Two-dimensional materials for next-generation electronics, optoelectronics and antipathogenic coatings: Fundamentals to Applied Industrial Solutions

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Our Research Focus Areas

Our current research activities include

- Electronic materials synthesis (Two-dimensional Materials)
- Light-matter interactions for photodetectors and neuromorphics
- Stitching heterostructures of dissimilar materials
- Biomaterials for antipathogenic coatings
- Flexible optoelectronics
- Research – Industry Partnerships

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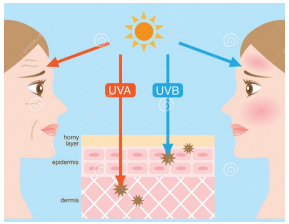
Technologies of the Future | Materials Driven

Industry Demand → New fundamental discoveries → Scalable manufacturing → Prototyping → Product

UV dosage indicators

ZEISS



Smart garments

GOLDILOCKS

Space Industry Hub

Esper: Satellite imaging technologies

Artificial retinas

BIONIC VISION TECHNOLOGIES

Antimicrobial Cannulas

TuCann Medical

Chemical sensors

Australian Government
Department of Defence

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Smart energy solutions for buildings

Chemical-free sanitisers

Wintermute Biomedical

3

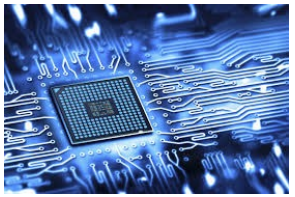
Two-dimensional materials

2D and unit-cell thick materials

Synthesis

- Solid phase
- Liquid phase
- Vapour phase

Applications



Energy efficiency

Chromic composites, Engine-oil lubrication

Electronics

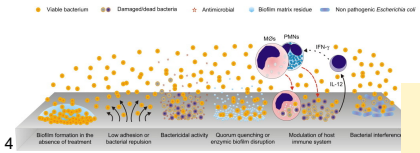
FETs, memory devices

Optoelectronics

Photodetectors, LEDs
Light-driven artificial neural networks for event-based detection

Flexible devices

Strain engineering of 2D materials



Healthcare

Antibacterial and antifungal coatings

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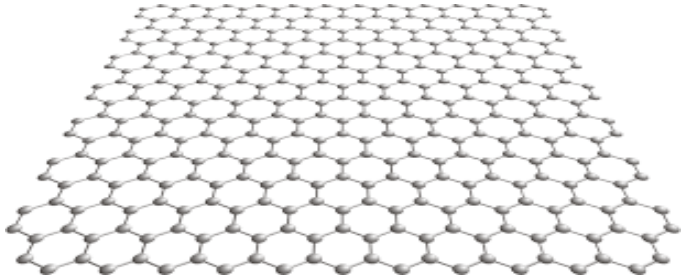
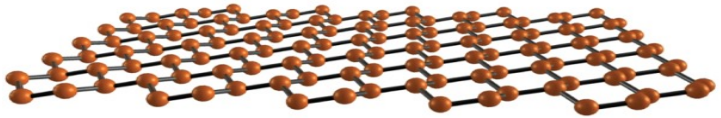
2D Materials

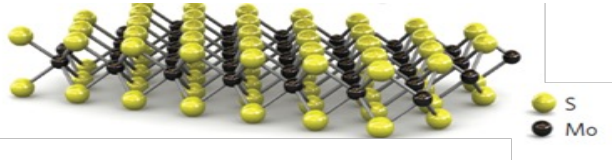
2D materials – Free standing, atomically thin single layer of a layered material.



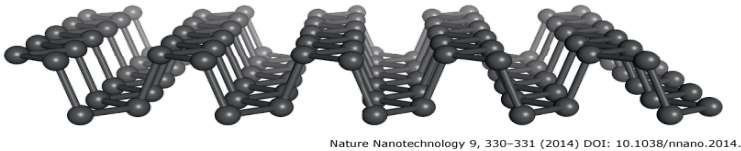
Graphene



Silicene



Molybdenum disulphide



phosphorene

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Phosphorene ?

Exists in a layered crystal form (Black phosphorus)

Allows easy exfoliation of layers.

Thickness dependent bandgap

Exhibits a natural direct bandgap,
which increases with reducing thickness

Highly flexible

Young’s modulus smaller than graphene

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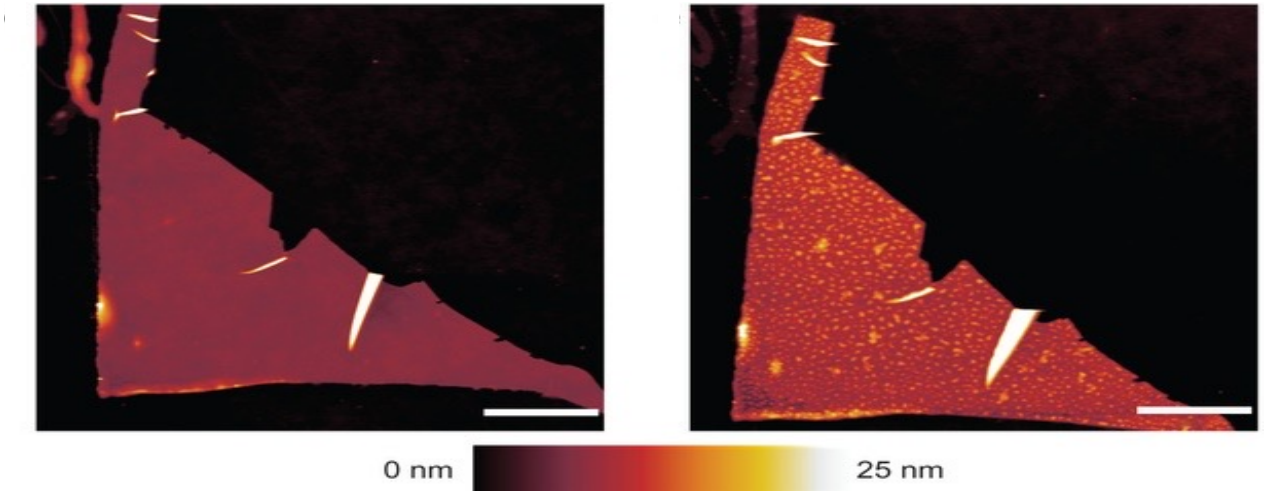
Problem with phosphorene

Degrades rapidly in an ambient environment

Initial reports suggested humidity causes degradation



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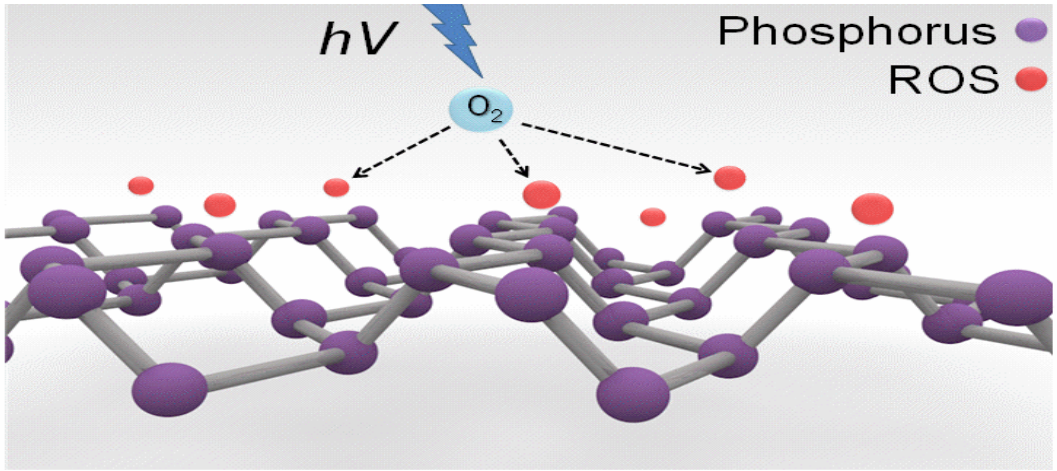
What degrades phosphorene

Photo-oxidation does!!

