UK-Japan Workshop on Advanced Materials

24-25 February 2016
University of York

Introduction

Both the U.K. and Japan have strong standing positions in the field of 2-dimensional device applications and have been prioritising it as a strategic research area. During this workshop, recent research trends in the U.K. and Japan in the field of Advanced Materials will be presented. Furthermore, the latest research programs implemented in Japan, including those on atomic or molecular 2-dimensional functional films, will be introduced. This workshop will give participants an opportunity to increase knowledge exchange in the field of Advanced Materials, and to discuss how to develop this area by leveraging international networks of research interconnections between the two countries.

Venue Location

24 February 2016

A) P/L 002 Lecture Theater, University of York, Heslington, York YO10 5DD

25 February 2016

A) Departments of Electronics and Physics, University of York, Heslington, York YO10 5DD

B) York JEOL Nanocentre, Helix House, Science Park, University of York, Heslington, York, YO10 5BR

Access to University of York

From the York station, it takes about 10-15 minutes by taxi or by uni bus (Line number 44) or ftr bus (Line number 4), both of which runs every 10-20 min.

Local Organising Committee

Prof. Atsufumi Hirohata (Organiser)

Department of Electronics, University of York

Ms. Kumiko Nakayama (Administrative support)

Japan Science and Technology Agency (JST) Paris Office

Programme

24 February 2016

12:00 **Registration**

13:00 **Welcome Remarks** *Chair: Atsufumi Hirohata, Professor at the University of York*

Tba

Ms. Kana Asano (Chief, Department of Innovation Research Department of Innovation, JST)

13:15 **Session I: 2D functional molecular/atomic thin films**

Chair: Atsufumi Hirohata, Professor at the University of York

JST/CREST on "2D Materials" - Research Supervisor's Policy and the Invitation for Applications -

Dr Atsushi Kurobe (Senior Fellow, Corporate Research & Development Center, Toshiba Corporation)

13:45 **Towards imaging and control of multiferroic domains in insulating antiferromagnets**

Prof. Paolo Radaelli (Department of Physics, University of Oxford)

14:15 **Formation of 2D skyrmion lattice above room temperature**

Dr Yasujiro Taguchi (Center for Emergent Matter Science, RIKEN)

14:45 **Nanocharacterisation for graphene and silicon two-dimensional device structures**

Dr Yoshishige Tsuchiya (Electronics and Computer Science, University of Southampton)

15:15 **Tea and Coffee**

15:30 **Session II: Functional materials for 2D device applications**

Chair: Yoshishige Tsuchiya, Lecturer at the University of Southampton

Heusler alloys for spintronic devices

Prof. Atsufumi Hirohata (Department of Electronics, University of York)

16:00 **2D materials in plasmonics**

Dr Jan Mertens (Department of Physics, University of Cambridge)

16:30 **Graphene-based hybrid structures for spintronic applications**

Dr Seiji Sakai (Advanced Research Center, JAEA)

17:00 **Exfoliated WS2 Nanosheets as Photoanodes for Photoelectrochemical Cells**

Dr Cecilia Mattevi (Department of Materials, Imperial College London)

17:30 **Closing Remarks** *Chair: Atsufumi Hirohata, Professor at the University of York*

Tba

19:00 **Dinner reception**

-21:00

25 February 2016

10:00 **Meet at the Reception in the Departments of Electronics and Physics**

10:00 **Laboratory Visit 1 (Departments of Electronics and Physics)**

Prof. Atsufumi Hirohata (Dept. of Electronics):
Nano-spintronic devices <http://www-users.york.ac.uk/~ah566/>
Dr Eugene Avrution (Dept. of Electronics: Photonic devices
<http://www.york.ac.uk/electronics/research/physlayer/microwaveoptic/>
Prof. Kevin O'Grady (Dept. of Physics):
Magnetic materials <http://www.york.ac.uk/physics/people/ogrady>
Prof. Sarah Thompson (Dept. of Physics):
IR measurements <http://www.york.ac.uk/physics/people/thompson/>
Dr Steve Tear (Dept. of Physics):
Surface analysis <http://www-users.york.ac.uk/%7Espt1>
Dr Gonzalo Vallejo-Fernandez (Dept. of Physics):
Magnetic measurements <http://www.york.ac.uk/physics/people/vallejo-fernandez/>
Dr Andrew Pratt (Dept. of Physics): Organic devices
<https://pure.york.ac.uk/portal/en/researchers/andrew-pratt(27e9f19e-c22b-4d86-a608-d7d054a1614b).html>

