Light-tunable, low-dimensional materials for futuristic electronics, optoelectronics and brain-inspired devices

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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
- Stretchable and flexible devices
- Biomarker detection using versatile sensing platforms
- Research – Industry Partnerships

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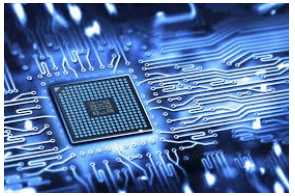
Low-dimensional materials

2D and unit-cell thick materials

Synthesis

- Solid phase
- Liquid phase
- Vapour phase

Applications



Electronics

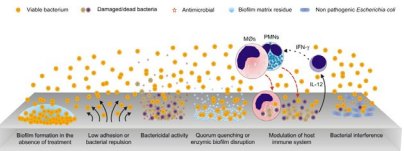
FETs, memory devices

Optoelectronics

Photodetectors, LEDs
Light-driven artificial neural networks

Flexible devices

Strain engineering of 2D materials



Antipathogenic coatings

Antibacterial and antifungal

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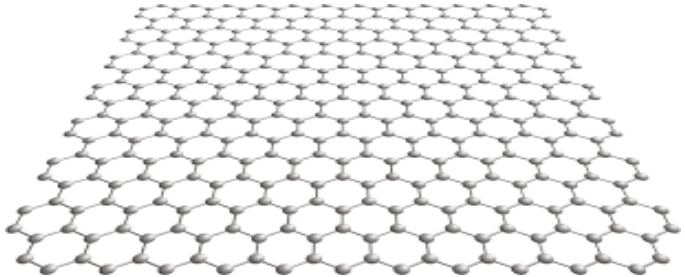
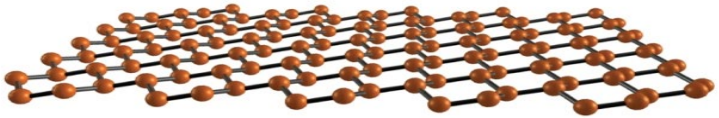
2D Materials

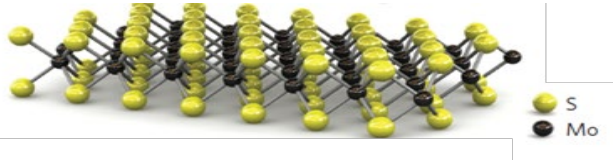
2D materials – Free standing, atomically thin single layer of a layered material.



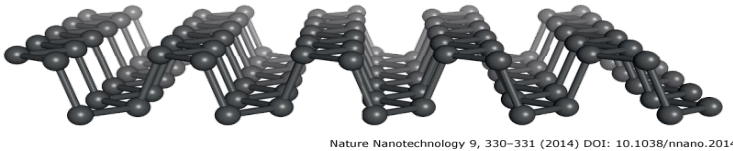
Graphene



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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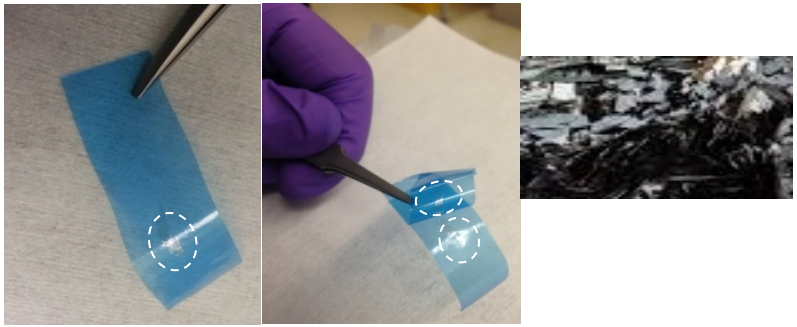
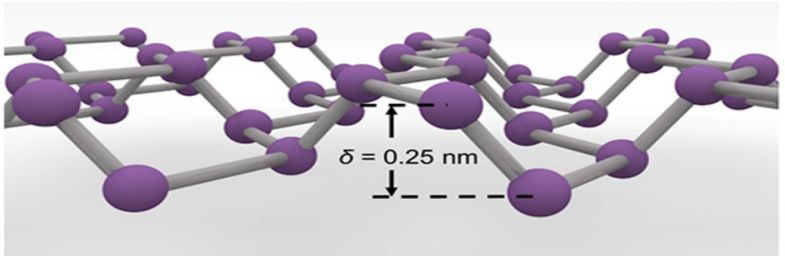
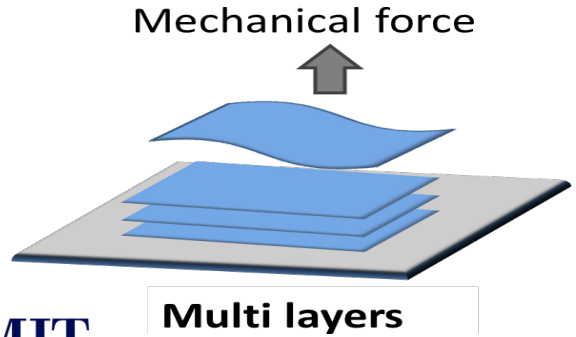
Production of phosphorene







Few-layer phosphorene can be obtained by mechanical exfoliation of black phosphorus

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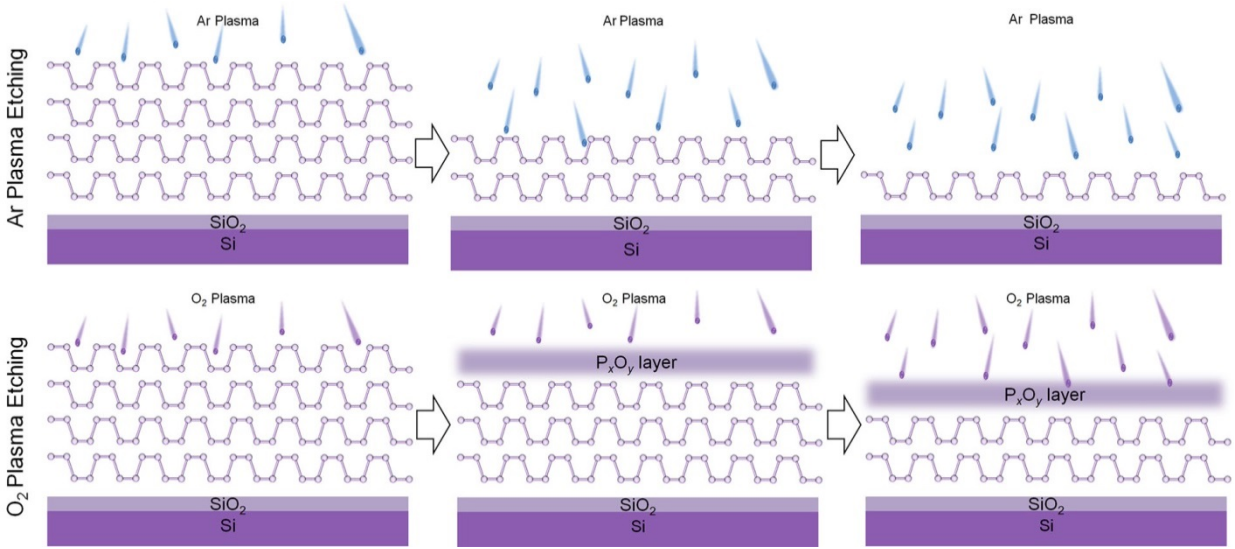
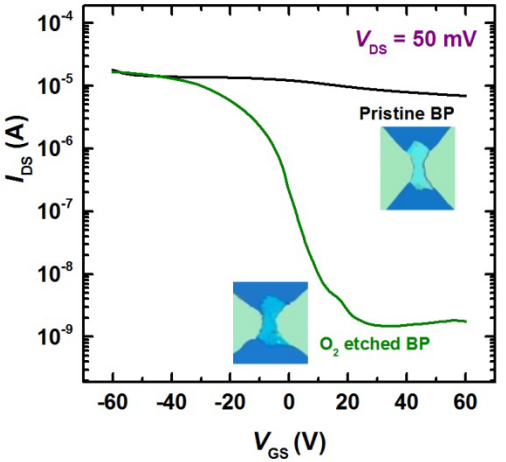
Thickness-control





