Singapore
Spain
Sweden
Turkey
UK
USA

176

People Involved

Students: **33**
Supervisors: **84**
PMB members: **7**
Theme leads: **6**
Reviewers: **40**

45

Industrial Stakeholders

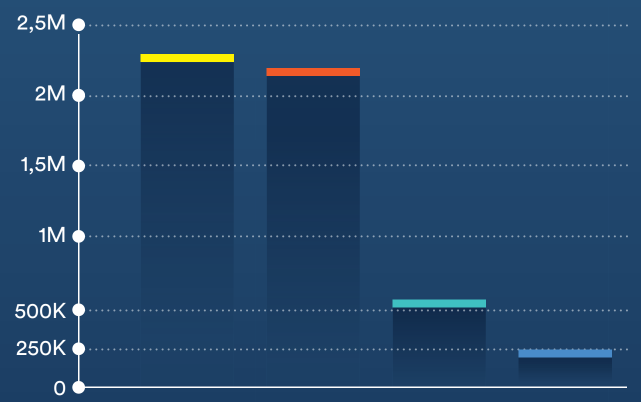
AGC Glass
Airbus
AkzoNobel
Applied Graphene Materials
Bougues Cobham Wireless (UK)
Conoco Phillips (UK)
Costain (UK)
Dow Corning (US)
Eight19 Ltd (UK)
European Thermodynamics (UK)
Glonatech
Graphenea
HR Wallingford Ltd
i.nanoEnergy
Intel Microelectronics
Johnson Matthey Haydale Ltd (UK)
Lloyd's Register Group
MIMOS Ltd (Malaysia)
Morganic Metal Solutions (UK)
Nanomagnetics Instruments (UK)
Nanotypos (Greece)
National Physical Laboratory (UK)
Nokia Bell Labs Ltd (US)
NTT Basic Research Laboratories (Japan)
NSG/Pilkington
OPS Structural Engineering (UK)
Pall Aerospace
PETRONAS Chemical Group (PCGB)
REAP Systems
RIKEN (Japan)
Shanghai Robio-Tech Ltd
Sigma-Merck
Silterra (Malaysia)
Statoil (UK)
STELIA North America
Techno-scientific
Temporal Computing Ltd
Transense Technologies
Thomas Swann & Co (UK)
Total UK (UK)
UKAEA
Versarien Ltd
WISEN Innovation (UK/China)

03.

ICON in numbers

Funding

- Value of grants awarded: **£2,274,705**
- Matched by Institutions: **£2,188,705**
- Industrial funding: **£536,000**
- Other funding: **£248,000**



Publications

19 JOURNALS

34 CONFERENCES

Equality, Diversity & Inclusion

16 Nationalities

20 Male Students

14 Female Students

04.

Research themes

Sensors

Sensors rely on newly invented nanomaterials and manufacturing techniques to make them smaller, more complex and more energy efficient. For example ICON students develop sensors that can be printed in large quantities on flexible rolls of plastic at low cost. Such sensors could be placed around critical infrastructure, say bridges or aircraft, to constantly check that everything is running correctly.

THEME LEAD

Alain Nogaret (University of Bath)

Alain Nogaret's research focuses on low dimensional electron systems confined by microscopically inhomogeneous magnetic fields, and micromachined transmission lines that propagate electrical impulses and mimic biological nerve fibres.

Smart Materials

Changing the structure of materials at the nanoscale can give them amazing properties – by giving them a structure that repels water, for example. ICON helps develop nanotechnology coatings and additives that can "heal" when damaged or worn. For example, dispersing nanoparticles throughout a material means they can migrate to fill in any cracks that appear.

THEME LEAD

Nicole Grobert (University of Oxford)

Nicole Grobert's research focuses on the synthesis, processing, and characterisation of novel carbon and non-carbon based nanomaterials, including nanoparticles, nanotubes, nanorods, graphene and other 2D nanomaterials.

Computing and Communications

The trend of embedding sensors everywhere will produce more information than we have ever had to deal with before – so we need new technologies to process it and spot patterns that will alert us to problems. This provides the inspiration for ultra-efficient algorithms for processing, encrypting and communicating data without comprising its reliability. ICON contributes new computer designs inspired by the brain that use energy more efficiently and so struggle less with excess heat (one of the key problems of shrinking electronic devices further).

THEME LEAD

Bernabé Linares Barranco (University of Seville)

Bernabé Linares-Barranco's research focuses on exploiting nano-scale devices for event-driven learning and processing via circuit design for telecommunication circuits and other topics.

Data Management

Nanotechnology is helping to create ultra-dense computer memory that will allow us to store the wealth of data generated by sensors. ICONcontributes technologies that help us use the "big data" from traffic sensors to help manage congestion and prevent accidents or prevent crime by using statistics more effectively to allocate police resources.

THEME LEAD

Ling Wang (University of Southampton)

Wang's research focuses on condition monitoring for tribological systems.

Nanotechnology and Risk

It is crucial that all nanotechnology innovations are developed responsibly and are not to be misused or generate any unexpected consequences. ICON strongly adheres to this principle and all developments will go hand in hand with the necessary safety, standards and risk assessments.

THEME LEAD

William Keevil (University of Southampton)

Bill Keevil's research focuses on environmental healthcare within biological sciences.

Energy and Storage

Nanotechnology has helped create batteries that can store more energy for electric cars and has enabled solar panels to convert more sunlight into electricity. ICON students develop new nanomaterials that turn a flat surface into a three-dimensional one, with a much greater surface area which means there is more space for the reactions that enable energy storage or generation to take place, so devices operate even more efficiently.

THEME LEAD

Eric Yeatman (Imperial College London)

Eric Yeatman's research focuses on optical devices and materials and micro-electro-mechanical systems (MEMS).

05.

2018 Highlights

Lloyd's Register Foundation International Conference 2018

This two-day event brought together grant holders, academia, industry and members of the public, and was a fantastic opportunity to learn more about the work and impact of the Lloyd's Register Foundation. The event featured keynote speakers, presentations and early career 'master classes' spanning all areas of Foundation grants funding, and showcased the excellent work done by grant holders covering four strategic themes - promoting safety and public understanding, advancement of skills and education, supporting excellent scientific research and accelerating the application of research.