Humidity facilitates this process



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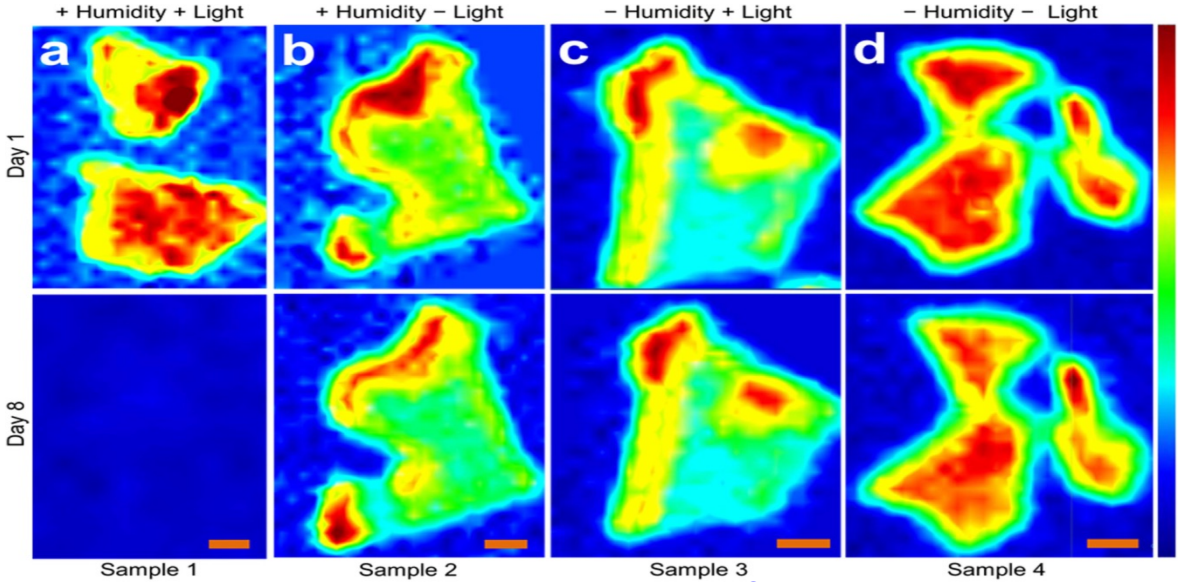
Walia et al., 2D Materials, 2016, 4, 015025
Walia et al., Advanced Materials, 2017 (10.1002/adma.201700152)
Ahmed et al., NPJ 2D Materials and Applications, 2017 1, 18

Light plays key role in phosphorene degradation

Humidity expedites the process!

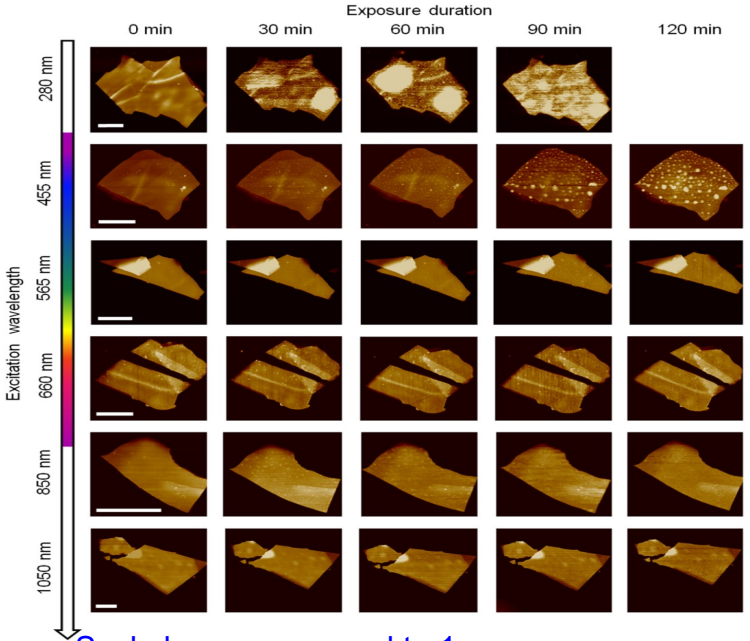


Scale bars correspond to 2 μm

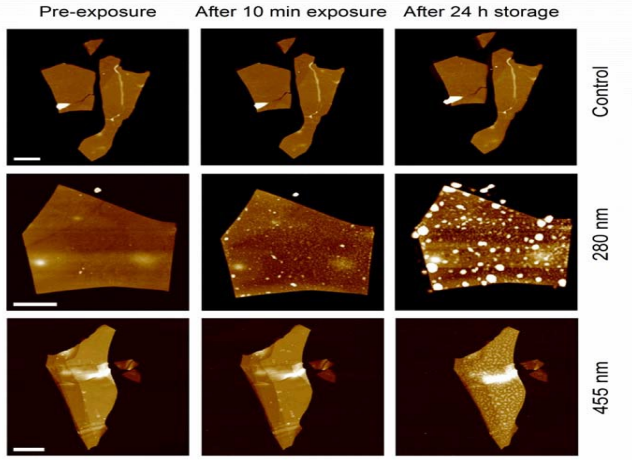
In fact, phosphorene can be used in humidity sensors when operated in dark

Walia et al., 2D Materials, 2016, 4, 015025

Which wavelength causes fastest degradation ?



Scale bars correspond to 1 μm



Short bursts of blue light are OK

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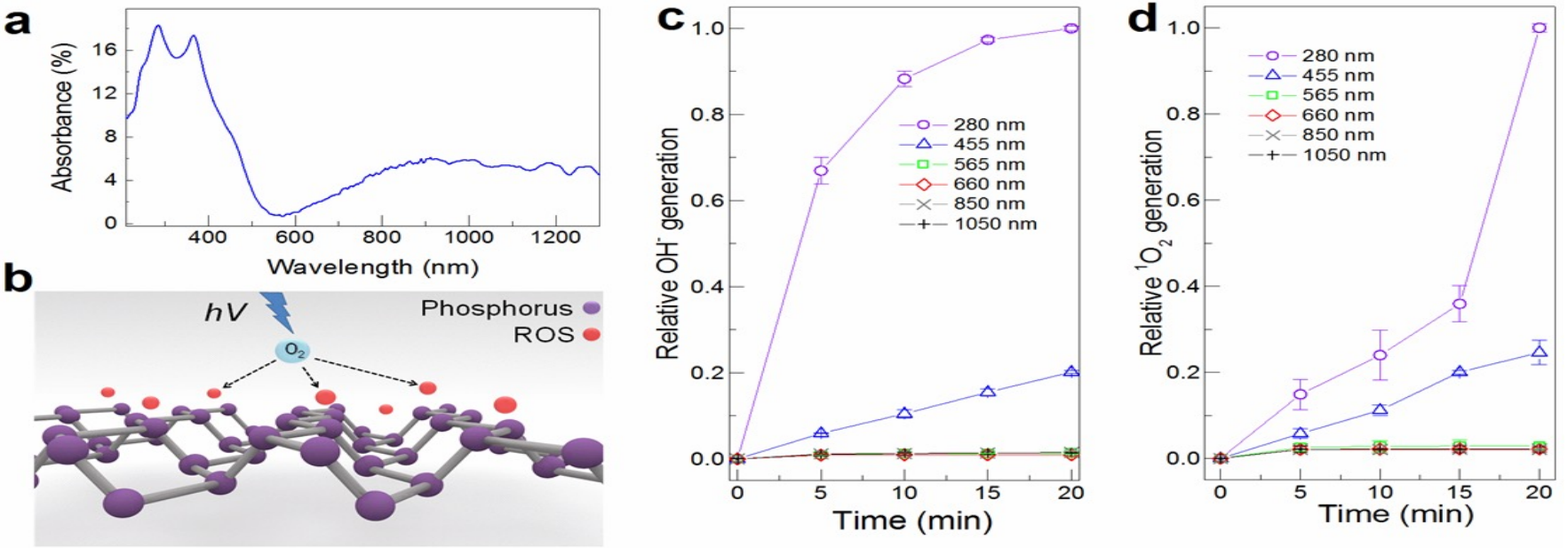
UV should be blamed for phosphorene degradation

T. Ahmed et al. NPJ 2D Materials and Applications 1 18

Why light causes rapid degradation?