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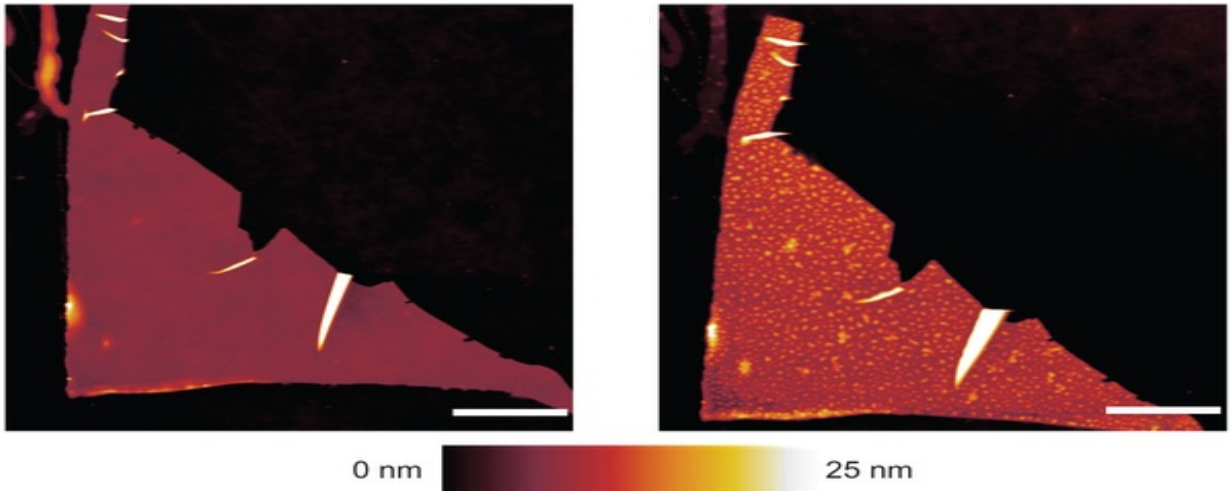
Applied Materials Today 12, 244-249 (2019)

Problem with phosphorene

Degrades rapidly in an ambient environment

Initial reports suggested humidity causes degradation



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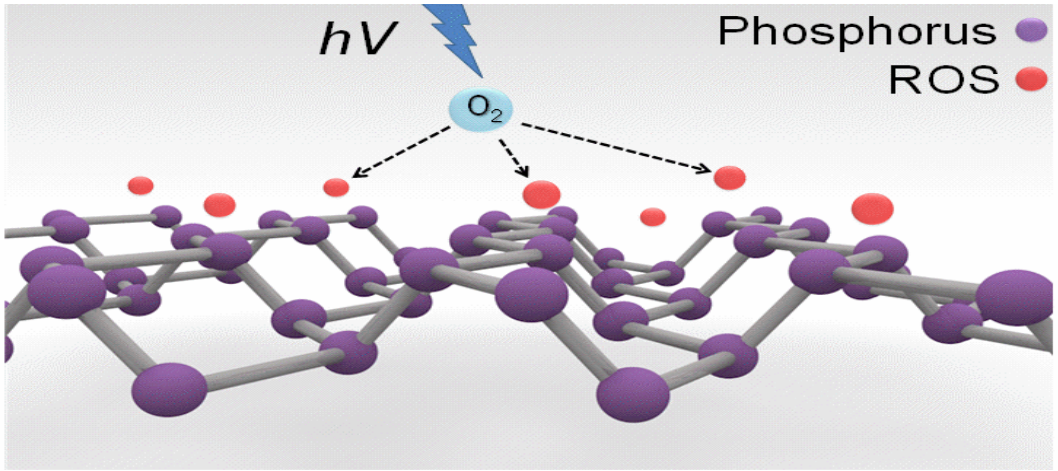
What degrades phosphorene

Photo-oxidation does!!

Humidity facilitates this process



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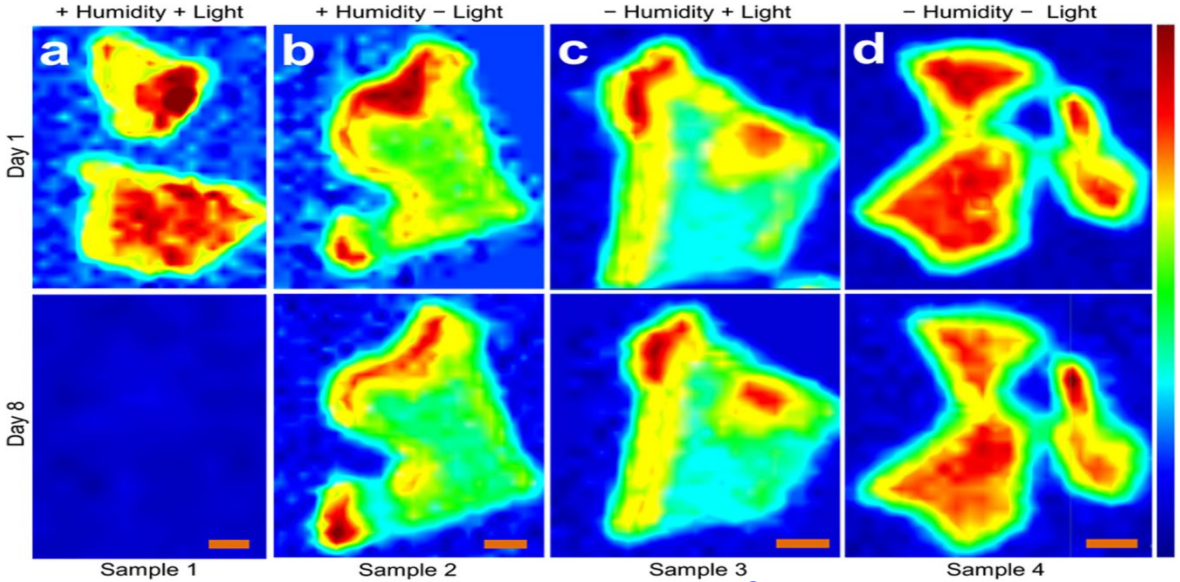
Walia et al., 2D Materials, 2016, 4, 015025
Walia et al., Advanced Materials, 2017 (10.1002/adma.201700152)
Ahmed et al., NPJ 2D Materials and Applications, 2017 1, 18

Light plays key role in phosphorene degradation

Humidity expedites the process!