Professor Richard Clegg, CEO Lloyd's Register Foundation, introducing this year's conference. Highlights from the first day included a presentation on the Safety by Design initiative by Paul Anderson, CEO of the Royal College of Art, which emphasised the importance of multidisciplinary teams working together to understand a broader range of safety risks than traditionally considered; an example of which includes design that takes into account how people both affect, and are affected by, design. A mention should also go to Professor Saiful Islam whose presentation entitled 'Green Energy Materials in 3D' proved to be both entertaining, with plenty of audience participation, and informative. The Conference exhibition provided an opportunity for the ICON team to engage with the wider Foundation community.

Highlights from the second day of the conference included the keynote from Adam Parr, venture capitalist and entrepreneur and the closing discussion panel.

Dr Hayaatun Sillem, CEO of The Royal Academy of Engineering, with the ICON Project Director, members of the Programme Management Board and ICON students at the conference exhibition.

Theresa Schoetz wins best student presentation at Foundation Conference

The Foundation supports over 250 students across a very diverse range of disciplines that underpin its commitment to 'Life Matters'. Each of nine students made a three minute presentation, without any slides or other props, on their research and its impact at the conference. Their performance was judged by Dr Kierann Shah, General Manager, National Space Academy, Dr Rebecca Sykes, Technology Innovation Leader, Lloyd's Register, Dr Tim Slingsby, Director of Skills and Education, Lloyd's Register Foundation and Professor Michael Fitzpatrick, Pro-Vice Chancellor, Coventry University. We were delighted that the competition was one by ICON student Theresa Schoetz.

Theresa Schoetz, holding her best student presentation prize, on the terrace at IET Savoy Place, London.

ICON Annual Conference 2018

We are grateful to the Foundation for allowing us to hold the ICON Conference 2018 in their historic building at 71 Fenchurch Street, London. The students were delighted to have the opportunity to tour the building.

Professor Richard Clegg (CEO Lloyd's Register Foundation) welcomed the ICON students to the Foundation's headquartesrs in London. The attendees then took part in an interactive session 'communicating talks' led by Andrew Halfacre from Lighthouse 365. This session helped participants understand how to overcome nerves, use body and voice together to structure and give an effective talk.

The afternoon session included several exciting and informative presentations by Andrew Hopkins (ARM), Professor Sir Richard Friend (Cambridge) and Maria Maragkou (Nature Materials). Our annual event concluded with a tour of the Royal Institution, where everyone had the opportunity to see Faraday's laboratory, and the Conference dinner was held in the Library.

ICON Distinguished Lecture Series

With our students spanning across 16 countries we felt the need to bring them a selection of inspirational talks by key role models. The inaugural ICON Distinguished was given by Dr Hayaatun Sillem, CEO of The Royal Academy of Engineering on 1 November 2018.

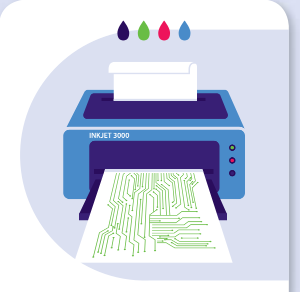
Hayaatun has worked for The Royal Academy of Engineering (RA Eng) since 2006 and held the post of Deputy Chief Executive Officer and Director of Strategy until her appointment as CEO. She previously served as Committee Specialist and later Specialist Adviser to the House of Commons Science & Technology Committee. She has extensive leadership experience in UK and international engineering and innovation policy and programmes.

In this lecture Hayaatun provided an overview of the work of the RA Eng, which is the UK's national academy for engineering, and outlined the RA Eng's work to improve public awareness and understanding of engineering. It is a national academy with a global outlook, very relevant to ICON. Hayaatun also expanded on the Academy's commitment to enhancing the diversity of engineers across all disciplines, in this year of engineering, via its successful 'This is Engineering' campaign and other initiatives.

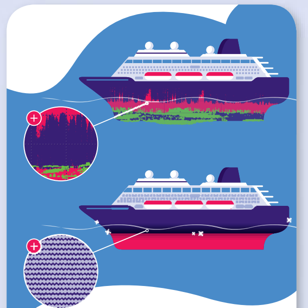
CHANGING THE WORLD

BUILDING A SAFER WORLD WITH NANOTECHNOLOGY

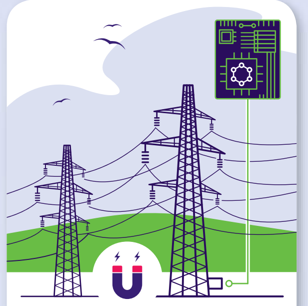
Our ICON students develop novel solutions and concepts enabled by nanotechnologies. The impact and vision of some of these projects is captured in these pages through accessible graphics.



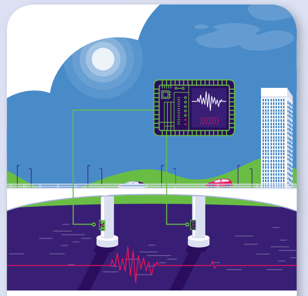
Flexible inkjet printed electronics
Low-cost, large-scale sustainable electronics
Heriot-Watt University
Georgia Institute of Technology



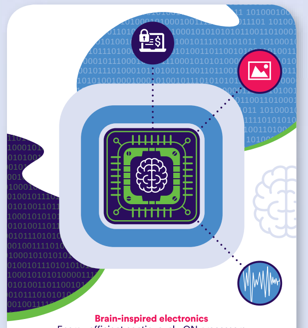
Anti-fouling materials for mineral scale prevention
Enhancing infrastructure resilience
University of Leeds
INDUSTRIAL PARTNERS: Statoil, ConocoPhillips and Total



Graphene magnetic imagers
Enhancing monitoring efficiency of energy infrastructure
University of Bath
Middle East Technical University (METU)

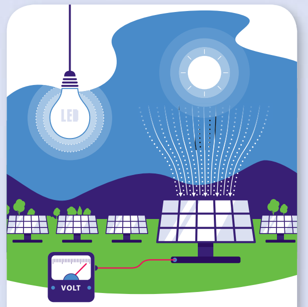


Self-powered vibration sensor
Enabling dynamic structure monitoring
University of Southampton
UC Berkeley and Central South University
INDUSTRIAL PARTNERS: Cobham Wireless, WISEN Innovation and Costain