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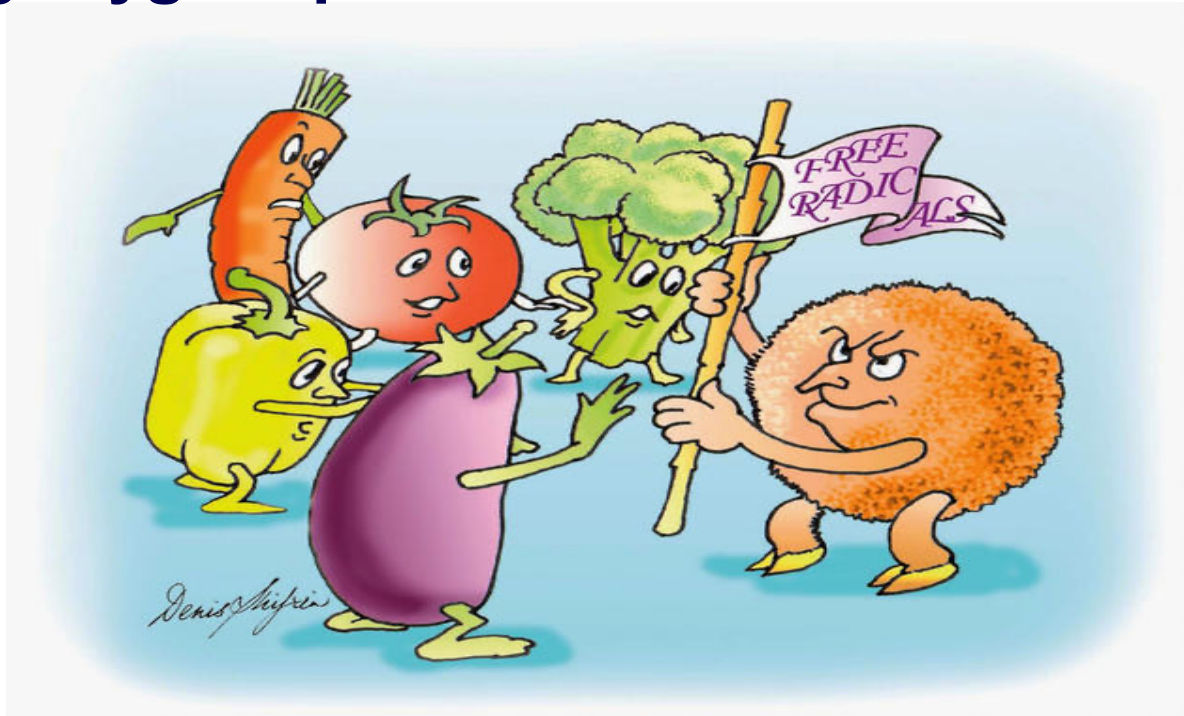
So how can we prevent phosphorene from these damaging oxygen species ?



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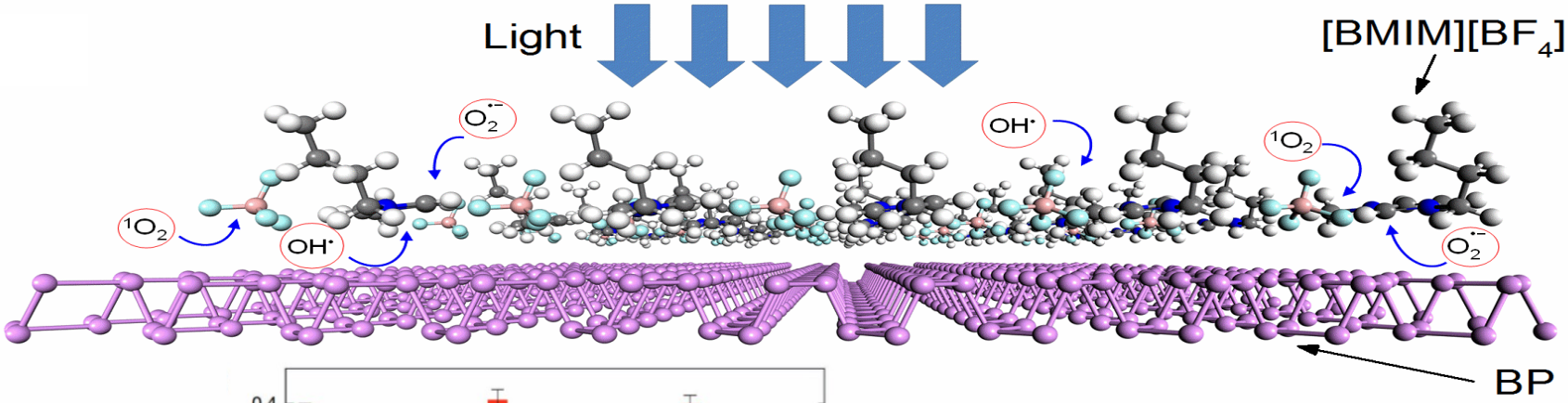
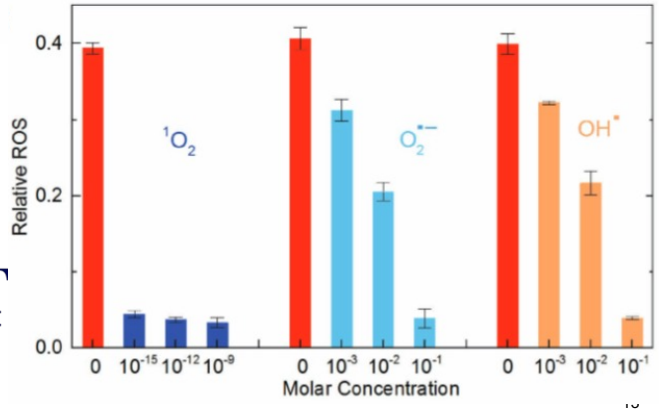
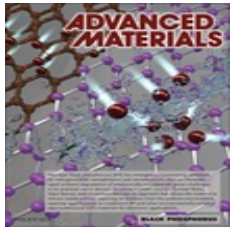
Anti-oxidant Ionic liquids (ILs) are effective





– IL-induced ROS quenching



Advanced Materials, (10.1002/adma.201700152)