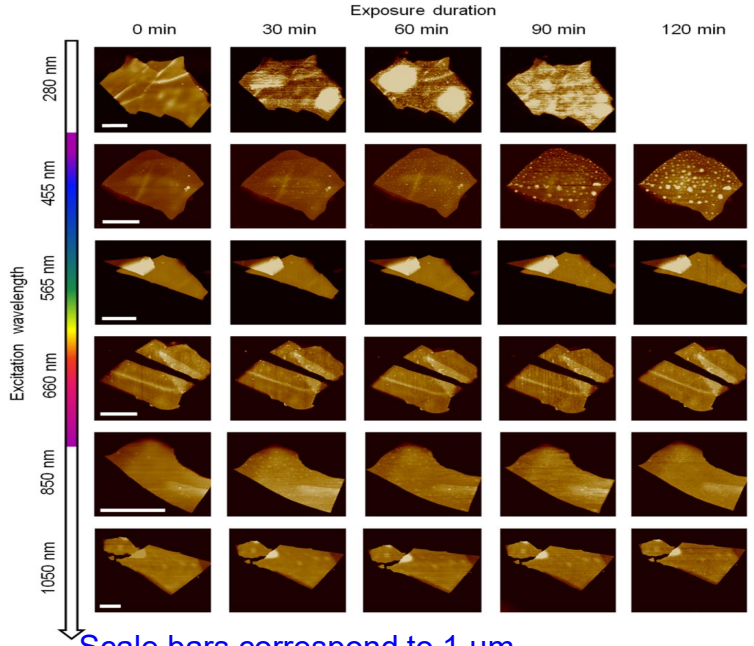


Scale bars correspond to 2 μm

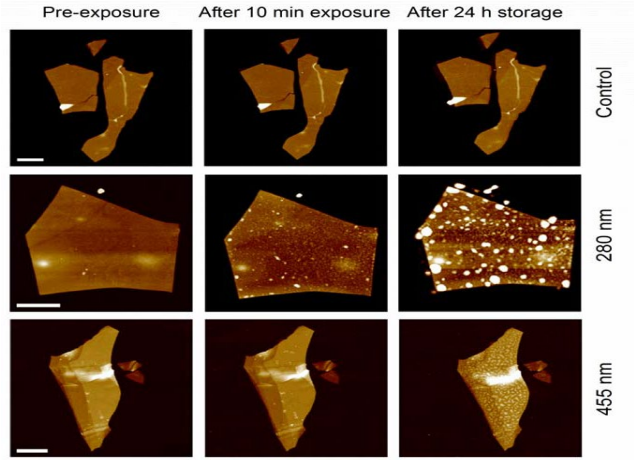
In fact, phosphorene can be used in humidity sensors when operated in dark

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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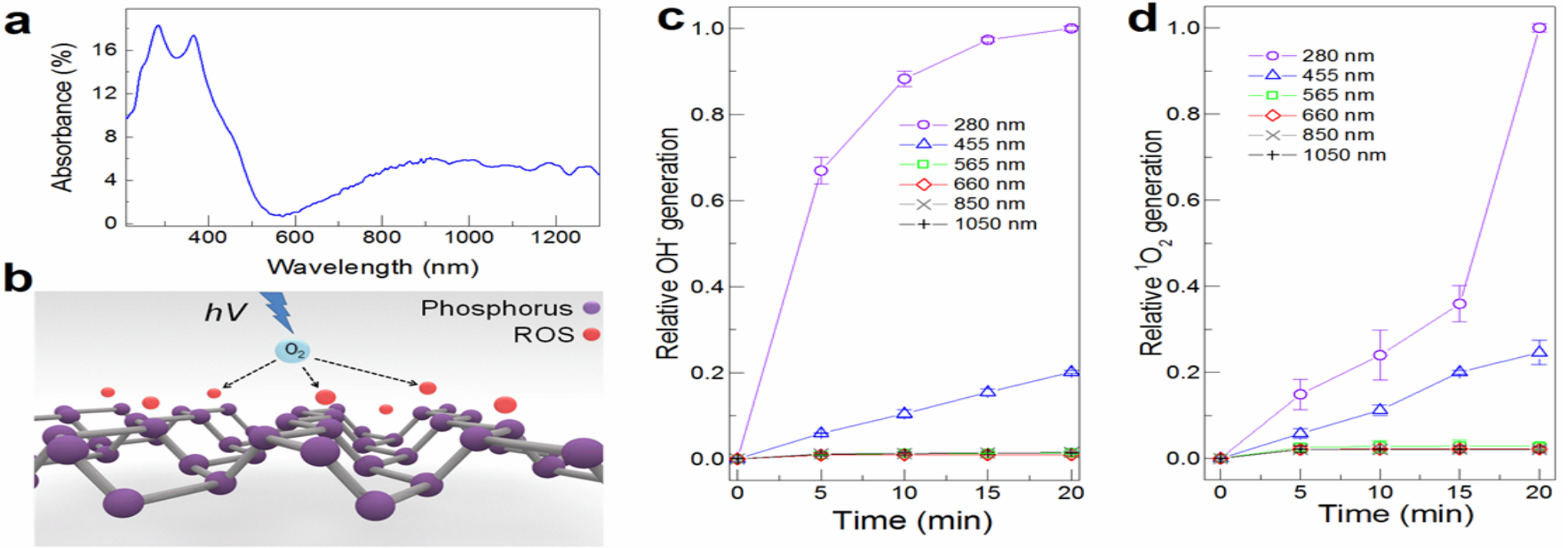
UV should be blamed for phosphorene degradation

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

Why light causes rapid degradation?



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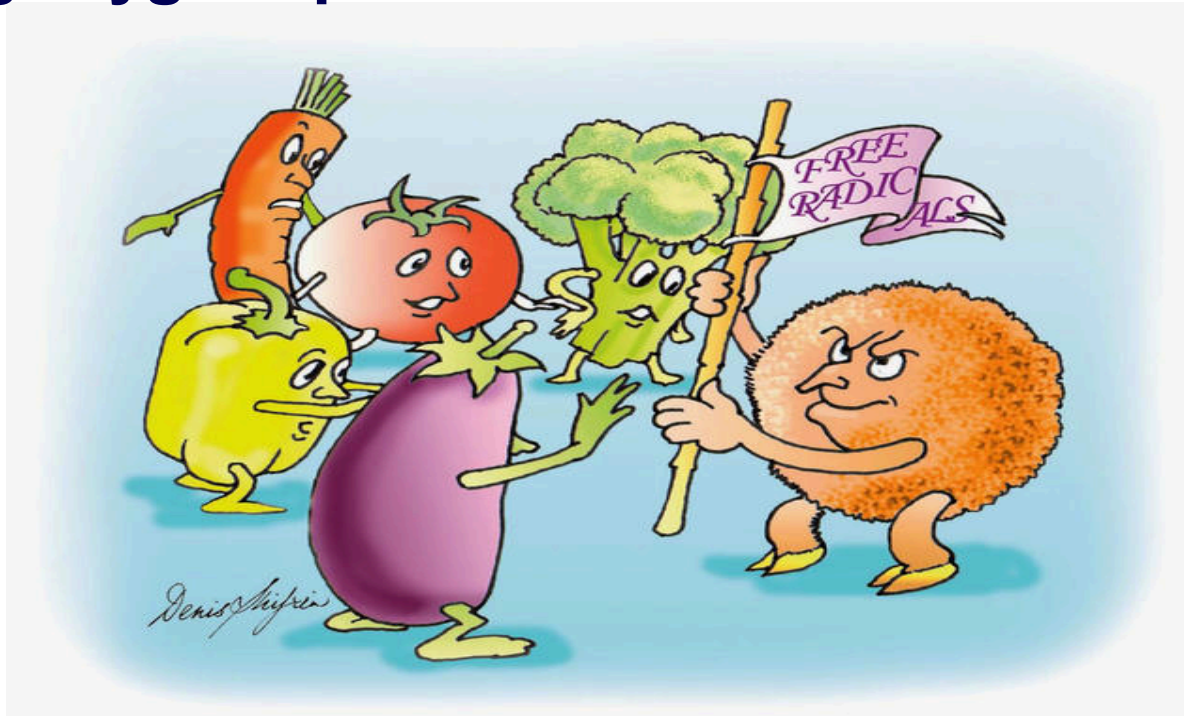
So how can we prevent phosphorene from these damaging oxygen species ?



