



Cite this: *RSC Adv.*, 2017, 7, 33419

# Highly active and porous single-crystal $\text{In}_2\text{O}_3$ nanosheet for $\text{NO}_x$ gas sensor with excellent response at room temperature†

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Porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet (ps- $\text{In}_2\text{O}_3$  NS) was designed and prepared through a method of calcination after liquid reflux. Compared with the other  $\text{In}_2\text{O}_3$  with different surface morphologies, the ps- $\text{In}_2\text{O}_3$  NS has gas sensing properties towards  $\text{NO}_x$  at room temperature. Gas sensing data strongly demonstrate that this porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet exhibits a distinguished response (89.48) and fast response time (16.6 s) to 97.0 ppm  $\text{NO}_x$ . Meanwhile, the ps- $\text{In}_2\text{O}_3$  NS sensor presents a favorable linearity and good selectivity, and the detection of  $\text{NO}_x$  is down to ppb levels at room temperature. The enhancement of the sensing response is attributed to the porous, single-crystal and two dimensional nanosheet structure of the synthesized ps- $\text{In}_2\text{O}_3$  NS, which has much higher BET surface area, effective gas diffusion of slit pores and thus provides more active sites for the reaction of  $\text{NO}_x$  with surface-adsorbed oxygen ions. This work would be important for the low-cost and high performance of the  $\text{In}_2\text{O}_3$  material with highly promising applications in gas sensors.

Received 14th May 2017  
 Accepted 26th June 2017

DOI: 10.1039/c7ra05446g

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## Introduction

Chemical sensing based on various nanostructures<sup>1,2</sup> has attracted enormous attentions, as that is widely perceived as one of the most promising fields for nanotechnology to generate significant impact. Among the chemicals studied, NO and  $\text{NO}_2$  ( $\text{NO}_x$ ) are amongst the most dangerous air pollutants, which play major roles in the formation of ozone and acid rain.<sup>3,4</sup> Continued or frequent exposure to  $\text{NO}_x$  concentrations higher than the air quality standard (53 ppb) may cause increased incidence of acute respiratory illness in children.<sup>5</sup> The detection and measurement of  $\text{NO}_x$  gas are thus of great importance in both environmental protection and human health.

Semiconducting metal oxides, such as,  $\text{In}_2\text{O}_3$ ,<sup>6,7</sup>  $\text{SnO}_2$ ,<sup>8,9</sup>  $\text{CuO}$ ,<sup>10,11</sup>  $\text{ZnO}$ <sup>12,13</sup> and  $\text{Fe}_3\text{O}_4$  (ref. 14) have been extensively studied as chemical sensing materials due to their extraordinary properties, such as good response, short response time

and selectivity to the ambient conditions in addition to the simplicity in materials synthesis and sensing device fabrication.<sup>15,16</sup> Among the semiconducting metal oxides,  $\text{In}_2\text{O}_3$ , an important functional semiconductor material with remarkable electronic properties, which has been proven to be a very good candidate with a pronounced response to detect chemicals like  $\text{NO}_x$ ,<sup>17</sup>  $\text{NH}_3$ ,<sup>18</sup> ethanol,<sup>19</sup>  $\text{H}_2\text{S}$ ,<sup>20</sup> acetone,<sup>21</sup> formaldehyde,<sup>22,23</sup>  $\text{Cl}_2$  (ref. 24) and so on, has attracted considerable interest for several decades. A great attention has been recently paid to the development of new material “architectures” based on  $\text{In}_2\text{O}_3$  at the nano-scale.<sup>25,26</sup> Since detection of a given gas involves adsorption process on the surface of the sensing material, it is expected that the higher the surface, the greater the sensor response. Thus, it is quite essential to control the size, shape, and surface characteristics of the sensing material in order to achieve reliable properties.<sup>27,28</sup> Two-dimensional (2D) and porous oxide provide a high surface area for chemical reaction, effective diffusion of gases species into the interface/surface, and enhance gas sensing performance.<sup>29</sup> Various synthetic strategies to prepare 2D and porous structures for gas sensor applications have been reported.<sup>30</sup> Compared with the other methods, such as vapor phase, the hydrothermal method are proven to be environmentally benign methods, which are able to produce  $\text{In}_2\text{O}_3$  nanostructures in mass quantities.<sup>31,32</sup> But, 2D porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet have not yet been reported. Our research is focused on enhancing the material surface area while keeping a high crystalline degree of the nanostructured  $\text{In}_2\text{O}_3$ .