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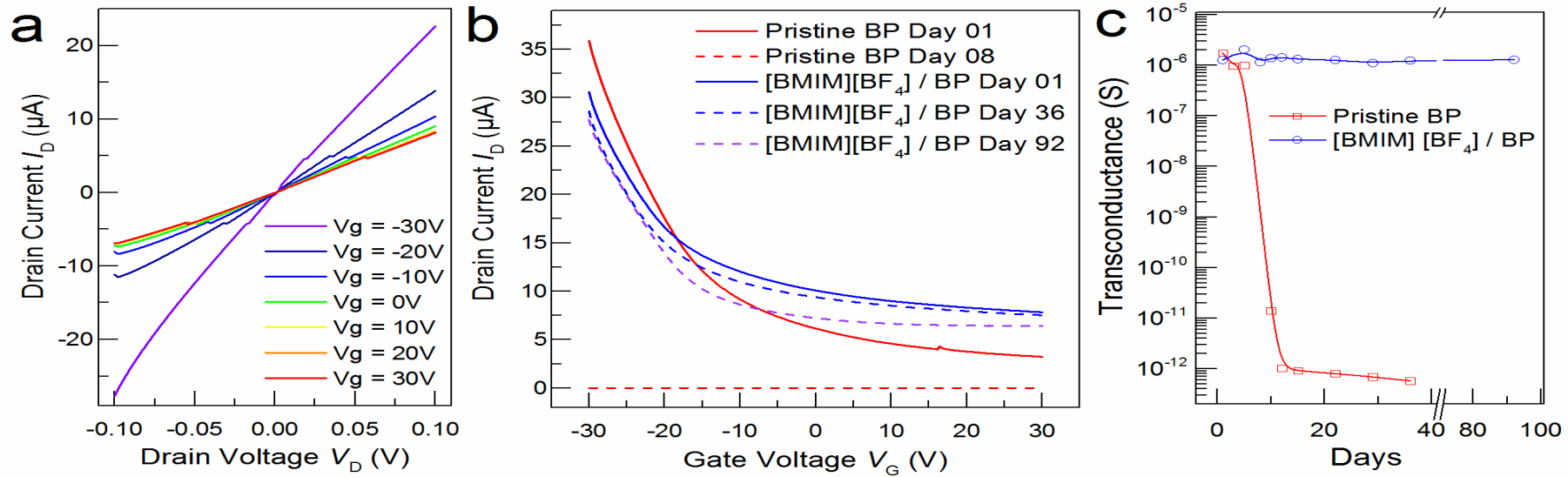
IL protected phosphorene retains electronic characteristics for over 3 months



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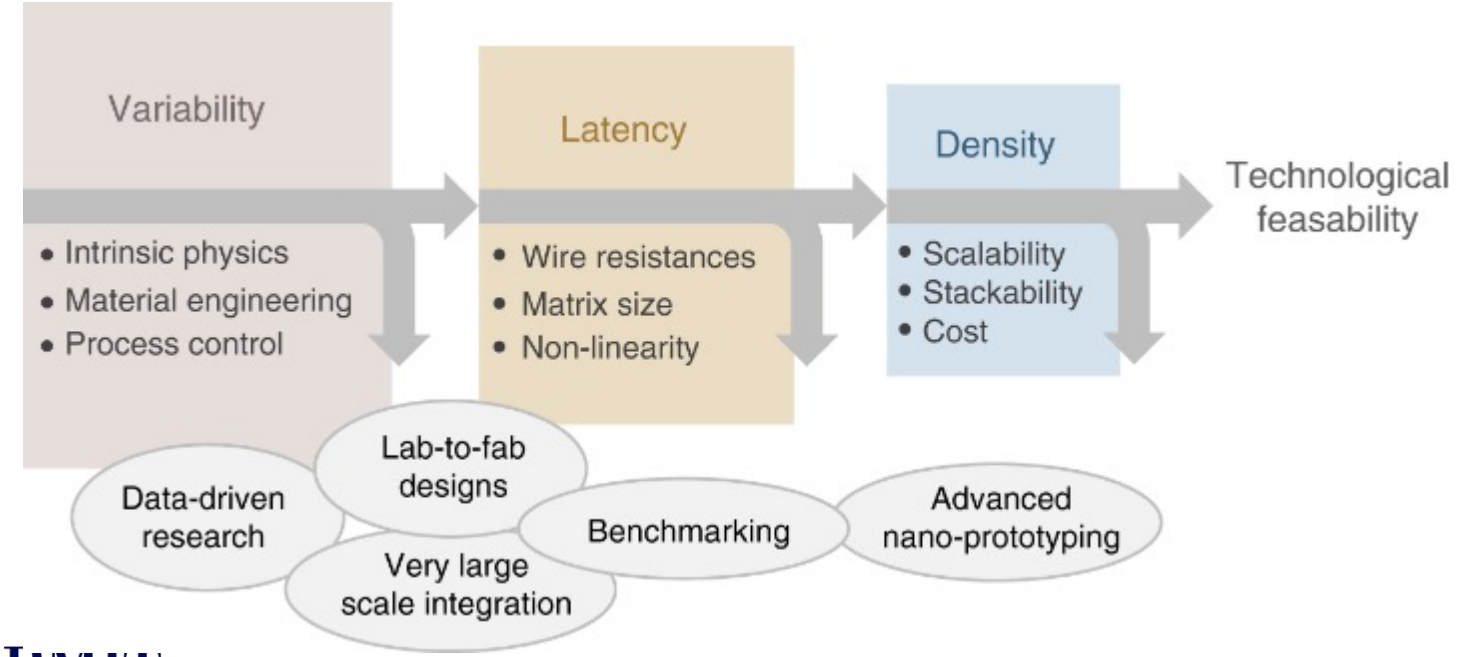
Advanced Materials, (10.1002/adma.201700152)

Holy Grail – Neuromorphics and artificial vision



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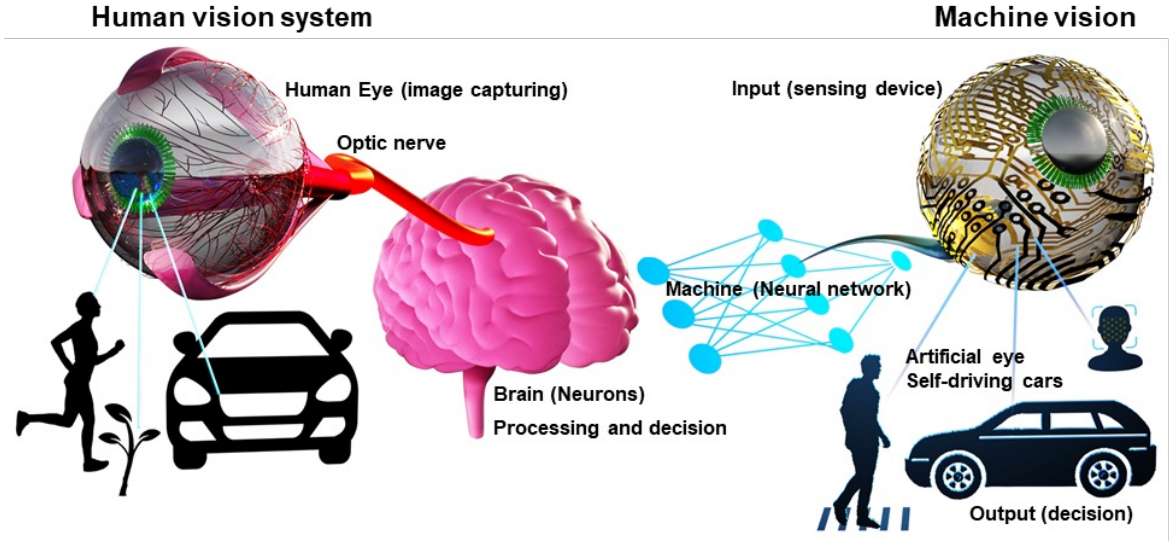
Nature Communications 9, 5267 (2018)

Human vision as inspiration



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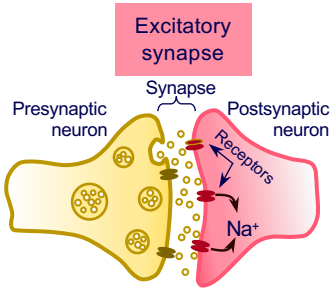
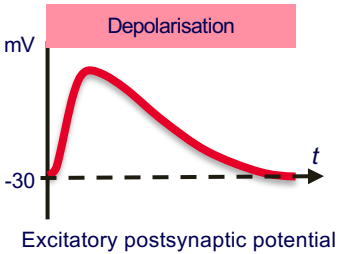
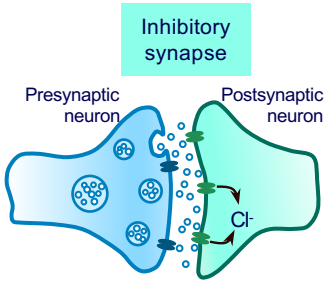
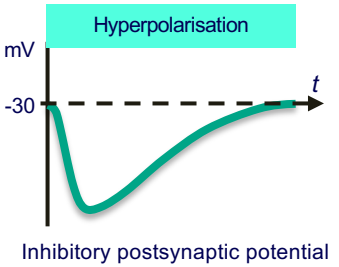
Invited Perspective Adv Mater Technol doi.org/10.1002/admt.202101494 (2022)