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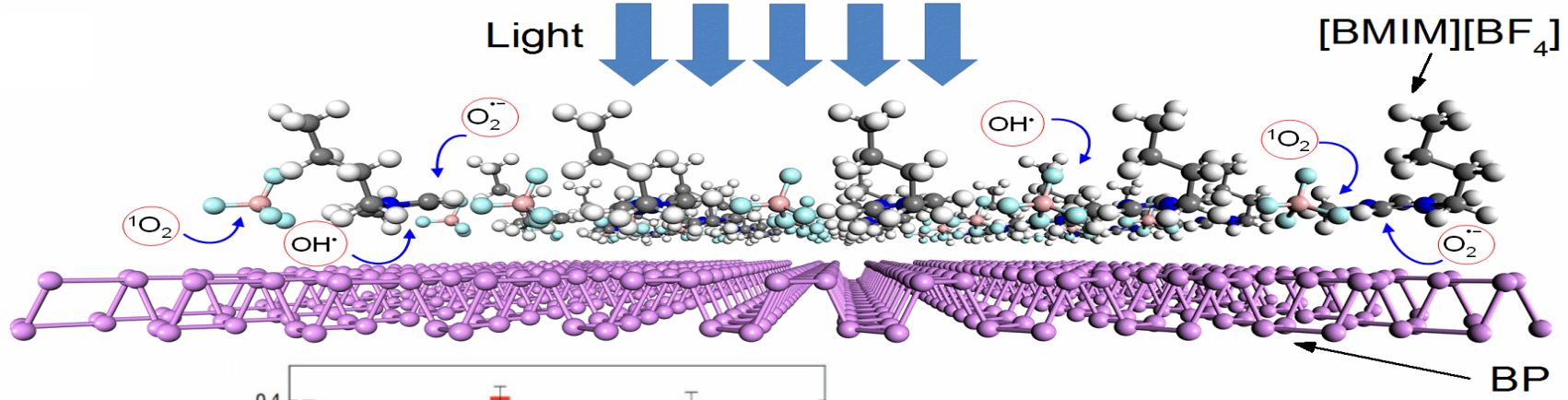
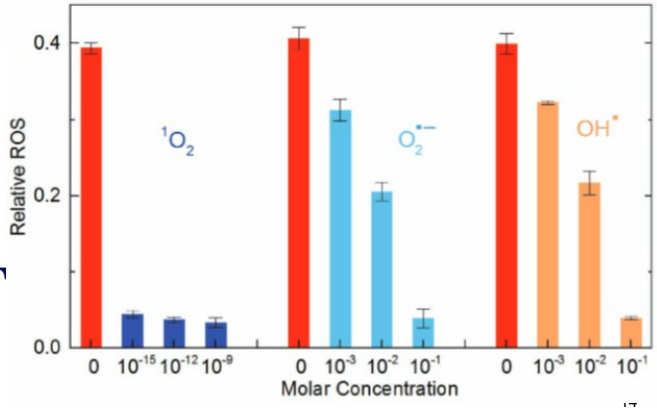
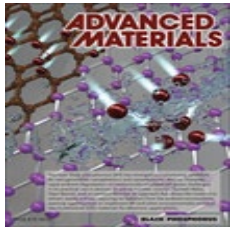
Anti-oxidant Ionic liquids (ILs) are effective





– IL-induced ROS quenching



Advanced Materials, (10.1002/adma.201700152)

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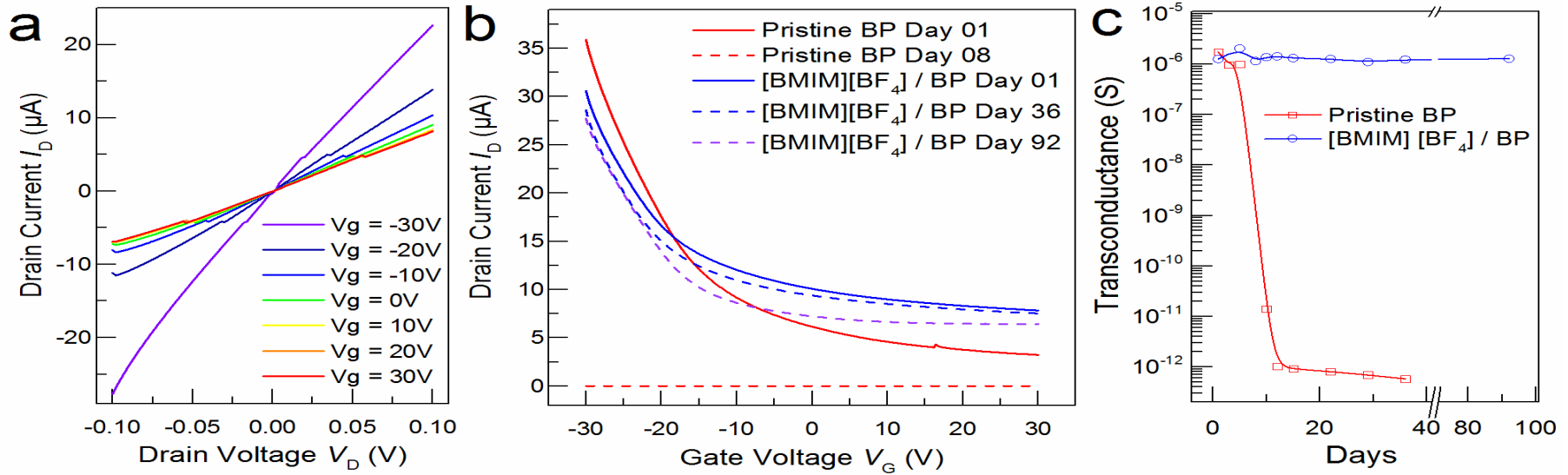
IL protected phosphorene retains electronic characteristics for over 3 months



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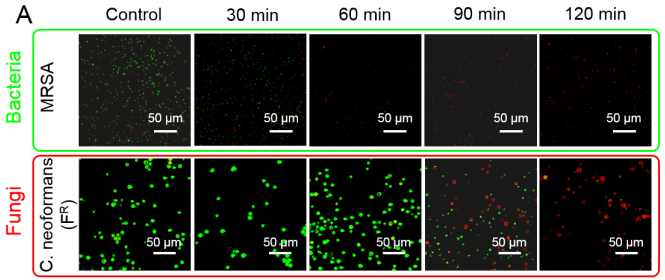
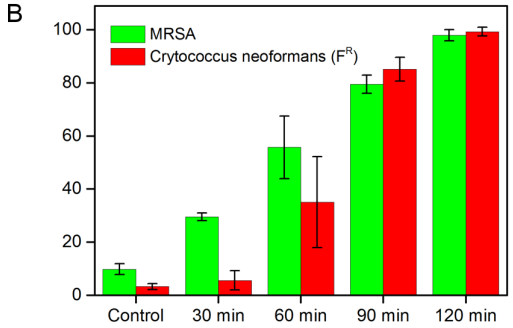
Advanced Materials, (10.1002/adma.201700152)

Exploiting reactive oxygen species for functionality

- Antibacterial and antifungal action



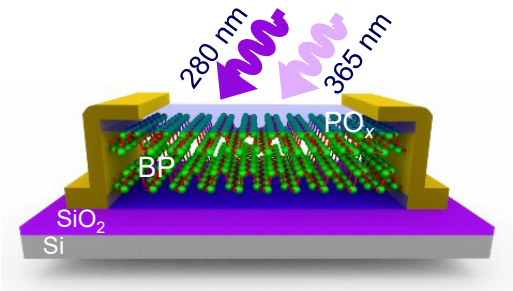


- Confocal laser scan microscope imaging
- Green and red nucleic acid and propidium iodide (PI) stains
- PI only permeates damaged cell membranes and bind in higher affinity to nucleic acid to replace the green stain

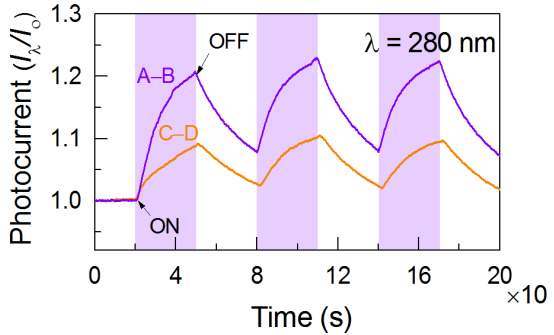
Microbial viability as a function of time. A) Time-lapse CLSM images of MRSA and fluconazole resistant *Cryptococcus neoformans* (F) cells following exposure to Black Phosphorus. **B)** Antimicrobial performance was quantified as a percentage of dead cells from the CLSM images as a function of time.