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† Electronic supplementary information (ESI) available. See DOI: 10.1039/c7ra05446g



In this paper, we reported the synthesis of porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet by calcinations of  $\text{In}(\text{OH})_3$  for the first time. During the synthesis, urea was used as an alkaline source and ligand for assembling the porous and single crystal nanosheet. The as-obtained ps- $\text{In}_2\text{O}_3$  NS was applied as a high performance gas sensor to detect  $\text{NO}_x$  down to 485 ppb, one order of magnitude better than the previously fabricated  $\text{In}_2\text{O}_3$  nanosheet  $\text{NO}_x$  sensors at room temperature, suggesting a great potential in sensing related application.

## Experimental

### Sample preparation

**Preparation of porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet.** All chemicals were purchased with analytic grade and used without further purification.  $\text{In}(\text{NO}_3)_3 \cdot x\text{H}_2\text{O}$  ( $M_w = 300.83$ ) and urea ( $\text{H}_2\text{NCONH}_2$ ,  $M_w = 60.05$ ) were purchased from Aladdin Chemical Reagents Co., Ltd. sodium dodecyl benzene sulfonate (SDBS,  $M_w = 348.48$ ) was bought from Guangfu Fine Chemical Research Institute. Deionized water was homemade.

The porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet (ps- $\text{In}_2\text{O}_3$  NS) were fabricated by a facile liquid reflux method with  $\text{In}(\text{NO}_3)_3$ , urea and SDBS as In source, precipitant and the structure-director, respectively. The process is schematically illustrated in Scheme 1. Typically,  $\text{In}(\text{NO}_3)_3$  (0.90 g), urea (0.80 g), SDBS (0.17 g) and  $\text{H}_2\text{O}$  (50 mL) were added into a beaker reservoir and then stirred vigorously for 1 h. The homogenous mixture was refluxed at  $100^\circ\text{C}$  for 3 h in a flask to obtain the precursor of ps- $\text{In}_2\text{O}_3$  NSs. Subsequently, the precursor was heated to  $550^\circ\text{C}$  for 4 h in air with a heating rate of  $2^\circ\text{C min}^{-1}$ . After naturally cooling to room temperature, the ps- $\text{In}_2\text{O}_3$  NS sample was obtained. Different dosage of  $\text{In}(\text{NO}_3)_3$  (0.6 g, 0.7 g, 0.8 g, 0.9 g, 1.0 g and 1.2 g) was marked as  $\text{In}_2\text{O}_3$ -0.6,  $\text{In}_2\text{O}_3$ -0.7,  $\text{In}_2\text{O}_3$ -0.8,  $\text{In}_2\text{O}_3$ -0.9,  $\text{In}_2\text{O}_3$ -1.0 and  $\text{In}_2\text{O}_3$ -1.2, while other reaction conditions are the same as that described above.

### Material characterizations

The X-ray diffraction (XRD) patterns were examined by using an X-ray diffractometer (XRD, Bruker NEW D8 ADVANCE, Germany) with monochromatized Cu-K $\alpha$  radiation with an accelerating voltage of 40 kV and an applied current of 20 mA. The morphologies and structures of the ps- $\text{In}_2\text{O}_3$  NS were observed

by scanning electron microscope (SEM, HITACHI S-4800) and transmission electron microscopy (TEM, JEOL-2100). X-Ray photoelectron spectra (XPS) were recorded with a AXIS ULTRA DLD (Shimadzu Corporation) system equipped to analyze the surface composition of porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet, using monochromatic Al K $\alpha$  radiation (1486.4 eV), and C 1s (284.6 eV) was utilized as a reference to correct the binding energy. The nitrogen adsorption/desorption isotherms were measured at 77 K using a Micromeritics Tristar II. The BET surface area was analyzed by Brunauer–Emmett–Teller (BET) theory. The pore size distribution was computed by the nonlocal density functional theory (NLDFT) method.