Biological Synapse | Basics and Functionalities

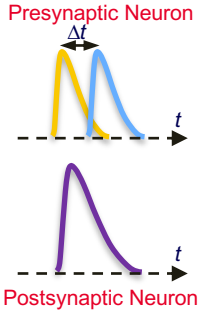


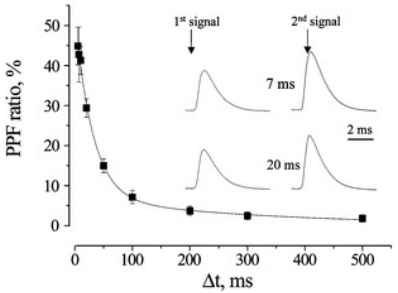




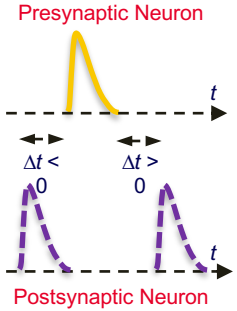


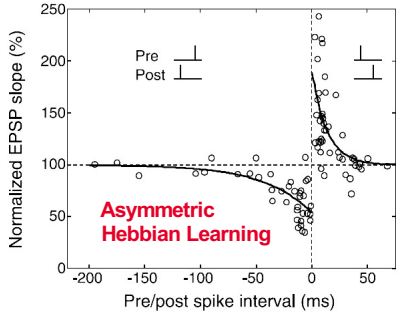
Summation - Pair Pulse Facilitation





Learning/Forgetting – Spike Time Dependent Plasticity





M. Mukhamedyarov *et al.* ***Eur J Physiol*** 458 (2009), RC Froemke *et al.* ***J Neurophysiol*** 95 (2006)

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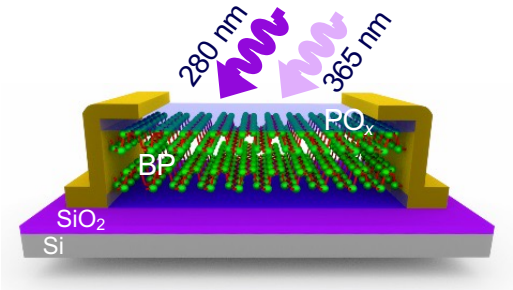
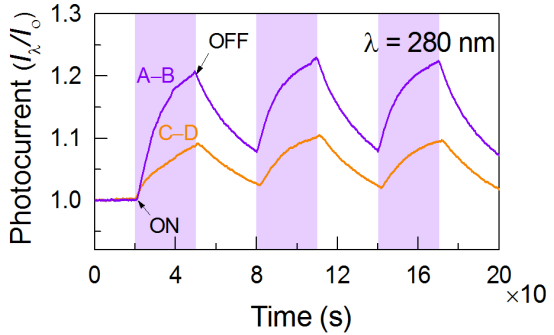
Can we use light in electronic devices to mimic Excitatory & Inhibitory action potentials of a synapse?

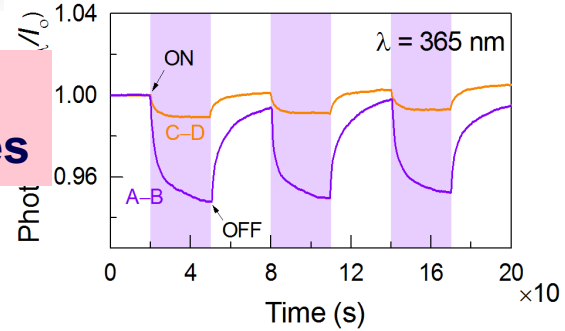
Dr Taimur Ahmed



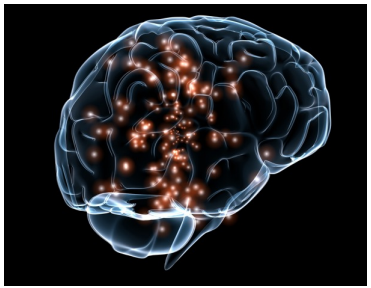
Few-layer BP Optoelectronic devices



Excitatory potential



Inhibitory potential



T. Ahmed *et al.*, ***Adv Func Mater*** 201901991 (2019)

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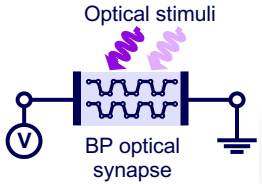
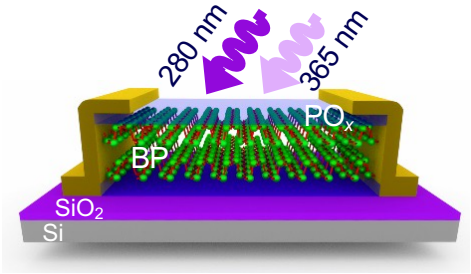
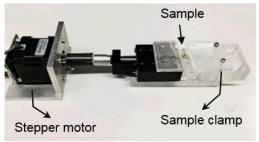
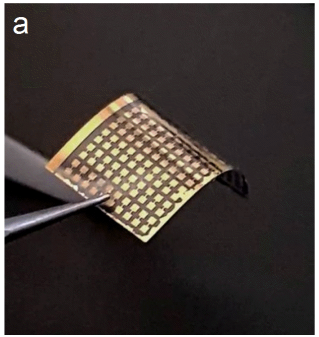
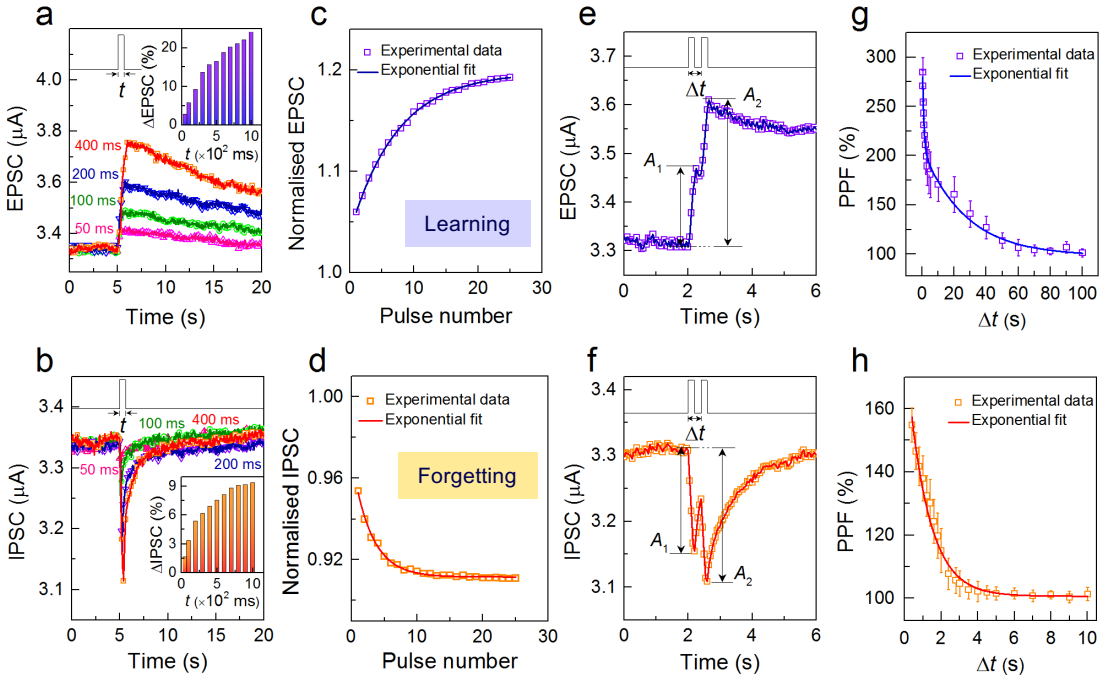
Black Phosphorus | Optoelectronic synaptic devices











excitatory postsynaptic current (EPSC) and inhibitory postsynaptic current (IPSC) pair-pulse-facilitation (PPF) for dynamic synaptic plasticity