Unpublished results

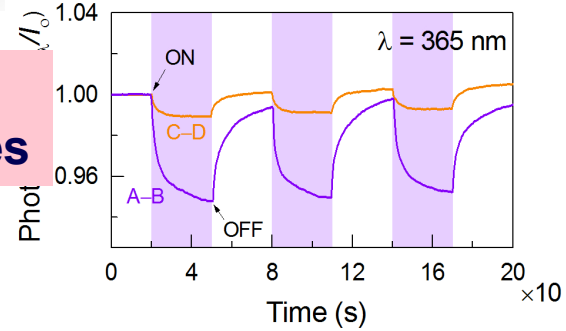
Can we use light in electronic devices to mimic Excitatory & Inhibitory action potentials of a synapse?



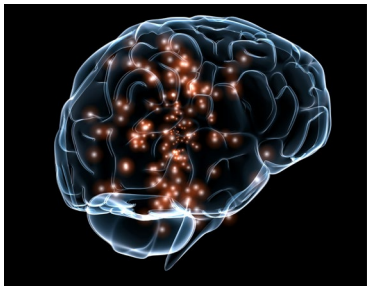
Few-layer BP Optoelectronic devices



Excitatory potential



Inhibitory potential



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

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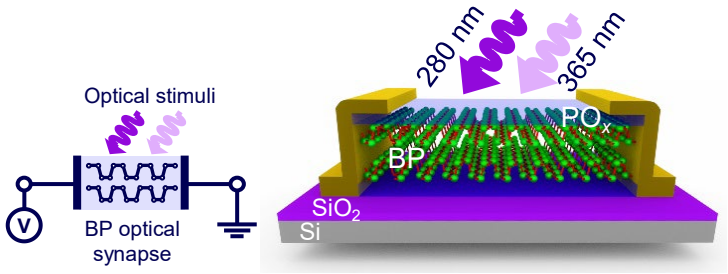
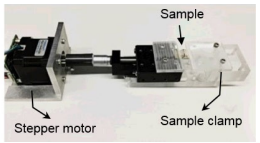
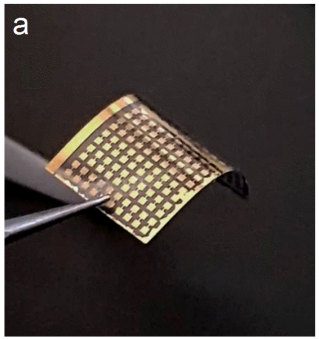
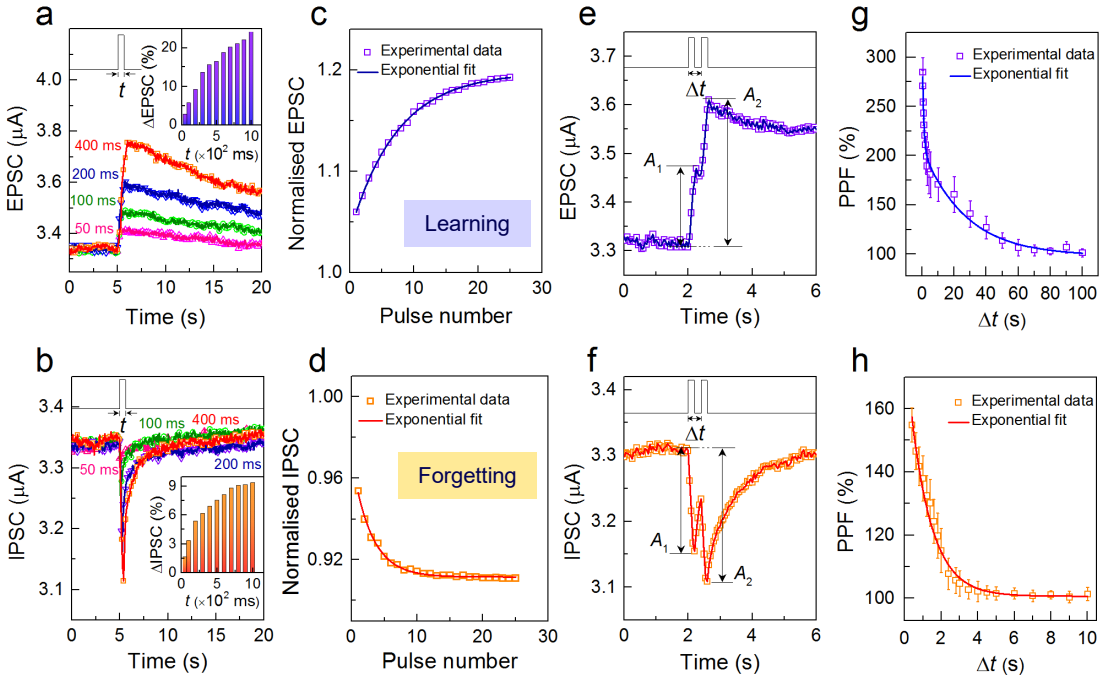
Black Phosphorus | Optoelectronic synaptic devices









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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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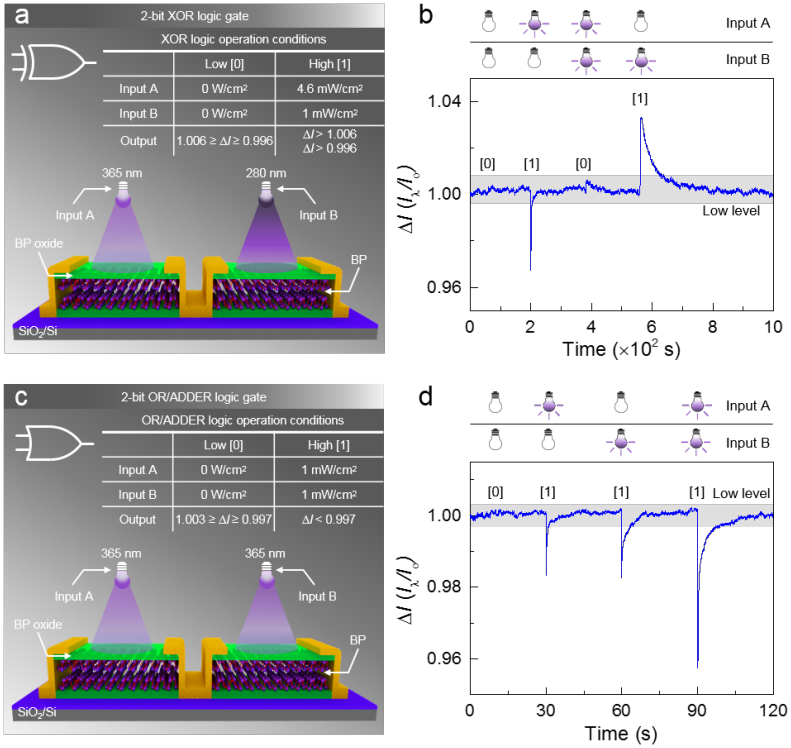
Black Phosphorus | Optical logic devices