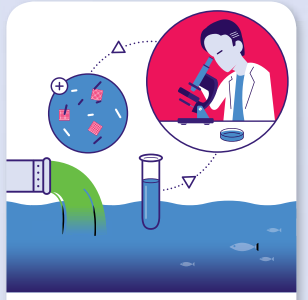
Brain-inspired electronics
Energy efficient continuously-ON processors
University of Sevilla
Jacobs University
CEA/LETI

Fast night vision imaging
Enhancing road safety for drivers and pedestrians
University of Western Australia

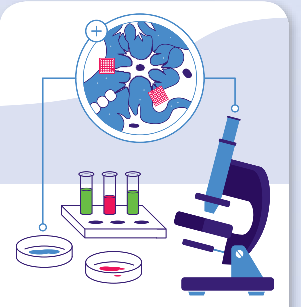


High efficiency light emissions and solar cells
Use nanomaterials safely & responsibly
University of Cambridge
INDUSTRIAL PARTNER: Eight19 Ltd

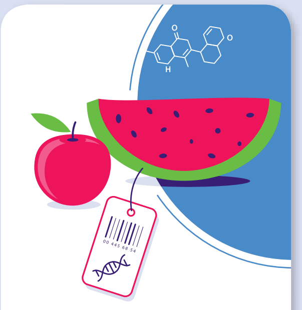
Nanowires phononics for temperature sensing
Keeping your computer cool & charged
Imperial College London
INDUSTRIAL PARTNER: European Thermodynamics



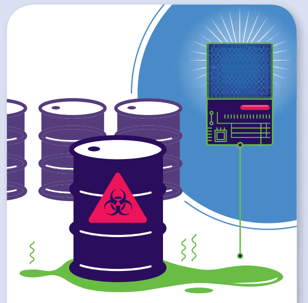
Longevity profiling of nanoparticles in waste
Identify long-term risk of nanoparticles in aquatic media
Queen Mary University
INDUSTRIAL PARTNER: HR Wallingford Ltd



Safety bioprofiling of nanomaterials
Understand the risks of inhaling nanoparticles
University of Manchester

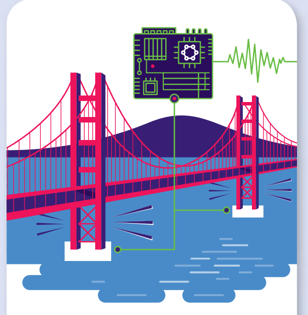


Invisible nanoscale chemical tagging
Traceable food supplies
York University

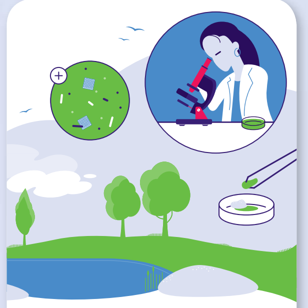


Carbon nanodot sensors
Tracing toxic metal ions
Shanghai Jiao Tong University
INDUSTRIAL PARTNER: Shanghai Robio-Tech Ltd

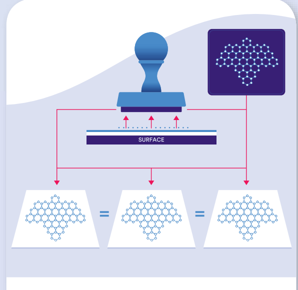
Sustainable high-performance batteries
Safe and efficient energy storage
University of Southampton



Structural health monitoring with graphene-silicone strain sensors
Increased public safety & lower costs
University of Bath

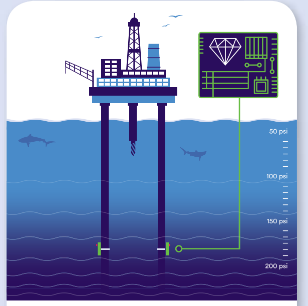


Safety profiling of 2D materials
Understanding risks of nanomaterials to the environment
Imperial College London

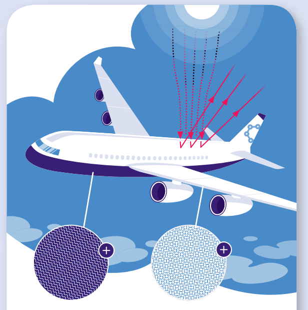


Scalable exfoliation of electronic materials
Enhancing the manufacturing yield and performance of electronics
UC Berkeley
Imperial College London
INDUSTRIAL PARTNER: Thomas Swan & Co Ltd

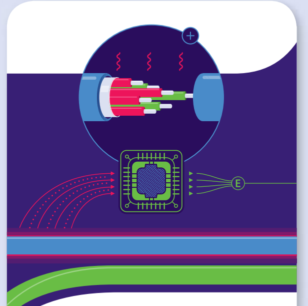
Nanoengineered smart surfaces
Improving energy efficiency
UCL
INDUSTRIAL PARTNER: AGC Glass



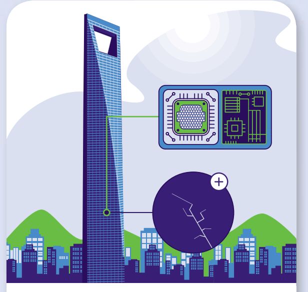
Diamond-based strain sensing
Enabling infrastructure integrity monitoring in extreme environments
Aston University
INDUSTRIAL PARTNER: Oak Ridge National Laboratory



Protective coatings
Shielding crafts from radiation and corrosion
University of Waterloo
INDUSTRIAL PARTNER: STELIA North America

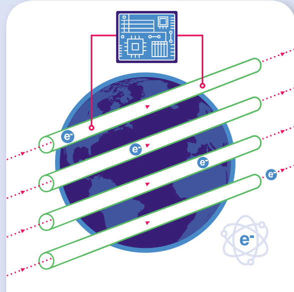


Thermo-electric heat scavengers
Enhancing environmental sustainability
Coventry University
INDUSTRIAL PARTNER: Morganic metal solutions Ltd

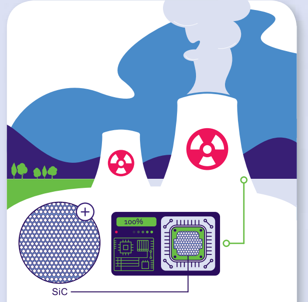


Flexible nanoparticle sensors for detecting microbreaks
Monitoring infrastructure safety
NTUA
Imperial College London
INDUSTRIAL PARTNER: Nanotypos