T. Ahmed *et al.*, ***Small*** 1900966 (2019)

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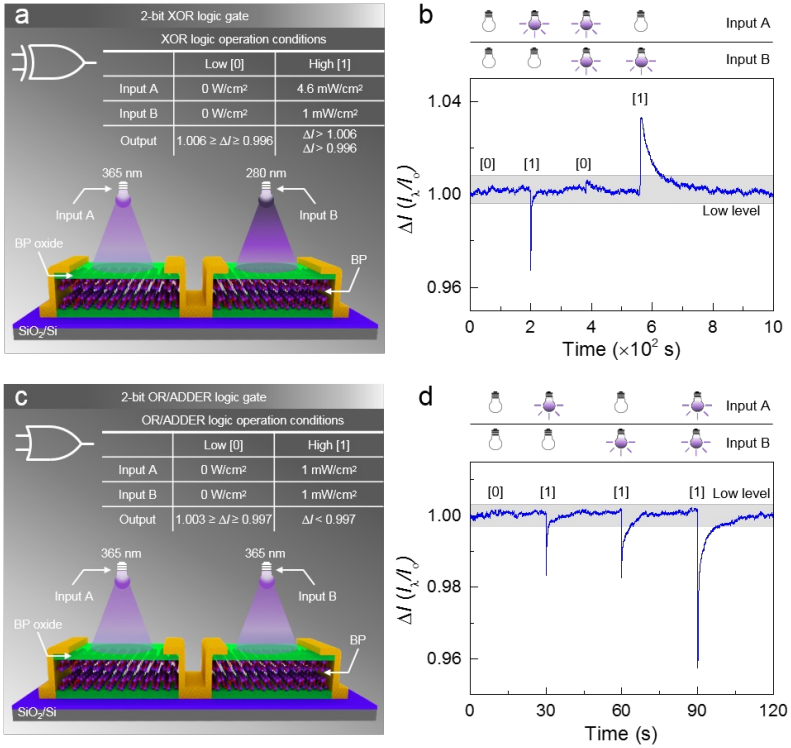
Black Phosphorus | Optical logic devices

- Optical Boolean logic in serially connected devices
  - Utilising 280nm and 365nm wavelengths
- 2-bit XOR logic
  - 280nm and 365nm inducing similar but opposite magnitude of change in output photocurrent
- 2-bit OR logic
  - Possible with either 280nm or 365nm
  - Both inputs augment net change in output photocurrent



T. Ahmed *et al.*, ***Adv Func Mater*** 201901991 (2019)

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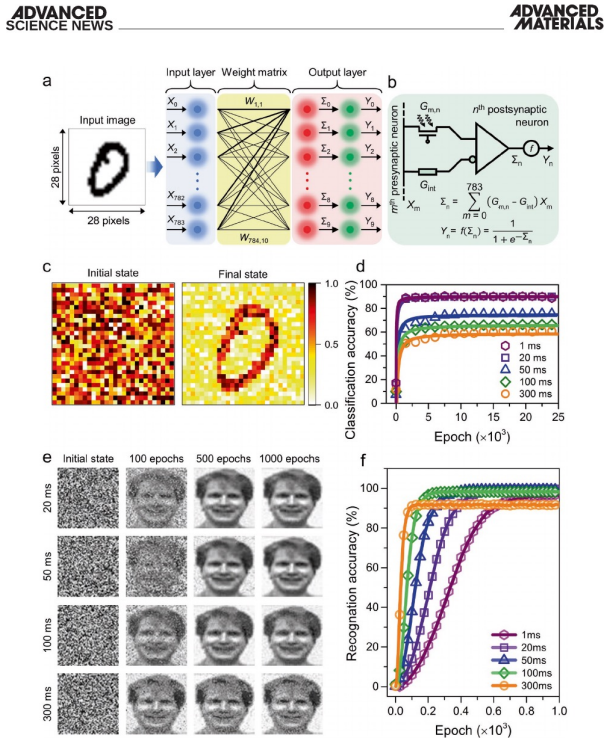
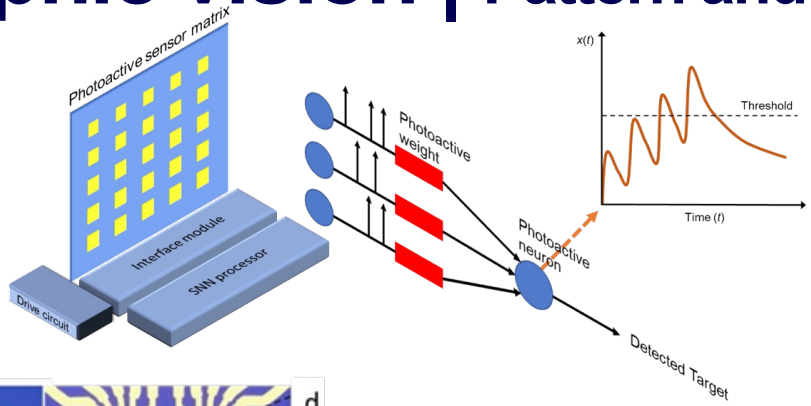
Artificial neural networks | Pattern and image recognition

- Can mimic long-term potentiation and depression
- Optical WRITE (280 nm) and Optical ERASE (365 nm) without using electrical gating



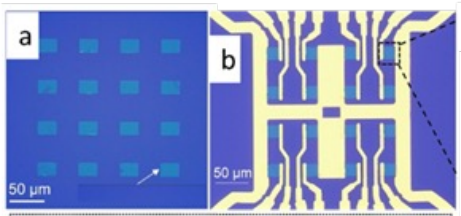
Advanced Materials 2004207

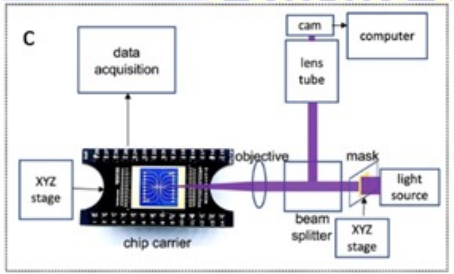
Neuromorphic vision | Pattern and image detection

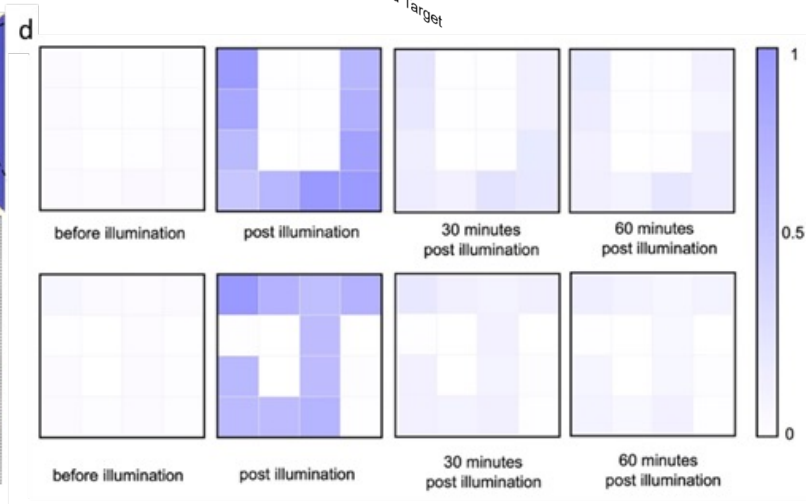


Aishani Mazumder:
(Thurs Dec 15 Room R7 12 PM)

