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Three research papers published in Nature series journals

Appendix

Optoelectronic resistive random-access memory (ORRAM) for neuromorphic vision sensors

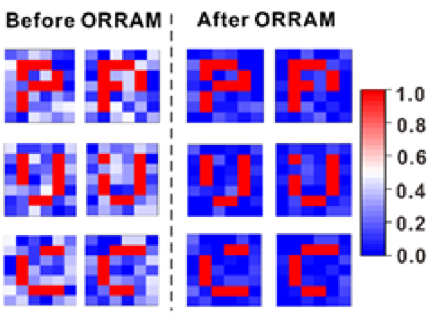
Principal Investigator: Dr Yang CHAI, Associate Professor, Department of Applied Physics, PolyU

Published journal:-
Feichi Zhou, Zheng Zhou, Jiewei Chen, Tsz Hin Choy, Jingli Wang, Ning Zhang, Ziyuan Lin, Shimeng Yu, Jinfeng Kang, H.-S. Philip Wong & Yang Chai. Optoelectronic resistive random access memory for neuromorphic vision sensors. *Nature Nanotechnology*, 14, 776–782 (2019) (Full text)

Over 80% of information a human being collects are from visual, and retina is the crucial first gateway in human visual system. The sensory neurons in retina can directly respond to optical stimuli, and perform the first stage image processing prior to passing the pre-processed information through optic nerve to the visual cortex in the brain for more complicated visual signal processing. Today's artificial visual systems mainly composed of photoreceptors to perceive the visual inputs as digital images, a memory unit to store visual information, and a processing unit. Unlike human retina, the units cannot directly respond to optical stimuli and needs image sensor arrays to convert optical signals to electrical ones for further processing. Such complicated circuitry design generates a lot of redundant data which occupies large amount storage space, with high power consumption.

PolyU's research team designed an optoelectronic resistive random-access memory (ORRAM) synaptic device with a two-terminal structure of Pd/MoO_x/ITO (palladium / molybdenum-oxide / indium tin oxide). It can sense optical signals (ultraviolet light) directly, and integrates sensing, memory and processing functions more efficiently. Experimental finding indicated that the ORRAM arrays can mimic human retina in enabling the functions of first-stage image processing, such as contrast enhancement and noise reduction. By transporting these pre-processed images to artificial neural network, tests on image training and recognition were conducted. The recognition efficiency, including processing speed and energy consumption, is proved to be largely improved by 41.5%, in comparison with images without being pre-processed by ORRAM.

The findings demonstrate the ORRAM device's great potential in enhancing neuromorphic visual system by simplifying the circuitry, and efficiently processing overwhelming amount of dynamic visual information from surrounding environment. By greatly reducing the amount of hardware and power consumption required, the innovation can contribute significantly to the development of applications in edge computing and Internet of Things.



Experimental demonstration of background noise reduction by processing images with ORRAM

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Continuous artificial synthesis of glucose precursor using enzyme-immobilised microfluidic reactors

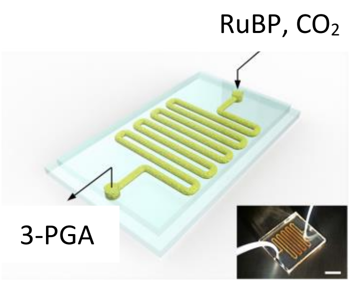
Principal Investigator: Dr ZHANG Xuming, Associate Professor, Department of Applied Physics, PolyU

Published journal:-
Yujiao Zhu, Ziyu Huang, Qingming Chen, Qian Wu, Xiaowen Huang, Pui-Kin So, Liyang Shao, Zhongping Yao, Yanwei Jia, Zhaohui Li, Weixing Yu, Yi Yang, Aoqun Jian, Shengbo Sang, Wendong Zhang & Xuming Zhang. Continuous artificial synthesis of glucose precursor using enzyme-immobilized microfluidic reactors. *Nature Communications*, volume 10: 4049 (2019) (Full text)

Glucose is the basic material of food produced by green plants, yet such natural photosynthesis suffers from low-energy efficiency (~1%), and is greatly limited by factors like soil, climate, water and labour. Various artificial photosynthesis methods usually present much higher efficiency, of about 12%, and demands much less usage of land and water without being constrained by climate conditions. However, the innovation of the PolyU research team, including doctoral student Yujiao ZHU, is the first ever successful attempt of fabricating micro-fluidic chips to build up a full photosynthetic pathway that replicates the opto-fluidic system of leave vein for conducting the first phase reaction of CO_2 fixation in natural photosynthesis.