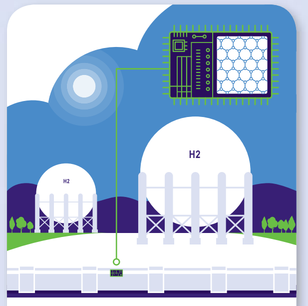
Carbon nanotube reinforced structures
Improving structural resilence and embedding nano monitoring
Imperial College London
NTU Singapore



Single electron transistors
Safeguarding communications with quantum technologies
University of Southampton
Tokyo Institute of Technology
INDUSTRIAL PARTNERS: National Physical Laboratory
NTT Basic Research Laboratories and RIKEN

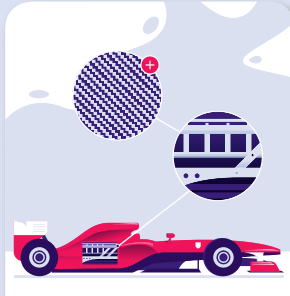


Advancing electronics with nanostructuring
Enhancing electronics resilience
University of Michigan
INDUSTRIAL PARTNER: Dow Corning



Graphene hydrogen gas sensors
Monitoring efficiency of energy infrastructure
Universiti Teknologi PETRONAS
INDUSTRIAL PARTNER: MIMOS Ltd

Next generation cathode materials
Enhancing sustainability and performance of energy infrastructure
University of Sheffield
INDUSTRIAL PARTNER: Johnson Matthey



Stronger, lighter, safer materials
3D additive manufacturing
Coventry University
INDUSTRIAL PARTNER: Morganic metal solutions Ltd

ICON International Consortium of Nanotechnologies

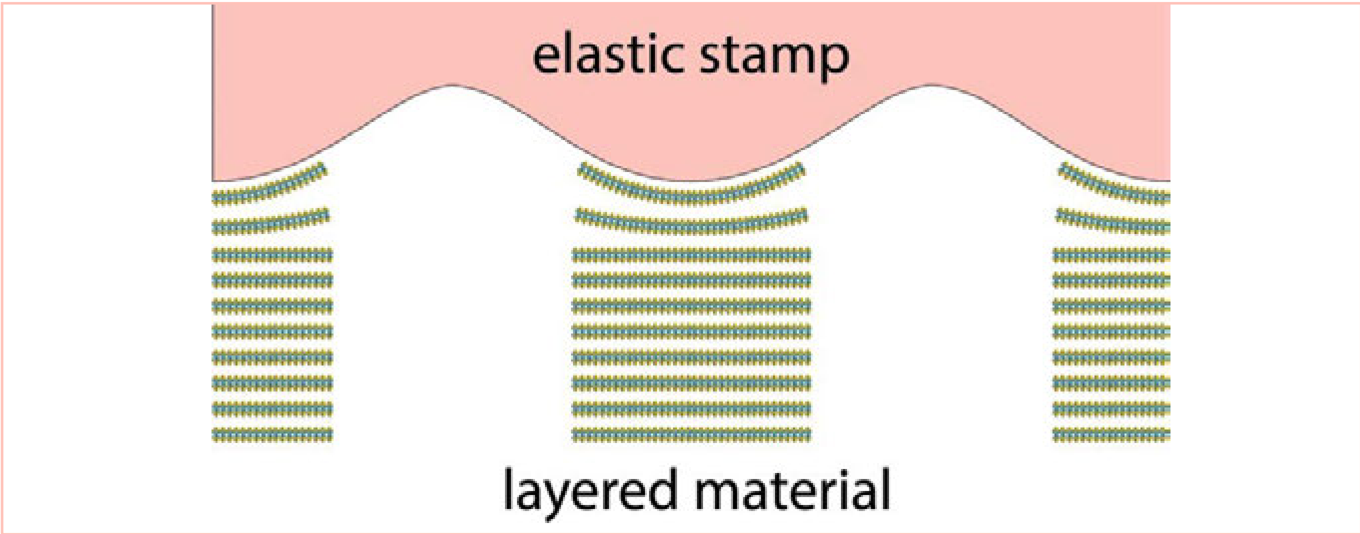
06.
Case Studies

PROJECT MEMBERS

Hannah Gramling (UC Berkeley)
Hayden Taylor (UC Berkeley)
Eric Yeatman (Imperial College)

Ambient Backscattering Sensors using for Ultra Low Cost and Low Power Wireless Applications.

Sensors



Motivation – why did you select your PhD?

Around the time I chose this project, in 2014, it had been a decade since the "discovery" of graphene but I still couldn't find this wonder material in any products outside the lab. Curious where the missing link was between promise and product, so to speak, my advisor and I discovered that the inability to manufacture devices at scale was a critical impediment. As mechanical engineers, we thought we were well-positioned to address this issue. Because semiconductors are critical to digital devices, we decided to focus on creating scalable production processes for atomically-thin semiconducting materials.

Method – what are you doing?

In parallel, we're trying to create scalable nanomanufacturing processes for 2D semiconductors, and try to understand the basic engineering behind these processes so we can design cheaper or higher-performance processes in the future. With the ICON project, we're modeling the separation, or exfoliation, of individual layers from stacks of material that can be millions of layers thick. We want to know how the mechanical properties of the stamp––whatever we're using to separate the layers––influences how many layers peel off, and when. We're especially interested in how these layers separate when they're much wider than they are thick. Being able to produce these very large sheets is advantageous for production of devices. To understand this, we're using simple analytical models and more complex finite element models.

Impact – what have you achieved to date?

From a simple model, we showed that one energetic contribution (bending) dictates how many layers come off, and at what strain they peel apart. This implies that the mechanical properties of the stamp, and specifically how much bending the stamp experiences under an applied load, could govern the exfoliation behavior. I presented these initial findings in a talk at the International Conference on Fracture (Rhodes, Greece, 2017). There are complicated interlayer interactions that we simplified in the analytical model. In order to create a physically accurate model of the exfoliation, we are developing a finite element model that can capture these effects more accurately, and at larger size scales.

Next steps?

Outside of this project, we developed a method for producing arrays of single-layer-thick semiconducting material with much higher yields than any existing methods. This approach relies on very specific techniques and materials, including the use of gold and commercial thermal release tape. Using the knowledge we gain from the modeling work, we hope to understand how best to design stamps to achieve layer selectivity, rather than relying on existing materials and methods. Ideally, the finite element model will give testable hypotheses about the ideal stamp modulus (and pattern aspect ratio) to produce a desired number of layers. We hope that these findings will help researchers and production engineers design effective two-dimensional material production methods, rather than relying on extensive and expensive benchtop experimentation to create only low-yield methods.