### Fabrication and measurements of gas sensors

An interdigitated Au electrode ( $7 \times 5 \times 0.38$  mm) was selected for the gas sensing detection and the electrode spacing was 20  $\mu\text{m}$ . The sample materials were spin-coated onto the interdigital electrode to form a sensitive film and then dried at  $70^\circ\text{C}$  for 5 h to obtain a gas sensor. The sensor was installed into a test chamber with an inlet and an outlet. The electrical resistance measurements of the sensor were carried out at room temperature and a relative humidity (RH) around 40%. The  $\text{NO}_x$  gas concentration was controlled by injecting volume of the gas and the chamber was purged with air to recover the sensor resistance. The gas response can be obtained from eqn (1).<sup>33,34</sup>

$$\text{Response } (R) = (R_N - R_0)/R_0 \quad (1)$$

where  $R_0$  and  $R_N$  are the resistances measured in air and the tested gas atmosphere ( $\text{NO}_x$ ).

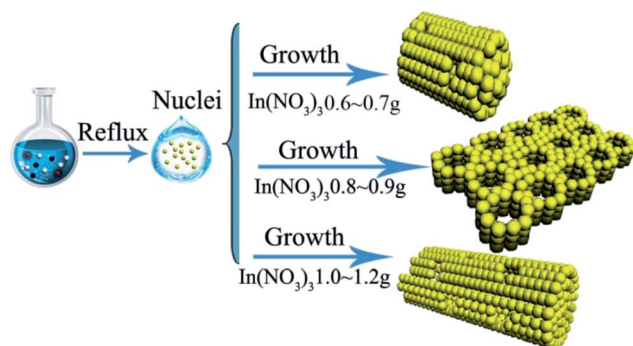
The response time is defined as the time required for the variation in resistance to reach 85% of the equilibrium value after a test gas was injected. The test was conducted at room temperature ( $20^\circ\text{C}$ ) with a relative humidity (RH) around 40%.

## Results and discussion

### Structure, morphology characterization of ps- $\text{In}_2\text{O}_3$ NS

Porous single-crystal  $\text{In}_2\text{O}_3$  nanosheet (ps- $\text{In}_2\text{O}_3$  NS) were synthesized by calcinating  $\text{In}(\text{OH})_3$  precursors. The phase transformation process of the  $\text{In}(\text{OH})_3$  sample during calcinations in air was studied *via* TG-DSC (Fig. S1†). It is observed that the decomposition started at  $200^\circ\text{C}$  in the TG curve of  $\text{In}(\text{OH})_3$ . The TG-DSC curve indicates an endothermic reaction around  $260^\circ\text{C}$ . The  $\text{In}(\text{OH})_3$  directly converts into cubic phase of  $\text{In}_2\text{O}_3$  in our experiment at  $290^\circ\text{C}$ . If a temperature higher than  $550^\circ\text{C}$  was chosen, the nanosheets shapes were destroyed and only  $\text{In}_2\text{O}_3$  nanoparticles were obtained. Hence, the annealing temperature is ascertained to be  $550^\circ\text{C}$  in order to obtain pure  $\text{In}_2\text{O}_3$  nanosheets.

Fig. 1a shows a typical TEM image of the ps- $\text{In}_2\text{O}_3$  NS, in which the annealed  $\text{In}_2\text{O}_3$  are porous nanosheet with a rough surface and many tiny pores with diameters of several nanometres exist along the whole area of the nanosheet. To further examine the surface morphology of the nanosheet, high-magnification TEM images were recorded, as shown in Fig. 1b and c. The selected-area electron diffraction (SAED) pattern



Scheme 1 The formation mechanism of the different porous  $\text{In}_2\text{O}_3$ .