Experiments on the RuBisCO-immobilized microfluidic reactor (RIMR) fabricated by the team indicated that it can significantly enhance the stabilities of RuBisCO (the enzyme involved in the first major step of photosynthesis), which is the key to success. The RIMRs also present good reusability, with 90.4% of its initial activity retained after 5 cycles of reuse, and 78.5% after 10 cycles. Moreover, the reactors can continuously produce 3-PGA (an organic acid crucial in producing glucose) by constantly injecting the basis materials (RuBP and carbon dioxide), using only a small amount of RuBisCO as its enzymatic reaction being greatly enhanced.

The novel RIMR thus offers great potential for industrial applications in producing food materials, like sugar and starch, and biofuel in a low-cost, convenient and durable way. In long run, the scientific approach can contribute towards relieving food crisis, a major challenge faced by the global community amidst growing world population against worsening climate change and shortages in energy and water.



Three-dimensional diagram and the photograph (inset) of the RIMR

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Enhanced sieving from exfoliated MoS_2 membranes via covalent funcationalisation

Principal Investigator: Dr Nicolas ONOFRIO, Assistant Professor, Department of Applied Physics, PolyU

Published journal:-
Lucie Ries, Eddy Petit, Thierry Michel, Cristina Coelho Diogo, Christel Gervais, Chrystelle Salameh, Mikhael Bechelany, Sébastien Balme, Philippe Miele, Nicolas Onofrio and Damien Voiry. **Enhanced sieving from exfoliated MoS_2 membranes via covalent funcationalisation.** *Nature Materials,* 18, 1112-1117 (2019) (Full text)

Membranes are semipermeable barriers that allow separating contaminants depending on various parameters including their size, charge and chemical affinity. Nanolaminate membranes made of two-dimensional (2D) materials such as graphene oxide (GO) are promising candidates for molecular sieving via size-limited diffusion in the 2D capillaries, but high hydrophilicity makes these membranes unstable in water. The team recently developed a nanolaminate membrane based on covalently functionalised molybdenum disulfide (MoS_2) nanosheets which demonstrate >90% and ~87% rejection for micropollutants and Sodium chloride (NaCl), respectively, when operating under reverse osmotic conditions.

The team chemically exfoliated the nanosheets from bulk layered crystals, and then prepared the nanolaminate membranes by vacuum filtration of the chemically exfoliated nanosheets. The nanosheets were covalently functionalised before or after filtration. The unique process of controlling the surface chemistry of the MoS_2 nanosheets allowed the team to precisely adjust and control the size, the nature and quantity of the functional groups and therefore finely tuned the surface chemistry of the nanosheets, determining the thickness of the nanolaminate membranes by controlling the volume of MoS_2 solution to be filtered.

The sieving performance and water flux of the functionalised MoS_2 membranes are attributed both to control of the capillary widths of the nanolaminates and to control of the surface chemistry of the nanosheets. Small hydrophobic functional groups, such as the methyl group, were identified as the most promising for water purification. Methyl-functionalised nanosheets show high water permeation rates as confirmed by molecular dynamic simulations, while maintaining high NaCl rejection.

The team's work is the first report that takes advantage of the surface chemistry of the 2D nanosheets for the development of novel nanolaminate membranes in which sieving is controlled by both the capillary width and the chemical interactions between the nanosheets and the permeate. The functionalised nanolaminate membranes thus produced do not swell and are therefore more stable when compared with graphene oxide membranes. They also outperform previous reports on nanolaminate membranes in terms of water flux and salt/micro-pollutant rejection.

The novel strategy is hopeful to be used to develop novel membranes for micro-pollutant removal and desalination.

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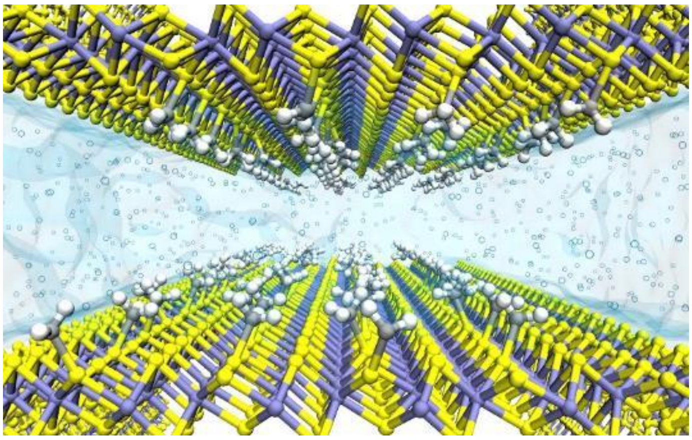

Molecular representation of the inside of methyl-functionalized MoS2 membrane.