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Thesis abstract

Indium phosphide nanowire arrays for gas sensing applications

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Semiconductor nanomaterial based chemiresistive gas sensor is one of the most promising technologies for the development of next-generation chemical sensing, with applications ranging from explosive detection and environmental monitoring to industrial safety, healthcare and the Internet of Things (IoTs). Recently, there have been growing efforts in developing room temperature chemiresistive gas sensors with high sensitivity, selectivity, long-term stability, and low power consumption. In this thesis, we design and demonstrate indium phosphide (InP) nanowire (NW) array based chemiresistive gas sensors, as a new and promising platform for achieving high-performance gas sensing for real-world applications.

Firstly, by carefully engineering the NW array geometry (i.e., diameter and pitch), we demonstrate a NO_2 sensor with superior sensitivity (limit of detection 3.1 ppb) at room temperature, with outstanding selectivity and long-term stability. Kinetic analysis and electrical simulation reveal the array geometry correlated sensing mechanism. To minimise the device power consumption, a novel axial p-i-n homojunction self-powered photovoltaic (PV) NW NO_2 sensor was further designed through numerical simulation and experimental optimisation. The fabricated InP NW array PV sensor achieved 84% sensing response to 1 ppm NO_2 with a record limit of detection down to sub-ppb level even under <5% of 1 sun illumination. With high fidelity to the nature lighting conditions, the sensor was integrated onto a commercial microchip interface for self-powered, dynamic monitoring of on-field motor vehicle exhaust.

Not only for oxidising gas such as NO_2, the InP NW array can also be fabricated into sensitive sensors for reducing gases such as acetone. By incorporation of chitosan as a surface-functionalisation layer and a Pt Schottky contact for efficient charge transfer and photovoltaic effect, self-powered, highly selective acetone sensing is achieved. The sensor has exhibited an ultra-wide acetone detection range, covering concentrations found in the exhaled breath of healthy individuals (300–800 ppb) as well as those at high risk of diabetic ketoacidosis (>75 ppm). Our acetone sensor was then integrated into a breath testing apparatus, named Ketowhistle, and proven to be promising for diabetes monitoring and diagnosis.

Finally, a wearable multipixel InP nanowire array sensor was fabricated on a flexible substrate. A signal decoupling strategy was designed and implemented through nanowire size control, surface-functionalisation and electrode metal selection. This approach has led to the demonstration of a multipixel

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sensor device consisting of sixteen sensing elements with integrated functionality, including NO_2 and acetone sensing, as well as simultaneous pulse and body temperature measurements, demonstrating potential as a personalised device for health and environmental monitoring.

The thesis work indicates that III–V compound semiconductor nanowire array presents a promising sensing platform for the development of high performance, miniaturised, low power consumption, multi-functional on-chip sensing system for future large-scale IoT technology.

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