11:00 **Bus transportation**

11:10 **Laboratory Visit 2 (York JEOL Nanocentre)**

Prof. Pratibha Gai (Depts. of Physics/Chemistry):
Nano-materials <http://www.york.ac.uk/physics/people/academic/gai/>
Prof. Edward Boyes (Depts. of Electronics/Physics):
Nano-structural studies <http://www.york.ac.uk/physics/people/academic/boyes/>
Prof. Thomas Krauss (Dept. of Physics):
Photonic devices <http://www.york.ac.uk/physics/people/krauss/>
Dr Vlado Lavarov (Dept. of Physics):
TEM analysis <http://www.york.ac.uk/physics/people/academic/lazarov/>

12:00 **Bus transportation to York City Center**

Abstract

Name (Title):

Atsushi Kurobe (Dr.)

Affiliation:

1. Senior Fellow, Corporate Research and Development Center, Toshiba Corporation
2. Research Supervisor, JST/ CREST on "Development of Atomic or Molecular Two-Dimensional Functional Films and Creation of Fundamental Technologies for Their Applications

Presentation Title:

JST/CREST on "2D Materials" - Research Supervisor's Policy and the Invitation for Applications -

ABSTRACT:

Recently, there has been a growing interest in 2D materials, such as graphene and transition metal dichalcogenides (TMDs), as they offer intriguing new phenomena which might be useful in future applications[1]. In 2014, Japan Science and Technology Agency (JST) launched a new CREST[2] research-area "Development of Atomic or Molecular Two-Dimensional Functional Films and Creation of Fundamental Technologies for Their Applications"[3], where the target area is "2D materials" in short. CREST is a funding program for team-oriented research with the aim of achieving the strategic goals set forth by the government ("2D materials" in the present case), by promoting and encouraging the development of break-through technologies. We started to select proposals from 2014, and this year will be the last (third) year to call for proposals. We would like this research area to cover an extensive range of disciplines. Fig.1 shows the overview of the received proposals in 2014 and 2015. Total number of applications was 141 (86 in 2015, 55 in 2016); 75 from Physics, 30 from Chemistry, 27 from Engineering, and 9 from Biology. The diversity in the research expertise is evident. Because of financial difficulties, we could accept only 7 best proposals after intensive discussions with 10 research-area advisors. We are looking forward to welcoming additional first class research teams through the third call for proposals to be scheduled this spring, which would complete the research portfolio of this research area.

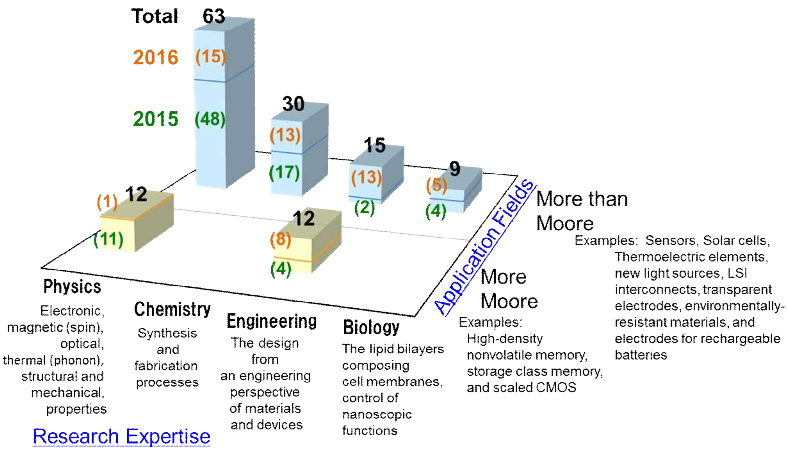

Fig. 1 Portfolio of the received proposals in 2015 and 2016

References:

[1] For example: A. C. Ferrari et al., Nanoscale 7, 4587 (2015); F. Bonaccorso et al., Science 347 1246501(2015); G. Fiori et al., Nature Nanotechnology 9, 768 (2014); M. Xu et al., Chem. Rev. 113, 3766 (2013). [2] CREST: Core Research for Evolutionary Science and Technology [3] http://www.jst.go.jp/kisoken/crest/research_area/ongoing/bunyah26-4.html

Corresponding Author: A. Kurobe

Title: Towards imaging and control of multiferroic domains in insulating antiferromagnets.