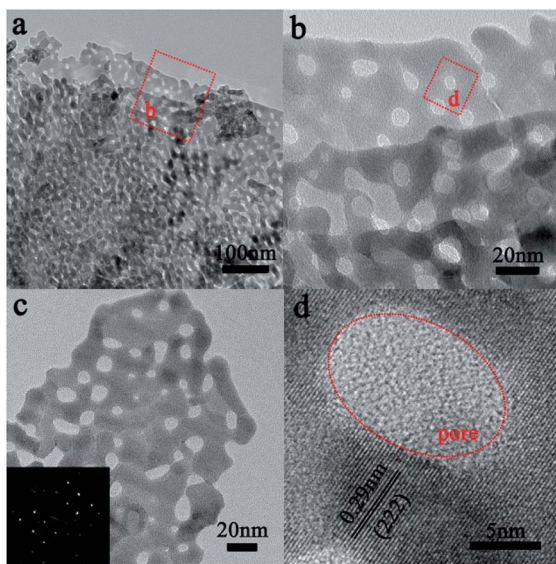


Fig. 1 (a–c) Representative TEM images of the synthesized ps- $\text{In}_2\text{O}_3$  NS, the inset shows the SAED pattern of the ps- $\text{In}_2\text{O}_3$  NS; (d) HRTEM image of ps- $\text{In}_2\text{O}_3$  NS, in which the (222) of cubic phase  $\text{In}_2\text{O}_3$  can be seen.

(lower left inset of Fig. 1c) has confirmed this structure with single crystalline nature. The HR-TEM image of ps- $\text{In}_2\text{O}_3$  NS is displayed in Fig. 1d. The fringe spacing is about 0.29 nm, corresponding to the (222) crystal planes of the cubic  $\text{In}_2\text{O}_3$ .

Fig. 2a shows the powder X-ray diffraction (XRD) pattern of the  $\text{In}(\text{OH})_3$  precursor. All diffraction peaks are sharp and well-defined, suggesting that the sample is highly crystallized. The peaks at  $2\theta$  values of 31.8, 34.4, 36.3, 47.5, 56.6, 62.9 and 68.1° are consistent with the cubic phase  $\text{In}(\text{OH})_3$  (JCPDS no. 76-1464).<sup>35</sup> The XRD pattern of the annealed ps- $\text{In}_2\text{O}_3$  NS is depicted in Fig. 2b. All of the detectable peaks in the pattern can be easily indexed to pure cubic  $\text{In}_2\text{O}_3$  phase with  $a = b = c = 10.140 \text{ \AA}$ , in good agreement with the standard data (JCPDS no. 65-3170),<sup>36</sup> confirming that this product is pure  $\text{In}_2\text{O}_3$  with

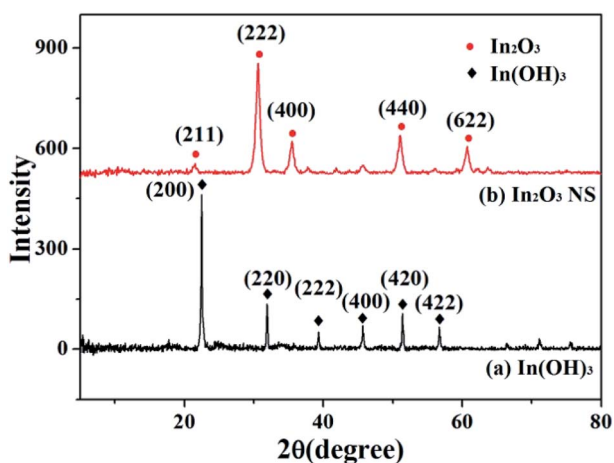


Fig. 2 XRD patterns of (a) the  $\text{In}(\text{OH})_3$  precursors, and (b) the synthesized ps- $\text{In}_2\text{O}_3$  NS.

a cubic structure. No other diffraction peaks related to impurities are observed, indicating the formation of pure cubic  $\text{In}_2\text{O}_3$ .