- 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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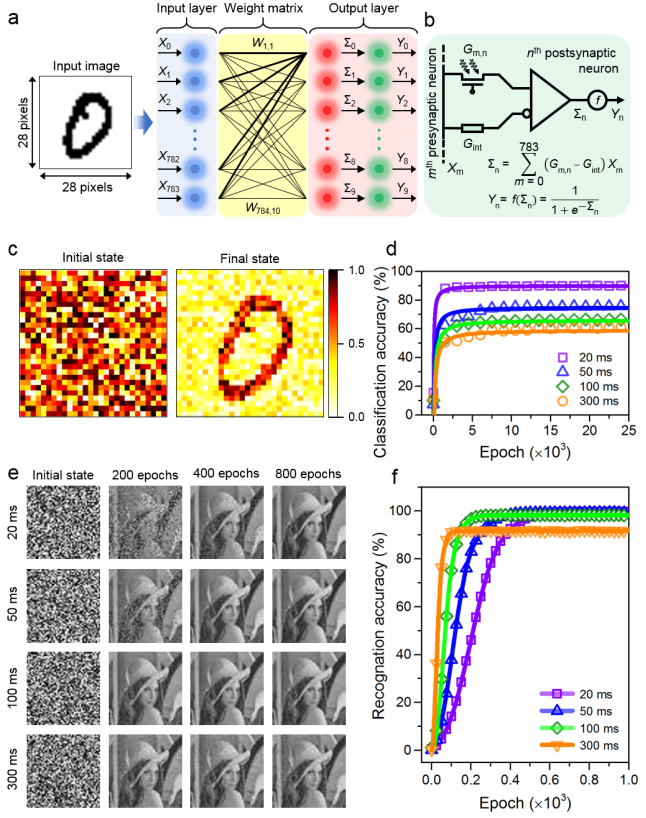
Artificial neural networks | Pattern and image recognition

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



Under Review

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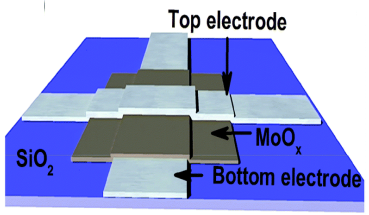
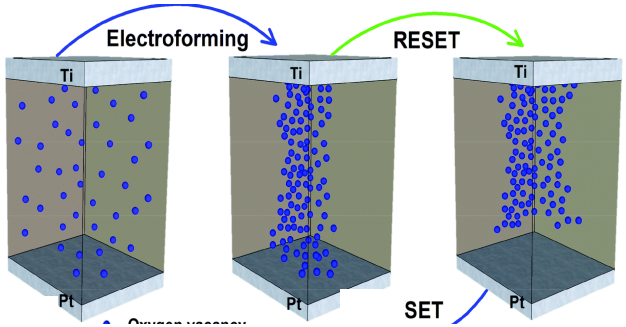
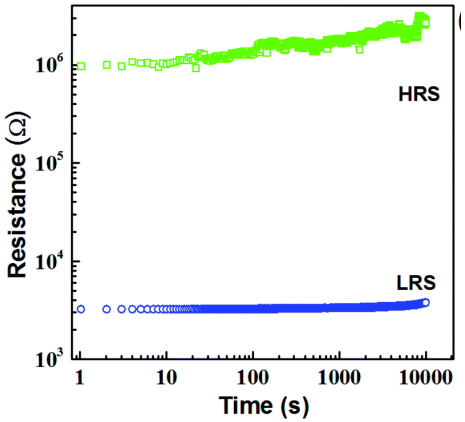
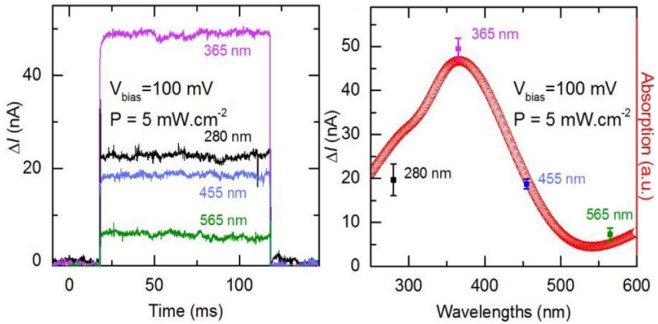
Memristors and UV detectors | Layered 2D MoO_3 films









- CVD prepared 2D MoO_3

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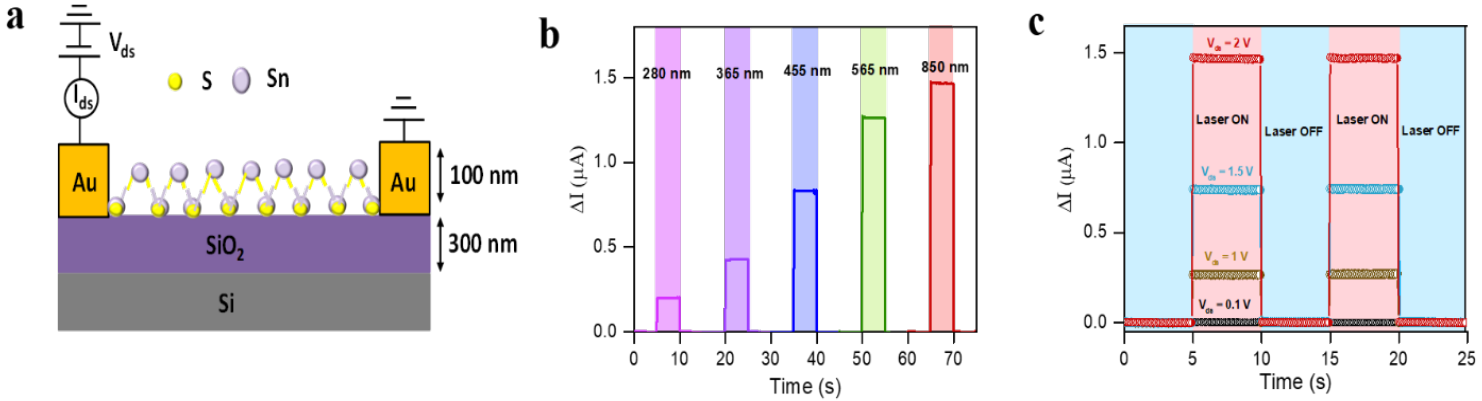
Nanoscale, 2018, 10, 19711-19719 ; 2D Materials 6 035031 (2019)

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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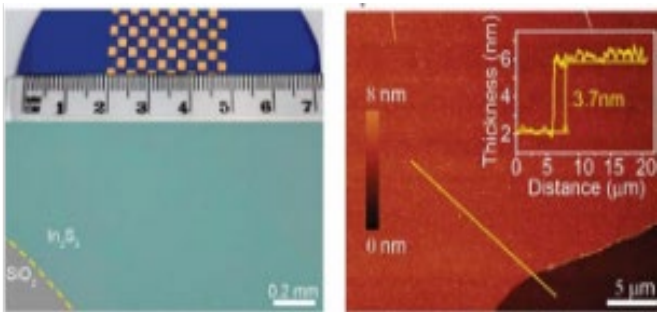
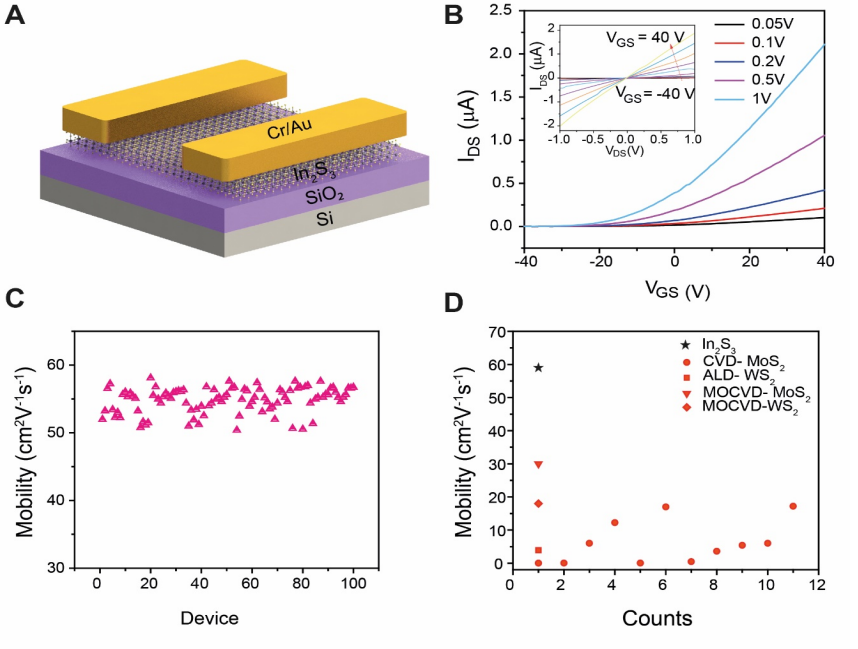
Unpublished results