Authors: N. Waterfield Price,[1,2] R. D. Johnson,[1,3] W. Saenrang,[4] F. Maccherozzi,[2] S. S. Dhesi,[2] A. Bombardi,[2] F. P. Chmiel,[1] C.-B. Eom,[4] and P. G. Radaelli[1]

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[3]ISIS Facility, Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, United Kingdom
[4]Department of Materials Science and Engineering, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA

Electrical manipulation of spins in insulators is a promising route to a new generation of fast, low-power electronics. In device architectures based on thin films, information would be stored by antiferromagnetic domains, manipulated using electric fields without any charge or spin current and retrieved by reading the state of a ferromagnetic top layer, coupled through the interface to the antiferromagnetic spins. However, imaging and controlling antiferromagnetic domains in these systems is currently a major challenge. I will show that the cycloidal magnetic domains and associated lattice strain in epitaxial films of the prototypical multiferroic $BiFeO_3$ can be measured quantitatively and imaged down to a few 100nm using a combination of non-resonant dichroic X-ray magnetic diffraction, XMLD-PEEM and neutron scattering [1]. The domain size, spin rotation pattern and associated strains are very different from the bulk even in rather thick films (~1 um). In particular, our findings suggest a much-enhanced magneto-elastic coupling, which could provide a new 'handle' for precise control of these domains at the nanoscale.

[1] N. Waterfield-Price *et al.*, "Imaging of coherent magneto-elastic domains in multiferroic $BiFeO_3$ films", http://arxiv.org/abs/1512.05242

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Presentation Title:
Formation of 2D skyrmion lattice above room temperature

Short CV:
Yasujiro Taguchi received his PhD in engineering from the University of Tokyo. He worked as a research associate at the University of Tokyo in 1997-2002, and moved to the Institute for Materials Research, Tohoku University, as an associate professor in 2002. In 2007, he moved to RIKEN as a team leader. Since 2013, he has been a team leader at Center for Emergent Matter Science. His research interest is to explore and synthesize novel strongly-correlated electron materials that show gigantic cross-correlation responses, such as multiferroics, thermoelectrics, and skyrmion materials.

ABSTRACT:
Magnetic skyrmions are nanometric particle-like objects in magnets whose stability is topologically protected due to their vortex-like spin structures, and therefore have recently attracted increasing attention from the viewpoints of possible technological applications for spintronics, as well as their interesting emergent electro-magnetic responses [1]. Toward technological applications, however, it is required to find materials that exhibit the skyrmion formation at and above room temperature.

Recently, we have discovered [2] a new class of cubic chiral magnets, namely β-Mn-type Co-Zn-Mn alloys, which host the skyrmion lattice with unique spin helicity at and above room temperature. Combined investigations in terms of Lorentz transmission electron microscopy, magnetization, and small angle neutron scattering (SANS) measurements unambiguously have revealed the formation of the skyrmion crystal under the application of magnetic field in both thin-plate and bulk forms. Our findings demonstrate the possibility that new skyrmion-hosting systems can be found in a variety of non-centrosymmetric crystal symmetries, which will stimulate further experimental exploration of other realization. Likewise, our discovery of stable skyrmion beyond room temperature overcomes a major difficulty in integrating the skyrmions into technological spintronics devices and applications.

References:
[1] N. Nagaosa, and Y. Tokura, Nature Nanotech. 8, 899 (2013).
[2] Y. Tokunaga, X. Z. Yu, J. S. White, H. M. Ronnow, D. Morikawa, Y. Taguchi, and Y. Tokura, Nature Commun. 6:7638 doi: 10.1038/ncomms8638 (2015)

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Presentation Title:
Nanocharacterisation for graphene and silicon two-dimensional device structures

Short CV:
Dr Yoshishige Tsuchiya is a Lecturer in Nanotechnology of the University of Southampton. He received a PhD in multidisciplinary science at the University of Tokyo in 2001 and then joined the Tokyo Institute of Technology as an Assistant Professor being actively involved in the JST CREST/SORST 'Neo-Silicon' project. Since he moved to Southampton, he worked as a Co-I of an EU FP7 project on nanoelectromechanical (NEM) molecular sensors and 2 EPSRC projects on Si quantum computing devices and energy-efficient NEM switches. His current interest includes silicon-graphene-integrated nanoscale devices for energy-efficient and quantum computing applications. He has over 170 publications including 58 journal papers.