Thiha Aung: **Poster #172**
Thurs Dec 15, 05.30 PM)







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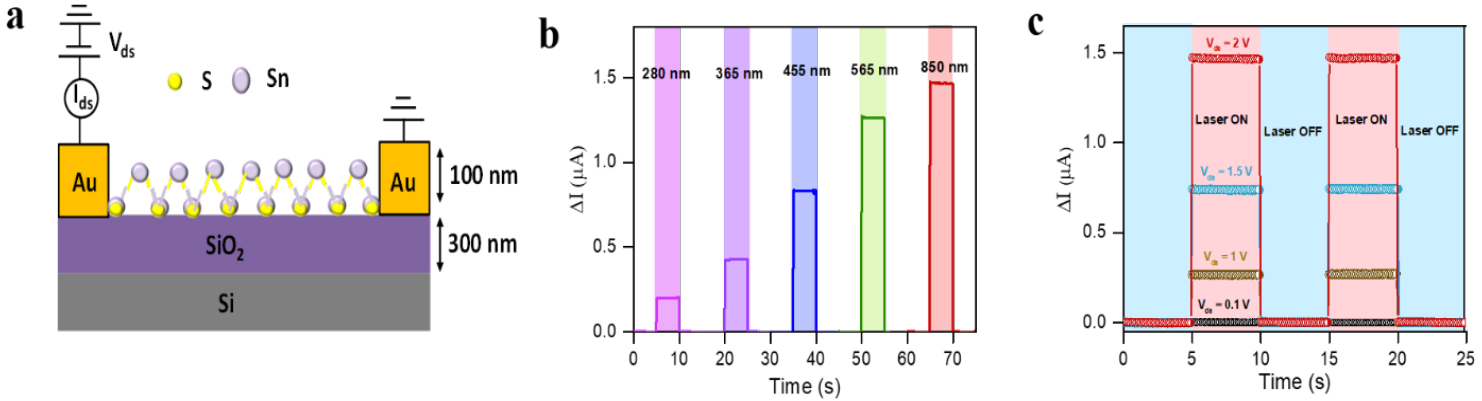
SnS based high-speed, broadband photodetectors



- μs fast response using 0.8-1.8 nm thick sheets
- Broadband (280-850 nm)
- One of the highest responsivities and detectivities for similar thickness systems

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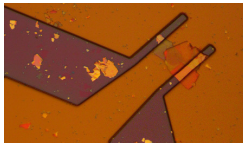
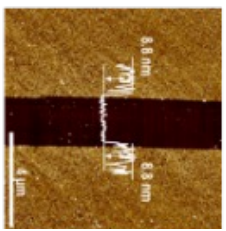
Dr Vaishnavi Krishnamurthi

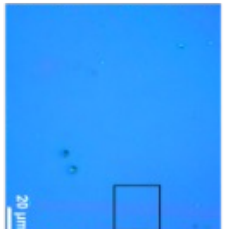
Advanced Materials 32 2004247

Heterostructures and large-area ultra-thin sheets

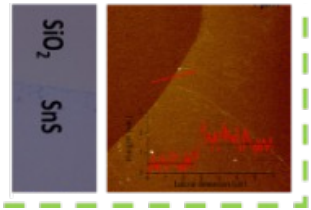


p-n junctions

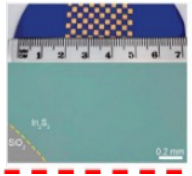




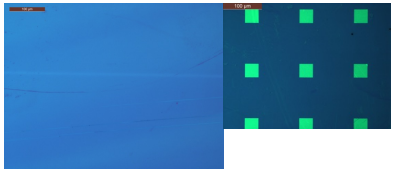
Antimonene



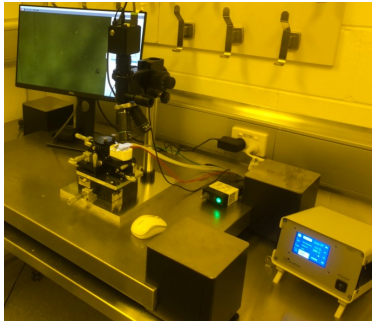
SnS



In_2S_3



Phase change materials – antimony sulfide/selenide/telluride



Alignment stage for heterostructures

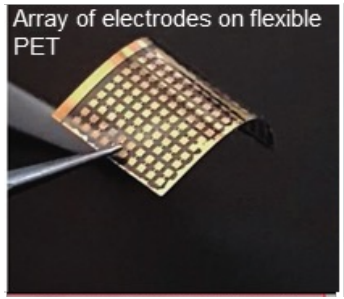
Maskless lithography

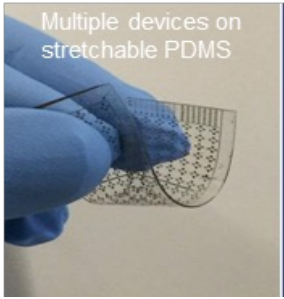
3-zone CVD

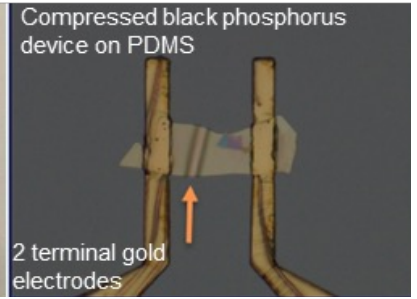
We synthesize most 2D materials in liquid phase too

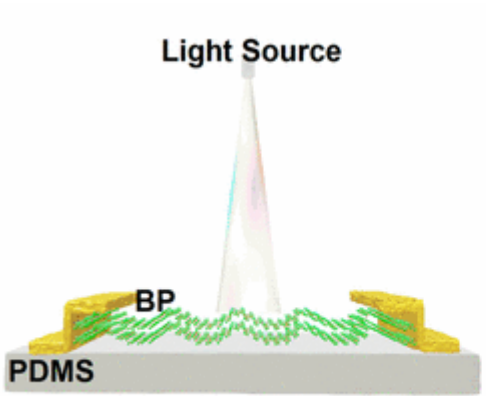
Integration of 2D materials with flexible, elastomeric platforms

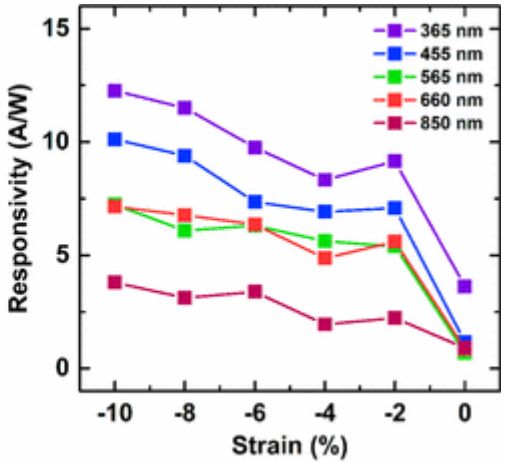
- Strain manipulation











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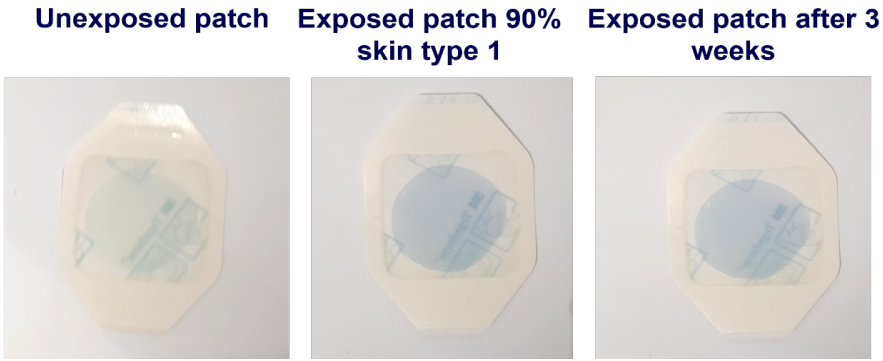
Mei Xian Low