In this synthesis, the indium ion concentration plays an important role in formation of different morphology  $\text{In}_2\text{O}_3$ . It can be seen that when the indium ion concentration is low (indium precursor of 0.6 g or 0.7 g seen in Fig. 3a and b and S2a and b,†),  $\text{In}_2\text{O}_3$  mainly are porous nanoparticles (NPs) with a rough surface and many tiny pores exist along the NPs. However, assembling of  $\text{In}_2\text{O}_3$  occurred, when further increasing the indium precursor to 0.8 g seen in Fig. 3c, and S3a and b.† When indium precursor is increased to 0.9 g shown in Fig. 3d, the ps- $\text{In}_2\text{O}_3$  NS has been synthesized. But, when further increasing the mass of the indium precursor to 1.0 g or 1.2 g seen in Fig. 3e and f and S4a and b,† the nanorods-like  $\text{In}_2\text{O}_3$  formed with many pores on the surface. These different morphologies of  $\text{In}_2\text{O}_3$  will affect the properties of gas sensing.

The different morphology structures of  $\text{In}_2\text{O}_3$  prepared with different contents of  $\text{In}(\text{NO}_3)_3$  is also studied by nitrogen adsorption-desorption measurement at 77 K. The  $\text{N}_2$  adsorption-desorption isotherm and pore size distribution curves of the typical synthesized  $\text{In}_2\text{O}_3$  samples are shown in Fig. 4 and

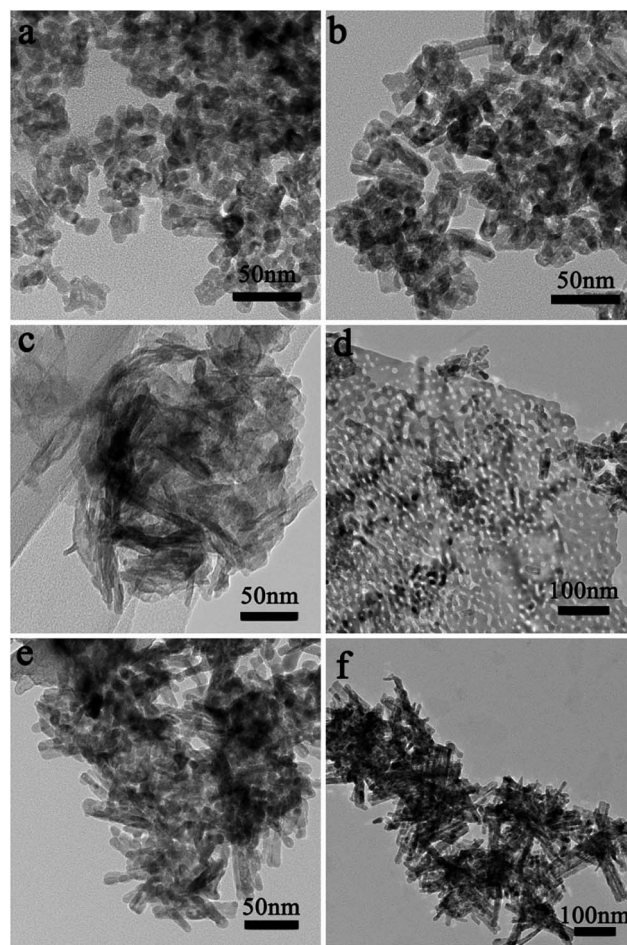


Fig. 3 Representative TEM images of the synthesized  $\text{In}_2\text{O}_3$  with different  $\text{In}(\text{NO}_3)_3$ , (a) 0.6 g, (b) 0.7 g, (c) 0.8 g, (d) 0.9 g, (e) 1.0 g and (f) 1.2 g.