ABSTRACT:
In recent years a trend of development of nanodevice technology has been changed from intensive dimensional miniaturization along with Moore's law to "More than Moore", where heterogeneous integration of exotic materials and dissimilar systems is considered to be of central importance. Two-dimensional materials such as graphene have been attracting great attention to be used for nanoelectronic and nanoelectromechanical devices. Whereas for integrated nanodevices, nanocharacterisation methods such as Scanning Probe Microscopy (SPM) play a vital role for in-depth understanding of their operational mechanism.

In this presentation, our recent attempts of nanocharacterisation of silicon/graphene two-dimensional systems will be shown. In situ Kelvin Probe Force Microscopy (KPFM) is applied for silicon nanowires and Field-Effect-Transistors (FETs) on thin Silicon-on-Insulator (SOI) and how the electrical characteristics and surface potential profile of the devices are correlated has been clarified [1,2]. Tip-Enhanced Raman Spectroscopy (TERS) is applied for suspended graphene on a silicon nanowire array and enhancement of the defect density on the suspended graphene has been successfully detected with high spatial resolution [3]. Annealing effects on graphene on SiC have been also investigated by using Raman spectroscopy, X-ray Photoelectron Spectroscopy (XPS), and Atomic Force Microscopy (AFM) [4].

References:
[1] S. Ye, M. K. Husain, S. Saito and Y. Tsuchiya, 2015 E-MRS Fall meeting, Warsaw, Poland. [2] S. Ye, M. K. Husain, S. Saito and Y. Tsuchiya, MNE2015, The Hague, The Netherlands. [3] Y. Nagahisa, T. Zelai, J. Reynolds, L. Boodhoo, C. C. Huang, D. W. Hewak, E. Tokumitsu, H. Mizuta, and Y. Tsuchiya, MMC2015, Manchester, UK. [4] Y. Nagahisa, Y. Tsuchiya, and E. Tokumitsu, Mat. Sci. Forum 821-823, 949 (2015).

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Presentation Title:
Heusler alloys for spintronic devices

Short CV:
Dr Atsufumi Hirohata is a Professor at the Department of Electronics in the University of York. He has over 15 years of experience in spintronics, ranging from magnetic-domain imaging to spin-current interference. Before coming to York in 2007, he was a researcher at RIKEN, where he designed a spin-current interference device. He was before working at Tohoku University and Massachusetts Institute of Technology. He received his PhD in Physics at the University of Cambridge in 2001. He was originally graduated from Keio University for his BSc and MSc studies in Physics.

ABSTRACT:
This talk reviews the requirements for the Heusler-alloy 2-dimensional films to be used in spintronic devices [1],[2]. Four key requirements are identified to be large giant magnetoresistance (GMR), large tunnelling magnetoresistance (TMR), large spin-transfer torque and fast spin resonance. These requirements can be achieved by utilising the fundamental properties of the Heusler alloys, such as atomic substitution, generalised Slater-Pauling behaviour, crystalline ordering, half-metallicity, low damping constant, high Curie temperature, good lattice matching and large activation volume. To date the main obstacles for the Heusler-alloy films to be used in spintronic devices are their (i) high crystallisation temperature, (ii) interfacial atomic disordering and (iii) small activation volume. Here, we have investigated these properties for both epitaxial and polycrystalline films and have found a favourable crystallisation orientation to lower the ordering temperature by inducing a two-dimensional growth. We have demonstrated the effect of interfacial dusting to maintain the crystalline ordering from atomic diffusion by annealing. We have also established the above requirements can be controlled by the competition between the structural and magnetic volume, the latter of which can be defined as activation volume. In all cases, the polycrystalline films have found to be advantageous over the epitaxial ones due to their strain-free growth with controlled grain size. We anticipate that the optimised polycrystalline films can be used in the next generation hard disk read heads and magnetic random access memory cells [3].
This work has partially been supported by EU-FP7 (NMP3-SL-2013-604398), EPSRC (EP/I000933/1, EP/K03278X/1 and EP/M02458X/1).

References:
[1] A. Hirohata *et al.*, *Spin* **4**, 1440021 (2014).
[2] A. Hirohata *et al.*, *Appl. Phys. A* **111**, 423 (2013).
[3] A. Hirohata and K. Takanashi, *J. Phys. D: Appl. Phys.* **47**, 193001 (2014).

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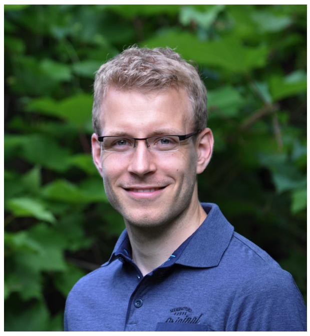

Presentation Title:
2D materials in plasmonics

Short CV:
Jan Mertens is a post-doctoral research fellow at the NanoPhotonics Centre of the Cavendish Laboratory in Cambridge. He joined the Centre as Winton scholar in 2011 and finished his PhD in physics in July 2015. He specialized on the study of the interaction of light with metallic nanostructures separated from each other by 2D materials.