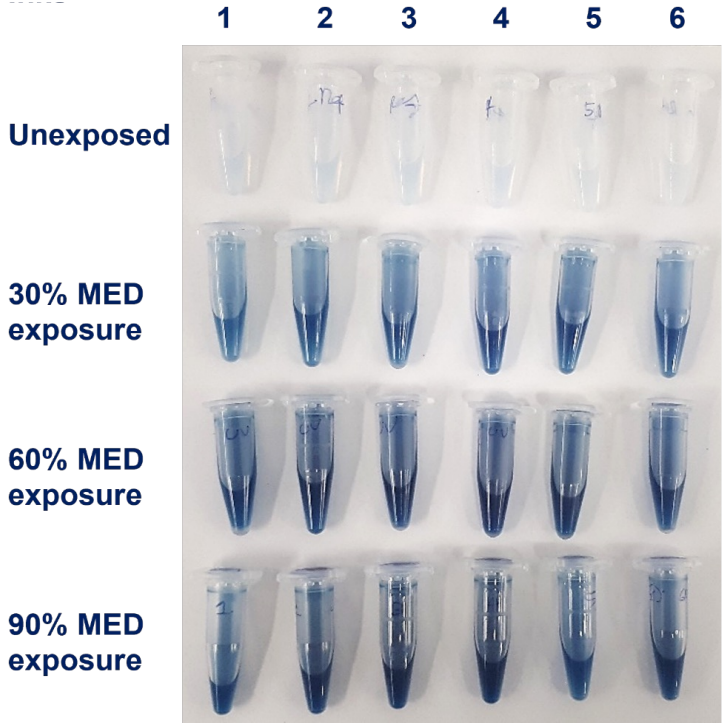
M.X. Low et al ACS Appl. Nano Mater. 2022, 5, 9, 12189–12195

Printed 2D inks for UV exposure indicator

a)

b)





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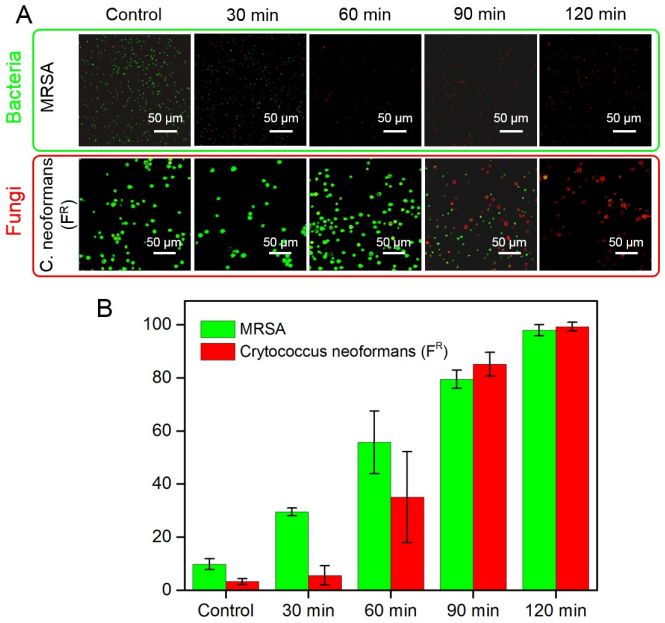
Sruthi Kuriakose

Kuriakose, S. ACS Appl. Nanomat. 2022 https://doi.org/10.1021/acsanm.2c04360

Exploiting reactive oxygen species for functionality

- Antibacterial and antifungal action



- Confocal laser scan microscope imaging
- Green and red nucleic acid and propidium iodide (PI) stains
- PI only permeates damaged cell membranes and bind in higher affinity to nucleic acid to replace the green stain

Microbial viability as a function of time. A) Time-lapse CLSM images of MRSA and fluconazole resistant *Cryptococcus neoformans* (F) cells following exposure to Black Phosphorus. **B)** Antimicrobial performance was quantified as a percentage of dead cells from the CLSM images as a function of time.

Mx Zo Shaw
Dr Aaron Elbourne

ACS Applied Materials & Interfaces 13 17340 2021
Nature Communications 12 1 2021

Technology capability areas

Our current research activities include

- Synthesis of atomically thin materials
- Photodetectors (detecting different wavelengths of light on demand)
- Artificial vision devices enabled by optoelectronic memories and machine learning
- Engineering Light blocking layers (Transmit and block selective wavelength bands on demand)
- Antibacterial and antifungal coatings

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MicroNano Research Facility

- Comprehensive facilities for the design, modelling, fabrication, packaging, and characterisation of micro and nano scale devices.

- Nine laboratories are housed within the 1200 square metre facility.

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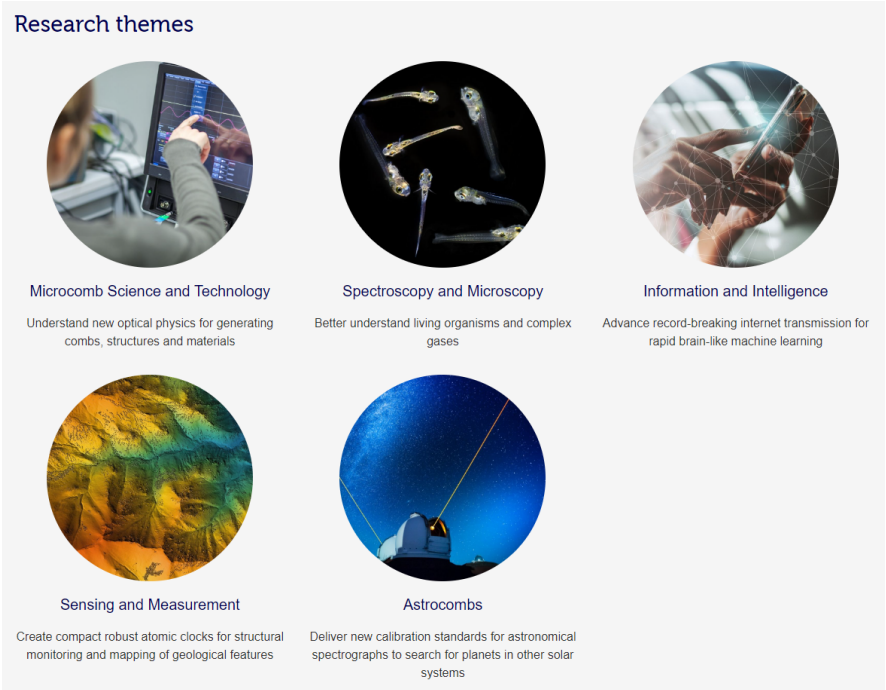
ARC Centre of Excellence in Optical microcombs for Breakthrough Science



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- Room E2, Thurs Dec 15, Hear from Prof Arnan Mitchell

Student presentations

- Aishani Mazumder (Oral): Non-volatile Resistive Switching in Layered InSe via Electrochemical Cation Diffusion

  (Dec 15 Thur Room R7 12 PM)

- Mei Xian Low (Oral): Enhanced Photodetection with BP – Organic Hybrid (Already presented)

- Thiha Aung: Prolonging memory retention in optoelectronics devices using compensation model

  (Poster #172, Thurs Dec 15, 05.30 PM)

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Department of Defence

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Department of Industry, Science, Energy and Resources

PhD students and postdoctoral fellows

All industry partners

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Get in touch for possible collaborations and partnerships!!

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