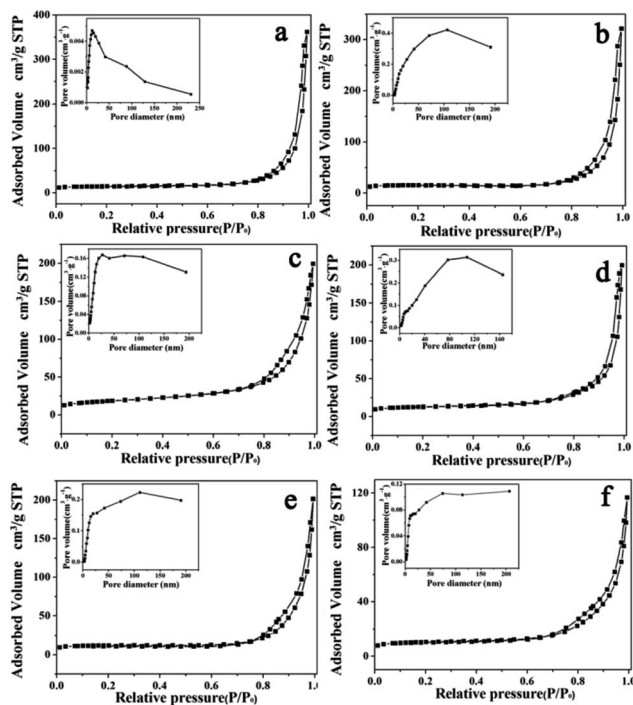


Fig. 4 Nitrogen adsorption–desorption isotherm and the corresponding pore size distribution (inset) of the synthesized  $\text{In}_2\text{O}_3$  with different  $\text{In}(\text{NO}_3)_3$  addition: (a) 0.6, (b) 0.7 (c) 0.8, (d) 0.9, (e) 1.0 and (f) 1.2.

Table S1.† The Brunauer–Emmett–Teller (BET) surface area and total pore volume are  $44.85 \text{ m}^2 \text{ g}^{-1}$  and  $0.28 \text{ cm}^3 \text{ g}^{-1}$ , respectively. In detail, the isotherm of ps- $\text{In}_2\text{O}_3$  NS exhibits typical type IV curve with H2 hysteresis loop. The pore size distribution exhibited in set of Fig. 4d also demonstrated multiple pore structure, and the average pore size about 25.51 nm. The large surface area and plentiful pores of ps- $\text{In}_2\text{O}_3$  NS can provide large accessible area for gas adsorption and desorption.

### Gas sensing performances and sensing mechanism

It is known that the response of the gas sensors is mainly related to the gas concentration. To study the gas sensor properties of the ps- $\text{In}_2\text{O}_3$  NS sensor, series of experiments were carried out by varying the  $\text{NO}_x$  gas concentration from 97.0–0.485 ppm. Fig. 5a shows the representative response–recovery cyclic curves for a the synthesized ps- $\text{In}_2\text{O}_3$  NS sensor to 97.0–0.485 ppm  $\text{NO}_x$  operated at room temperature. The resistance signal represents the increase from the background resistance  $R_0$  to an equilibrium value  $R_N$  when the  $\text{NO}_x$  gas enters the test chamber, and restores to the background value when pure air enters the chamber. Finally, the almost complete recovery of the baseline resistance values at the end of each pulse indicated a reversible interaction between the sensing element and the target analytes, a key issue in view of eventual technological applications.