In_2S_3 based Field-effect transistors





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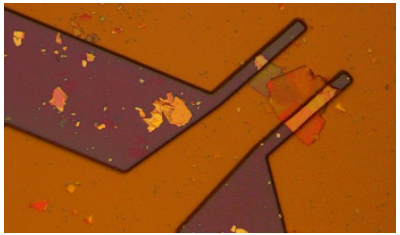
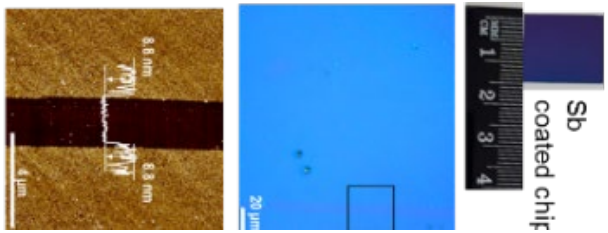
Materials Horizons 7 (3), 827-834 (2020)

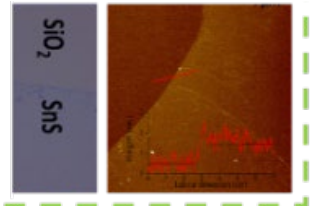
Heterostructures and large-area ultra-thin sheets



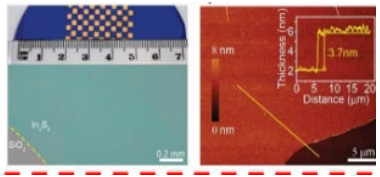
p-n junctions



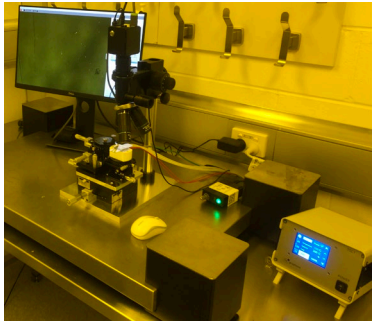
Antimonene



SnS

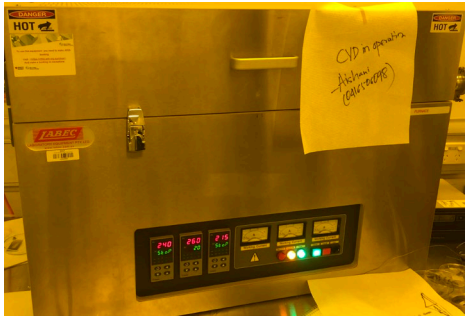


In_2S_3



Alignment stage for heterostructures

Maskless lithography



3-zone CVD

We synthesize most 2D materials in liquid phase too

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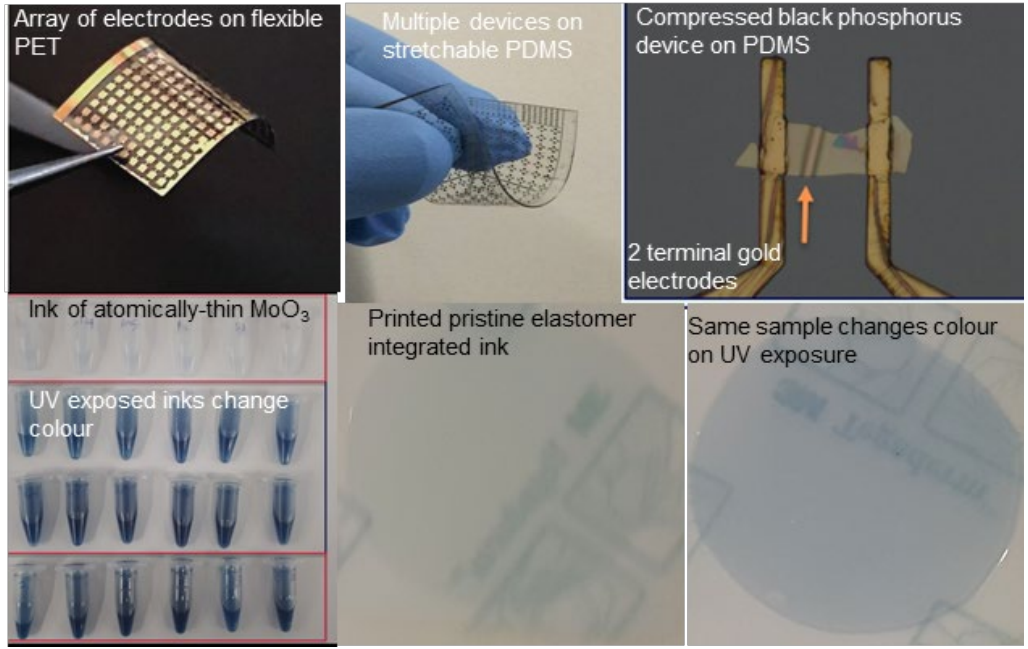
Integration of 2D materials with flexible, elastomeric platforms

- Strain manipulation
- Printed chromic inks



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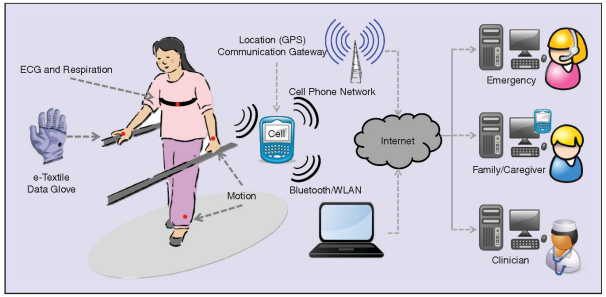
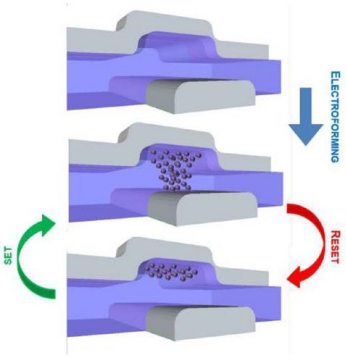
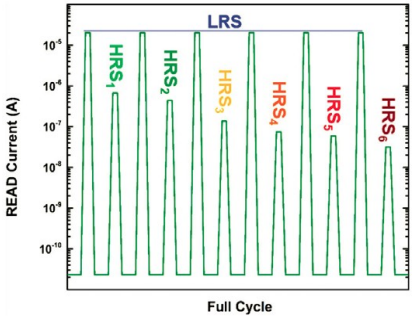
Other areas of research – Oxide thin films

Wearable sensors (Pressure and biometrics)



Oxide Memristors (Multi-state memory storage)





Semiconductor-free transistors (air-channel as transport channel)