PROJECT MEMBERS

Zahra Andaji Garmaroudi (University of Cambridge)
Richard Friend (University of Cambridge)

Compositional engineering of perovskite materials for light harvesting and light emission.

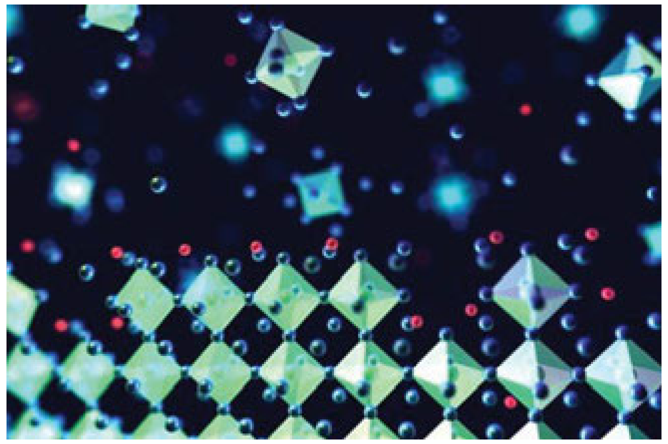
Smart Materials

Motivation – why did you select your PhD?

Sunlight is arguably the most abundant clean source of energy that is capable of enabling "indefinite" and sustainable economic growth, with minimum detrimental impact on the environment. Synthetic perovskites have been identified as possible inexpensive base materials for high-efficiency commercial photovoltaics. They showed a conversion efficiency of up to 23%. Due to their high photoluminesence efficiencies, perovskites are also good candidates for use in light-emitting diodes. This project mainly focuses on the optical and electronic properties of perovskite materials as an emerging semiconductor.

Method – what are you doing?

My research is mainly focused on innovations that could help to boost low-cost, transformative electronics applications including photovoltaics and lighting. My PhD project aims to develop new functional materials, based on lead halide perovskites, for use in light emission and in solar cells.



Impact – what have you achieved to date?

We explored the impact of doping with different additives on the optoelectronic quality and structural properties of metal halide perovskite. We found significant enhancement in both micro-photoluminescence and photoluminescence quantum efficiency. We validate these enhancements in operating solar cells where we obtain a remarkable increase in power conversion efficiency upon addition of additives. Our results are published in high impact journals like Nature, ACS Energy Letters, Advanced Energy Materials, etc.

Publications:

1. Mojtaba Abdi-Jalebi, **Zahra Andaji-Garmaroudi**, Stefania Cacovich, Camille Stavrakas, Bertrand Philippe, Johannes M Richter, Mejd Alsari, Edward P Booker, Eline M Hutter, Andrew J Pearson, Samuele Lilliu, Tom J Savenije, Håkan Rensmo, Giorgio Divitini, Caterina Ducati, Richard H Friend, Samuel D Stranks, Maximizing and stabilizing luminescence from halide perovskites with potassium passivation, Nature, 2018, 555 (497).
2. Mojtaba Abdi-Jalebi, **Zahra Andaji-Garmaroudi**, Andrew J Pearson, Giorgio Divitini, Stefania Cacovich, Bertrand Philippe, Håkan Rensmo, Caterina Ducati, Richard H Friend, Samuel D Stranks, Potassium-and Rubidium-Passivated Alloyed Perovskite Films: Optoelectronic Properties and Moisture Stability, ACS Energy Letters, 2018, 3 (2671).
3. Guangjun Nan, Xu Zhang, Mojtaba Abdi-Jalebi, **Zahra Andaji-Garmaroudi**, Samuel D Stranks, Gang Lu, David Beljonne, How Methylammonium Cations and Chlorine Dopants Heal Defects in Lead Iodide Perovskites, Advanced Energy Materials, 2018, 8 (13).
4. Michal Baranowski, Joanna M Urban, Nan Zhang, Alessandro Surrente, Duncan K Maude, **Zahra Andaji-Garmaroudi**, Samuel David Stranks, Paulina Plochocka, Static and Dynamic Disorder in Triple-Cation Hybrid Perovskites, The Journal of Physical Chemistry C, 2018, 122 (17473)
5. Mojtaba Abdi Jalebi, M Ibrahim Dar, Satyaprasad Premswarup Senanayak, Aditya Sadhanala, **Zahra Andaji Garmaroudi**, Luis M Pazos Outón, Johannes M Richter, Andrew J Pearson, Henning Sirringhaus, Michael Grätzel, Richard Henry Friend, Charge Extraction via Graded Doping of Hole Transport Layers Gives Highly Luminescent and Stable Metal Halide Perovskite Devices, 2018, Science advances (accepted for publication)

Conferences:

1. Zahra Andaji Garmaroudi, Mojtaba Abdi Jalebi, Sam Stranks, Efficient Energy Transfer in Mixed Halide Perovskite Semiconductors, ABXPV (perovskite thin films photovoltaics) conference, 2018.
2. Zahra Andaji Garmaroudi, Mojtaba Abdi-Jalebi, Mohammad Reza Mohammadi, Richard H. Friend, A facile low temperature route to deposit a TiO2 scattering layer for efficient dye-sensitized solar cells, PVTC (Photovoltaic technical conference), 2017.
3. Zahra Andaji Garmaroudi, Mojtaba Abdi-Jalebi, Richard H. Friend, Sam Stranks, Origin of Ion Segregation in Lead Mixed Halide Perovskite, HOPV (International Conference on Hybrid and organic photovoltaics), 2017.
4. Andrew Winchester, Christopher Petoukhoff, Mojtaba Abdi Jalebi, **Zahra Andaji-Garmaroudi**, Vivek Pareek, E Laine Wong, Julien Madéo, Michael K. L. Man, Samuel Stranks, Keshav Dani, Imaging the Inhomogeneous Trap State Distribution in Hybrid Organic-Inorganic Perovskite Films MRS fall meeting, 2018.

