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# **Liquid Metal-Derived Two-Dimensional Metal oxides: A Scalable Pathway to Energy Efficient Multifunctional Sensing**

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## **ABSTRACT**

*Non-stratified two-dimensional(2D) materials exhibit unsaturated dangling bonds at the interface, and hence chemically active surfaces and highly sensing activities. Liquid metal printing is emerging as an ideal platform for harvesting non-layered 2D films with a thickness down to a few nanometres, (1-3) leading to an ultra-large surface-to-volume ratio that is ideal for gas sensing applications. Tin oxide ( $\text{SnO}_2$ ) and zinc tin composite metal oxide (ZTCMO) could be a promising candidate for gas sensing owing to its wide bandgap, good chemical stability and high electrical conductivity. This study employed a well-established liquid metal-based van der Waals printing technique to fabricate ultra-thin  $\text{SnO}_2$  and ZTCMO nanosheets from a eutectic alloy of molten tin and zinc, all within a vacuum-free environment(4). The resulting ultrathin nanosheets have a composition of approximately  $82.7 \pm 0.9$  at% ZnO, and the remainder consists of  $\text{SnO}_2$ . The ZTCMO nanosheets demonstrate strong potential as multifunctional sensors, exhibiting high responsiveness to UV light as optical sensors, and excellent selectivity and sensitivity toward  $\text{NH}_3$  gas at room temperature. The ammonia sensors were studied with a combination of electrochemical(bias), optical (UV excitation) and temperature as external sensor stimuli to improve the sensitivity and the selectivity of the sensor toward  $\text{NH}_3$  gas. This unique surface properties of the nanosheets enables the detection of  $\text{NH}_3$  gas down to 5 ppm with highly promising limit of detection capabilities. The ultrathin  $\text{SnO}_2$  and ZTCMO nanosheets also demonstrated a high cross-selectivity to different gases, including both organic and inorganic species. The 2D nanosheets and fabricated sensors exhibit high stability under both air storage and sensing environments for several months, indicating a promising technique for fabricating  $\text{NH}_3$  sensors with low-cost, reproduceable, selective, and reliable performance. These findings highlight the potential of composite metal oxide-based devices with the capability of multifunctional sensing, making them well-suited for a wide range of applications.*

## **KEY WORDS**

*Liquid metal, functionalized metal oxide, DFT, Flexible sensor*

## **BIOGRAPHY**

Dr Nitu Syed is a Vice-Chancellor's Fellow at the School of Engineering, RMIT University, and an Associate Investigator at the ARC Centre of Excellence for Transformative Meta-Optical Systems

(TMOS). She holds a PhD in Electronic Materials Engineering from RMIT and completed her MSc and BSc in Electrical and Electronic Engineering at BUET, Bangladesh. She previously received the prestigious McKenzie Postdoctoral Fellowship (2022–2025) from the University of Melbourne. Her research focuses on advanced functional materials, particularly liquid-metal-derived metal oxides for nanoelectronics, environmental sensing, and optoelectronics. Dr Syed has published in leading journals including Nature Communications, Nature Electronics, Advanced Functional Materials, and ACS Nano.

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