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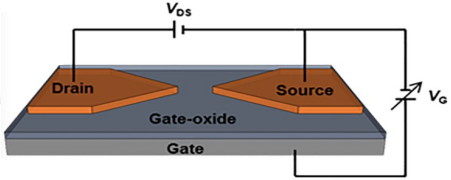
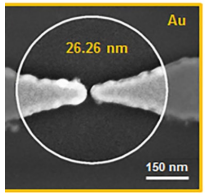
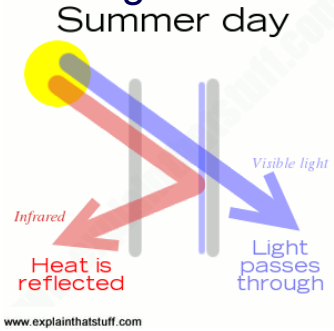
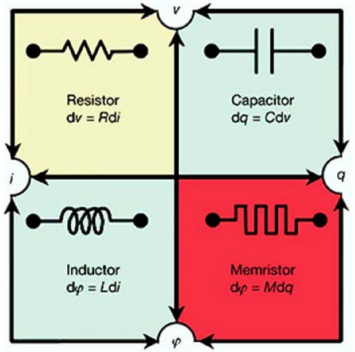


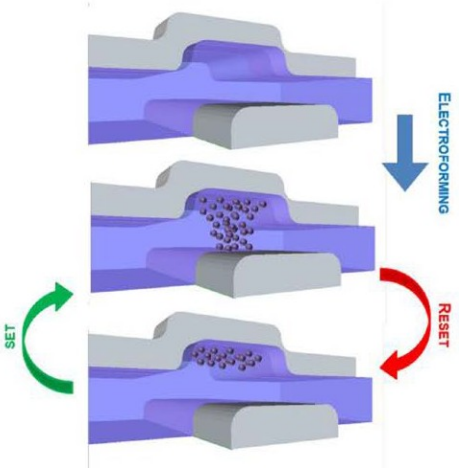


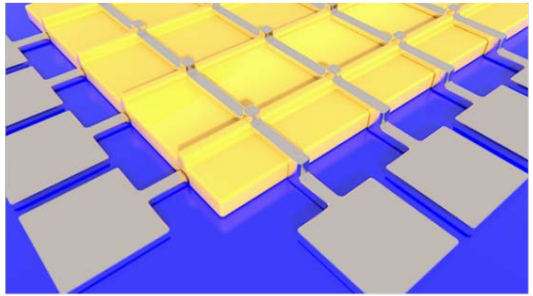
Smart coatings for infrared control



Memristors | Amorphous Complex Oxides







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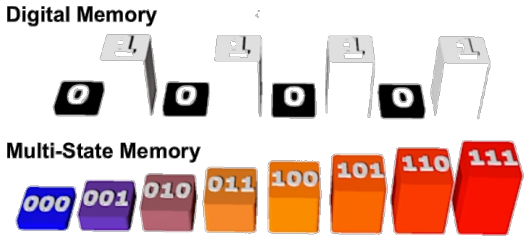
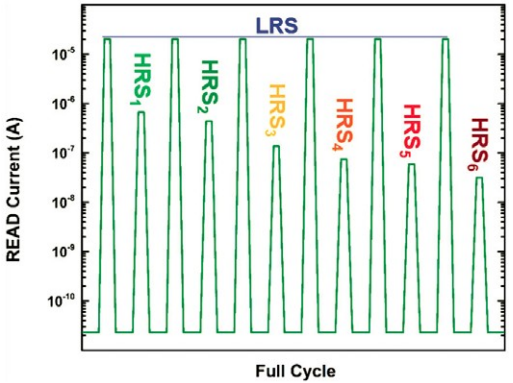
Adv. Funct. Mater. 24 6741 (2014); *Adv. Funct. Mater*. 25 3172 (2015); *Nanotechnol*. 27 505210 (2016).
International PCT Patent Application No. PCT/AU2016/051145; Australian Provisional Patent 2016902654.

Memristors | Nanoscale Switching

- Memory behaviour relies on prior information
  - Learns from experience
- Resistance to store information
  - Can attain multiple information states
- Long-term stability
  - Years to decades without data loss
- Ultra-high density
  - Memory elements as small as 2-4 nm
- Low power technology
  - Make devices last longer
  - Near-zero power in ‘off’ state





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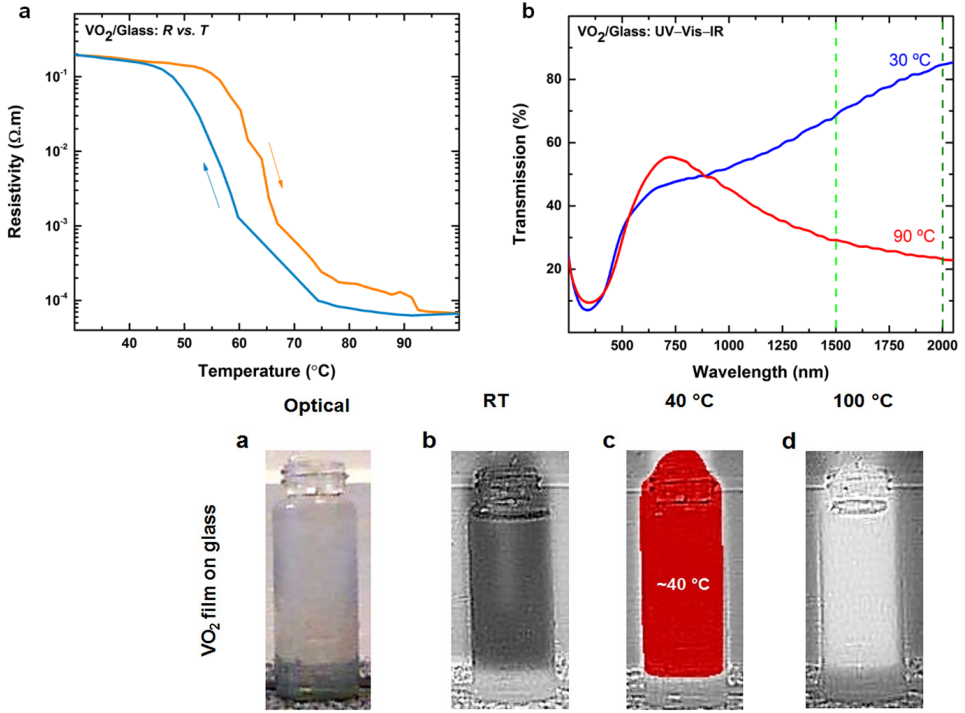
VO_2 enabled phase-transition

- Ability to fabricate on a variety of substrates (glass, quartz, silicon, PDMS)
- IMT ratio: ~10^4
- >60% optical change in the infrared region
- Smart-windows and masking of infrared signatures



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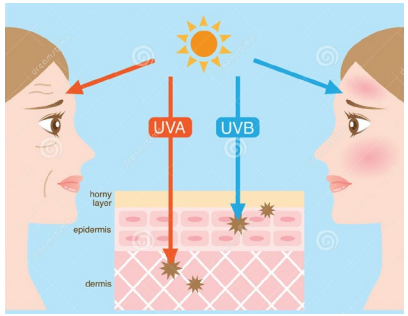
Wearing the Future | Applications

UV Sensors

ZEISS



Biometrics/Health Markers

nutromics
PERSONALISED NUTRITION

Smart bedding for aged-care

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sleeptite

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Sleepeezee

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Technology capability areas

Our current research activities include

- Synthesis of atomically thin materials
- Photodetectors (detecting different wavelengths of light on demand)
- Artificial neural networks
- Engineering Light blocking layers (Transmit and block selective wavelength bands on demand)
- Wireless electronics on wearable and stretchable platforms
- Communication of sensors to smart devices wirelessly
- Specific Biomarker sensors (saliva, sweat etc). We engineer selective sensors based on target biomarker
- Antibacterial and antifungal coatings

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Our facilities

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Micro Nano Research Facility

Acknowledgements

Get in touch for possible collaborations and partnerships!!

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