PROJECT MEMBERS

Vaggelis Aslanidis (NTUA)
Dimitris Tsoukalas (NTUA)
Christos Papavassiliou (Imperial College London)

Nanoparticle sensor arrays on flexible substrates

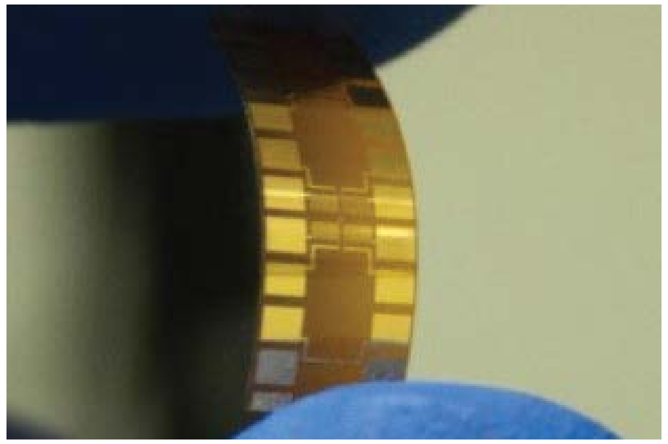
Sensors

Motivation – why did you select your PhD?

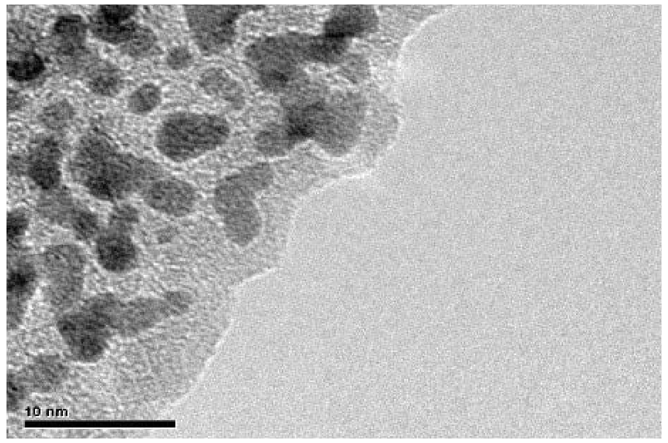
Since the beginning of this specific project, we started to manufacture nanoparticle based sensors which are far more sensitive than the commercial ones. While understanding in depth the possibilities of sensor technology on preventing possible fatal events, we also came to realize certain restrains. The nanoparticle based sensors have proven to be more sensitive but lack signal selectivity. This can lead to misinterpretation of the signal, thus to bad performance of the sensor itself. Our work on strain sensors made it clear that we needed to resolve this problem and create sensors, sensitive only to strain, unaffected from humidity, temperature etc.

Method – what are you doing?

During the previous year, we manufactured strain sensors made either on silicon or on flexible substrates. The devices consist of two gold electrodes, deposited using electron beam evaporator. Between these two electrodes, we deposited platinum nanoparticles, the properties of which we use to sense strain. We studied the sensors (Fig. 1) under different operating conditions. In particular, we studied their sensitivity at different relative humidity values as well as their performance after a large stress cycle as both of these factors are important for the efficient use of the sensors in practice. We found that following the application of a large number of stress cycles, the sensors maintained their sensitivity. However, during measurements under different relative humidity conditions, it we realized that they are very vulnerable to moisture, which affects their performance. In order to overcome this problem, we deposited an aluminum oxide layer of varying thicknesses (Fig. 2) with ALD, to use it as a protective layer for moisture and environmental conditions in general. We also studied the influence of humidity, while the sensors are under strain.



Sensors on flexible polyimide substrate



TEM image of Pt nanoparticles coated with 5 nm aluminum oxide

Impact – what have you achieved to date?

The above mentioned studies showed that the ALD layer adequately protect against moisture. Therefore, the alumina layer proved to be sufficient to protect the nanoparticle sensor from moisture without affecting its sensitivity which exhibits an average value of 40, an order of magnitude higher as compared with continuous metal strain sensors. We presented our findings at MNE 2018 in Copenhagen, at Micro and Nano 2018 conference in Thessaloniki and at the 33rd Panhellenic conference on Solid State Physics and Materials Science 2018 in Cyprus.There are complicated interlayer interactions that we simplified in the analytical model. In order to create a physically accurate model of the exfoliation, we are developing a finite element model that can capture these effects more accurately, and at larger size scales.

Next steps?

For the following year we are preparing a journal publication based on the above work while, at the same time, our goal is to explore new concepts that could potentially further increase the nanoparticle sensor sensitivity. In parallel, I am constructing a Monte Carlo simulation to improve our understanding of the conductive mechanism of the platinum nanoparticle film. Also, we are working on building a read out system that will allow us to read multiple sensors. For the moment we are also discussing with MX3D about the potential use of our sensors on their 3D printed bridge.

PROJECT MEMBERS

Minhyung Ahn (University of Michigan)
Jamie Phillips (University of Michigan)
Steven Yalisove (University of Michigan)

Ultrafast nanostructuring of wide bandgap SiC for electronics in harsh environments

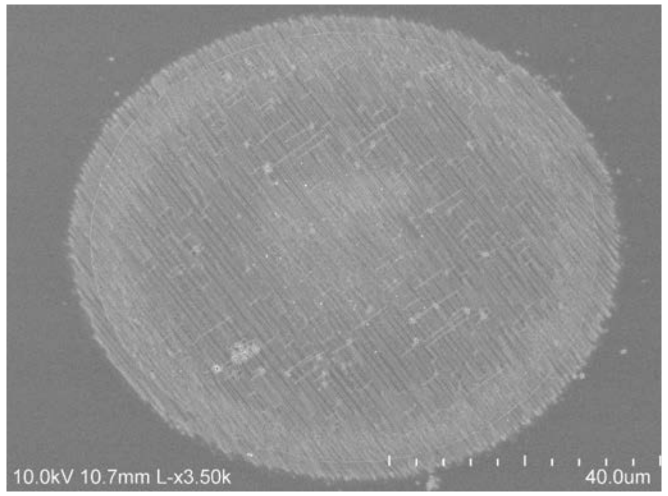
Energy and Storage

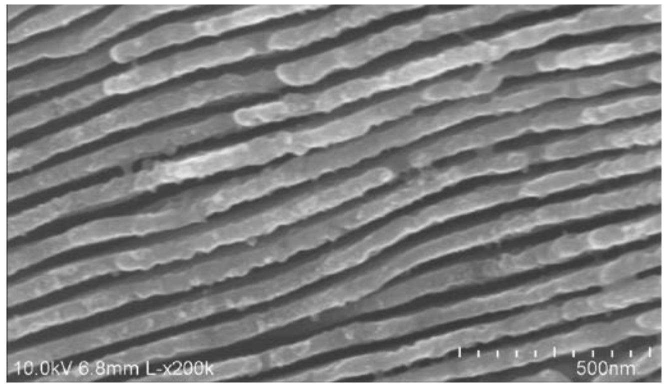
Motivation – why did you select your PhD?