ABSTRACT:
We use 2D materials to create stable subnanometre junctions in plasmonic dimers. Such ultra-small plasmonically-coupled gold cavities can be tuned optically using laser irradiation.

Subnanometre-scale plasmonic junctions are of wide interest due to their ability to confine and strongly enhance optical fields in the gap. However, separating junctions in a robust and precise manner is extremely challenging on these length scales. Here, precise separation between 80 nm gold nanoparticles and a gold mirror (NPoM) is achieved using graphene and molybdenum disulphide (MoS_2). This allows us to produce a robust and easy to fabricate equivalent geometry to the NP dimer system.

We study individual NPoMs with graphene [1] and MoS_2 [2] using dark field spectroscopy (Fig. 1a). A new splitting of the surface coupled resonance is observed, which originates from a strong coupling between non-radiative, strongly localised plasmonic gap modes and dipole plasmons (Fig. 1b). Gap plasmons are present in nanocavities between AuNP and gold surface whereas the dimer plasmon acts as an antenna for the far-field coupling.

Irradiation of individual NPoMs with a UV laser reveals how such plasmonic modes directly trace atomic-scale changes of the cavity morphology in real time (Fig.1c).[2] During optical irradiation, spectral shifts of plasmonic modes are observed, originating from increases in the nanoparticle facet size at the junction, thus altering the cavity resonances.

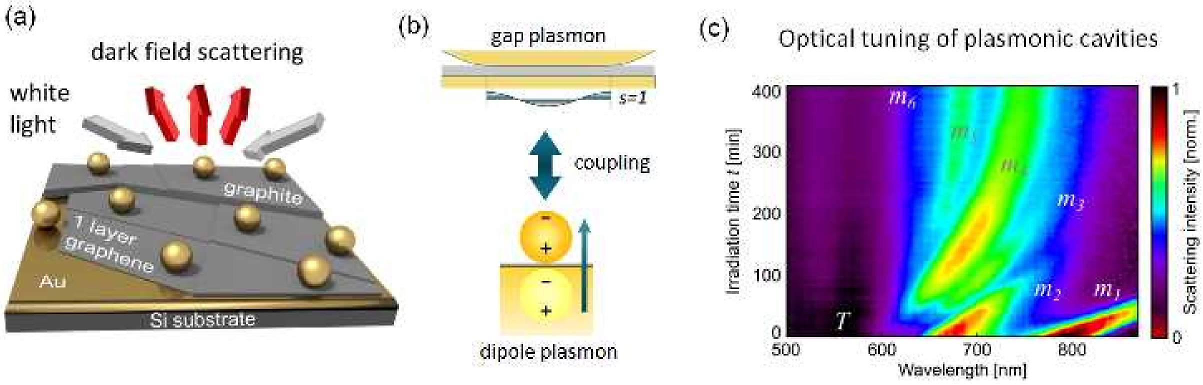

Fig 1. (a) Scattering from AuNPs on exfoliated graphene layers. (b) Coupling between gap and dipole plasmon in the NPoM geometry. (c) Optical tuning of scattering from an individual NPoM.

References:
[1] J. Mertens, A. L. Eiden, ... , A. C. Ferrari, and J. J. Baumberg, Nano Letters **13**, 5033 (2013)
[2] D. O. Sigle, J. Mertens, ... , C. Tserkezis, J. Aizpurua, and J. J. Baumberg, ACS Nano **9**, (2015)

Name (Title):
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Presentation Title:
Graphene-based hybrid structures for spintronic applications

Short CV:
Dr. Seiji Sakai is currently Principal Researcher of Japan Atomic Energy Agency and deputy leader of spin-polarized positron beam group. Dr. Sakai is also Visiting Researcher of National Institute for Materials Science (NIMS). Specialization: nanomaterials science and molecular spintronics.