Studying the world of 'ultrafast or femtosecond (10-15 s)' is very attractive itself. Pushing the imagination to the time scale of atomic vibration encourage my spirit of inquiry. Ultrafast lasers, such as their ability to offer high power on extremely short timescales that can be faster than thermal interactions. As a result, laser-material interactions show unique properties such as laser induced periodic surface structures (LIPSS) and point defect generations. I want to connect these unique properties into practical applications during my PhD.

Method – what are you doing?

Our research is mainly focused on ultrafast laser-material interactions especially on wide band gap materials. Wide band gap materials are important for electronic devices operating in harsh environment, but the processing is challenging due to high temperature requirement. On the contrary, high energy ultrashort laser pulse allow the material processing even in room temperature. We have been tried to understand underlying physical mechanism of ultrafast laser-material interactions which the theory is still under debate. Based on experimental results, we develop the model of the interactions and try to apply the unique properties of ultrafast laser-material interactions to material processing. For example, the creation of the periodic surface structures can enhance the optical and surface properties. Ultrafast laser irradiation can modify the electrical properties of wide band gap materials by point defect generation. To demonstrate the ideas, we characterized the surface morphologies and crystallinity of ultrafast laser irradiated materials and built electrical devices such as Schottky diode.





Impact – what have you achieved to date?

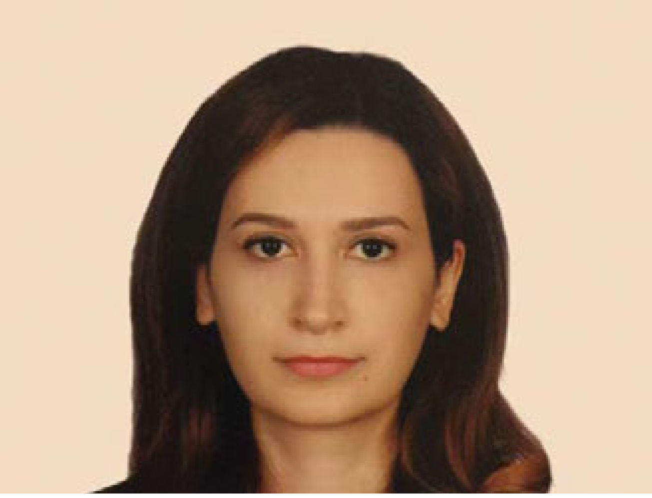
We showed room temperature electrical modification can be achieved by ultrafast laser processing on 4H-SiC. This research demonstrated that ultrafast laser can be low cost and unique tool for material processing of wide band gap materials which has been challenged by high processing cost due to stability of the materials. These results are published in 'Journal of Applied Physics 123 (14), 145106 (2018)'. We further expand the scope of wide band gap material to β-Ga2O3 which has been noticed by the next generation power electronics material. We discovered ultrafast laser irradiated β-Ga2O3 exhibits thermal cracking behavior which has not been observed in other materials. We also reported the crystal properties of ultrafast laser irradiated β-Ga2O3 for the first time. These results would be good reference for the future ultrafast laser processing research. The results are in reviewing process for journal publication.

Next steps?

There are still many unanswered questions in our results such as the characterization of the generated defects and dynamics of LIPSS formation in wide band gap semiconductors. we are seeking to further the understanding of point defect formation, while also seeking to directly apply our new knowledge to real devices such as SiC based resistive memory and Ga2O3 UV detector. The applying the intentional point defects to SiC based resistive memory devices can increase the electrical properties. Morphological change of ultrafast laser irradiated surface can enhance optical properties of Ga2O3 based UV solar blind detector which is suitable for safety sensor in harsh environment.

07.

Awards and Achievements



Zahra Andaji Garmaroudi wins 1st place in the prestigious CUE competition

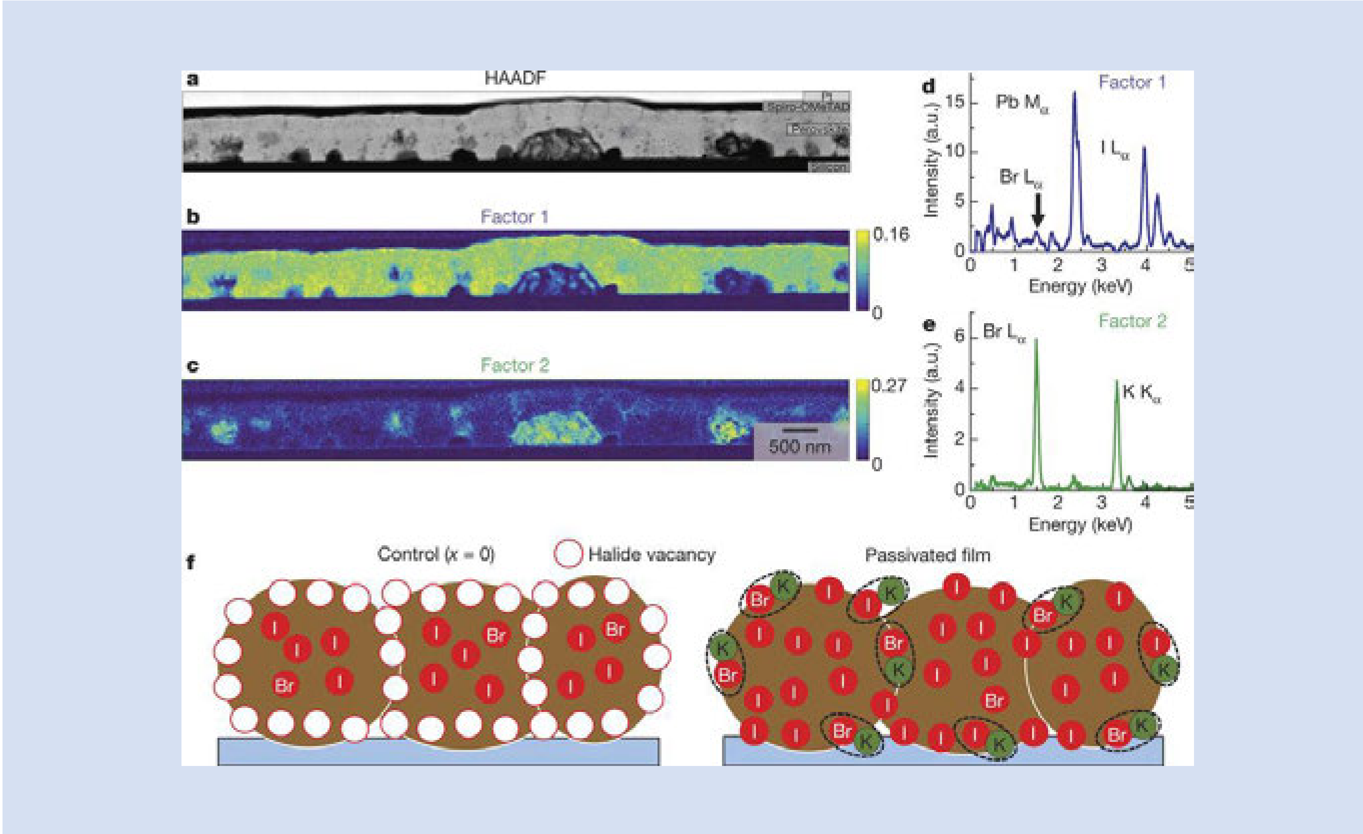
Zahra won the 2018 Cambridge University Entrepreneurs (CUE) competition in the field of Science and Technology with a commercialisation ready disruptive photovoltaic and lighting technology. This technology would provide a cheaper and safer alternative to kerosene lamps that are used in communities in the developing world. This can also find applications in wireless sensors networks, internet of thing and consumer electronics such as smart phones and wearable electronics. They could also be used by people displaced by natural disasters.

Ben Craig awarded Chartered Engineer of the Institute of Mechanical Engineers.

Ben Craig was recently awarded Chartered Engineer of the Institute of Mechanical Engineers. This award recognised three and a half years working for Dstl, MOD as a gas turbine engineer on future fighter jet concepts, and his plan going forwards to make an impact in the energy storage nanomaterials field as a postgraduate researcher. This early achievement of professional membership demonstrates the drive, impact and ambition of Lloyd's Register Foundation International Consortium of Nanotechnologies students.

The International Physicists' Tournament

The International Physicists' Tournament (IPT) is an international undergraduate physics tournament where students have a year to solve then present and defend a pre-selected set of unanswered and open ended physics questions - essentially a 'world cup' of physics. Courtesy ICON's support during his PhD David Collomb has been able to preside over this tournament, working towards providing undergraduate students with an early taste of scientific research; as well as giving him valuable project and team management lessons along the way.



Nature publication

Our students are publishing in Nature. For example, Zahra Andaji Garmaroudi 's work on the paper entitled 'Maximizing and stabilizing luminescence from halide perovskites with potassium passivation' was published in Nature in March 2018. This research is focussed on innovations that could help boost low-cost, transformative electronics such as solar cells and lighting. Great work Zahra!

2018 Electronics Travel Awards

We are delighted that the inaugural PhD award, following the highly competitive global application process, was made to ICON student Spyros Daskalakis. Spyros used his award to attend the International Microwave Symposium in Philadelphia.

EIT RawMaterials Battery Challenge

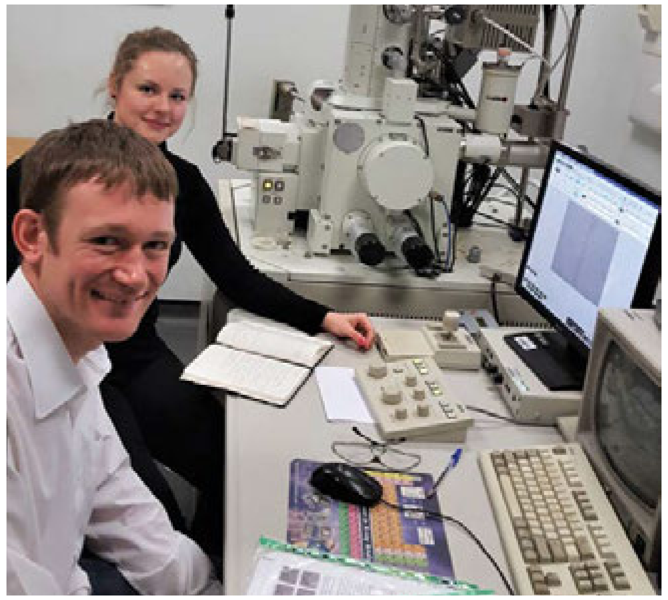
ICON student Ben Craig has been selected to pitch for the EIT Raw Materials Battery Challenge, which calls for ideas to radically change raw materials sourcing, processing and design for energy storage in electric mobility. We wish Ben the best of luck with his pitch in March 2019.

08.
Changing Minds

Introducing the nanoworld to young students

In June we hosted over 50 children, age 7-11, from West Dean Primary School on our introduction to the nanoworld programme. We were ably assisted by 5 female students, from St Anne's School Southampton, who acted as peer educators to deliver our programme. These peer educators had been identified via our interaction with the local Royal Academy of Engineering outreach network. During the day the children were introduced to the nanoworld, used a microscope, learnt the correct gowning process for a cleanroom and conducted their own lithography experiment.

ICON addresses several outstanding safety challenges. We particularly welcome collaborations with industrial stakeholders whose vision aligns with ICON.



Ben and Theresa taking measurements using a SEM whilst working on a more efficient battery design.

Nurul producing nanostructured elements for hydrogen sensors.

09.
Social

Sophia, Charanraj, Minhyung and Alize at the Royal Institution Library.

Charanraj, Jamie and Spyros.

ICON students at the Foundation's headquarters in London.

We believe in balance, so ICON isn't just about the research and work without any fun!

Dinner at the Royal Institution in London after a tour that included Faraday's Laboratory.

ICON
International
Consortium of
Nanotechnologies

T. +44 (0)23 8059 9512
E. info@lrf-icon.com

Mountbatten Building 53,
University of Southampton
Southampton
SO17 1BJ
UK

www.lrf-icon.com