ABSTRACT:
Graphene- and its related materials attract great attention as a candidate material for future spintronics. Despite considerable efforts in recent years, it is still challenging to efficiently manipulate the spins of conduction electrons in graphene-based spintronic devices. Considering the two-dimensional (2D) nature of graphene, the understanding of the spin-related properties in the graphene-based 2D hybrid structures is of special importance for realizing efficient spin manipulation in the devices. In this talk, I will present our recent results on the spin-related properties of the 2D hybrid structures of graphene-related materials and magnetic materials [1-6]. The central topic of this talk will be on the magnetic proximity effect in the single layer graphene (SLG)/half-metallic manganite ($La_{0.7}Sr_{0.3}MnO_3$, LSMO) junctions. By employing spin-polarized metastable He deexcitation spectroscopy (SPMDS) with an extreme sensitivity to the surface electronic states [7], we successfully demonstrated that in the SLG/LSMO junctions a large spin polarization parallel to the spin polarization direction of LSMO is induced in the graphene π band without giving rise to significant changes in the electronic structures of SLG, which are useful for carrier and spin transport. Interestingly, it was also shown that the spin polarization degree in SLG on the surface of the SLG/LSMO junctions is significantly higher than that on the LSMO surface without SLG, suggesting the thermal robustness of the π band spin polarization in SLG. Our study revealed the potential applications of the graphene-magnetic oxide hybrid structures in realizing high performance spintronic devices based on graphene.

References:
[1] S. Entani et al., Carbon 61, 134 (2013). [2] X. Sun et al., J. Appl. Phys. 114, 143713 (2013). [3] Y. Matsumoto et al., J. Mater. Chem. C 1, 5533 (2013) [4] M. Ohtomo et al., Appl. Phys. Lett. 104, 051604 (2014) [5]. X. Sun, et al., J. Appl. Phys. 115, 17C1173 (2014). [6] S. Sakai et al., in submission. [7] Y. Yamauchi et al., Appl. Surf. Sci. 169, 236 (2001).

Name (Title):
Cecilia Mattevi (Dr.)

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Presentation Title:
Exfoliated WS2 Nanosheets as Photoanodes for Photoelectrochemical Cells

Short CV:
Cecilia Mattevi is a Lecturer and Royal Society University Research Fellow in the Department of Materials at Imperial College London since October 1, 2012. Her research interests centre on science and engineering of novel 2D atomically thin semiconducting materials to enable applications in optoelectronics and energy storage. Mattevi's research group focuses on the synthesis of these materials and on the fabrication of devices based on planar structures and highly porous 3D hierarchical structures where a diverse range of assembly methods is employed. Prior to this appointment Cecilia, gained her PhD in Materials Science in 2008 undertaking her doctoral research at the European Synchrotron Facility Elettra, Trieste, IT. Cecilia then joined the group of Prof. Manish Chhowalla in the Materials Science and Engineering Department at Rutgers University, NJ, USA as a postdoctoral associate where she worked on chemically derived graphene for large area optoelectronic applications. In 2010, Cecilia joined Imperial as Junior Research Fellow.

ABSTRACT:
Single-layer group VI- transition metal dichalcogenides (TMDCs) are actively investigated as potential candidates for future technologies. In particular, their strong light-matter interaction, high charge carrier mobility and their atomically thin nature, render them promising novel materials for optoelectronic applications such as photovoltaic cells and light emitting devices. WS_2 have been identified to be potentially suitable for photoassisted water oxidation, thus oxygen evolution reaction (OER), owing to its favorable band edge energies in respect to the redox potentials of water, relatively high absorption of incident light, and good stability in aqueous solutions [1].

We report exfoliated WS_2 flakes as photoanode for water oxidation in a complete photoelectrochemical cell (PEC). Atomically thin layers of WS_2 were isolated from their bulk counterpart via liquid phase exfoliation of lithiated WS_2 [2]. Colloidal suspensions of predominantly single layered flakes were attained and uniform and continuous films of exfoliated WS_2 were assembled onto FTO electrodes. WS_2 electrodes exhibit positive photocurrent density at excitation wavelengths below the direct band gap edge at 630 nm (2 eV), confirming their n-doped nature and applicability as photoanodes for solar fuels production. Chronoamperometry characterization shows that the films are stable and suggests that improvements in the stacking of WS_2 nanosheets could enhance the transport of photoexcited carriers. These results demonstrate the capability of monolayer WS_2–based electrodes to oxidise water in a complete PEC at low overpotentials and their possible use into PECs [3].

References:
[1] H. Zhuang, R. Hennig, J. Phys. Chem. C, 117, 20440 (2013).
[2] H.L. Tsai, J. Heising, J.L. Schindler, C.R. Kannewurf, M.G. Kanatzidis, Chem. Mater. 9, 879 (1997).
[3] F. Pesci et al. submitted 2016.