Response to  $\text{NO}_x$  was obtained from the calculation of resistance value by using eqn (1).<sup>37</sup> According to experimental results, the resistance increased when  $\text{NO}_x$  contacts the ps- $\text{In}_2\text{O}_3$  NS surface. The ps- $\text{In}_2\text{O}_3$  NS is a N-type (electron

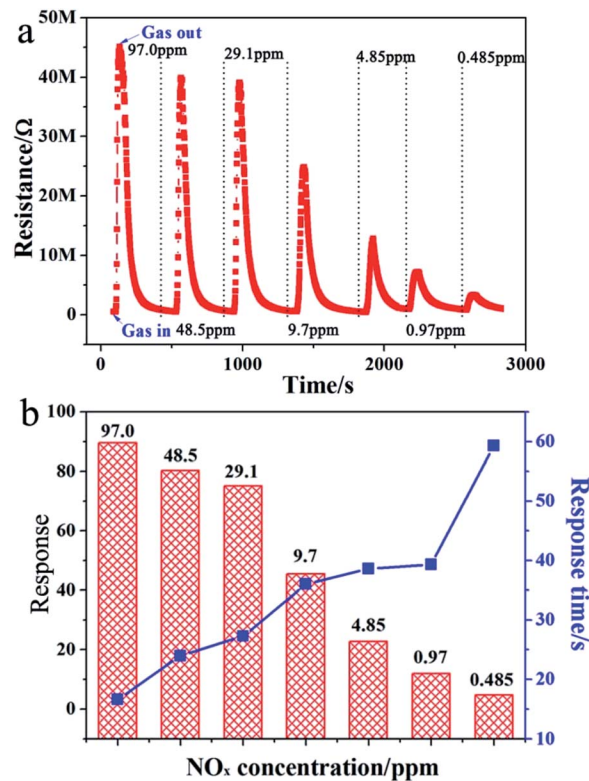


Fig. 5 The results of the gas response of the synthesized ps- $\text{In}_2\text{O}_3$  NS sensor to 97.0–0.485 ppm  $\text{NO}_x$  operated at room temperature. (a) The representative response–recovery cyclic curves; (b) corresponding response and response time curves.

conductivity) semiconductor. Similar results were obtained by Keying Shi and co-workers<sup>38</sup> using a N-type  $\text{SnO}_2$ - $\text{In}_2\text{O}_3$  composite sensing material. Fig. 5b shows the corresponding relationship between response and response time under different  $\text{NO}_x$  concentrations. When the concentration of  $\text{NO}_x$  is 97.0 ppm, the response time is only 16.6 s, while the highest response reached is 89.48. It is found that response declined gradually with the decreased concentration of  $\text{NO}_x$ . The limitation of  $\text{NO}_x$  detection reaches as low as 485 ppb, and the response increases with the increasing gas concentration, which means the sensor is suitable for detecting a wide concentration range of  $\text{NO}_x$ . Compared with the gas response and response time of the  $\text{In}_2\text{O}_3$ -0.7,  $\text{In}_2\text{O}_3$ -0.8,  $\text{In}_2\text{O}_3$ -0.9,  $\text{In}_2\text{O}_3$ -1.0 and  $\text{In}_2\text{O}_3$ -1.2,  $\text{In}_2\text{O}_3$ -0.9 shows the best gas sensing performance (in Tables S2 and S3†). Moreover, we list the literatures about the gas sensing device that detect  $\text{NO}_x$  ( $\text{NO}$  or  $\text{NO}_2$ ) sensing in Table S4.† It is observed that the gas sensing based on ps- $\text{In}_2\text{O}_3$  NS shows a low working temperature (room temperature), short response time and low detection limit. The detailed data would be seen in Table S2† ( $\text{In}_2\text{O}_3$ -0.9).

Fig. 6a shows response changes as the  $\text{NO}_x$  concentration varies from 97.0–0.485 ppm. It was revealed that the linearity of the line formed by plotting  $\log R$  (response) against  $\text{NO}_x$  was  $R^2 = 0.94379$ . In view of practical applications, the sensor selectivity is a key concern and, at the same time, we measured the response to some gases such as  $\text{NO}_x$ ,  $\text{O}_2$ ,  $\text{NH}_3$ ,  $\text{H}_2$ ,  $\text{C}_2\text{H}_2$  and CO



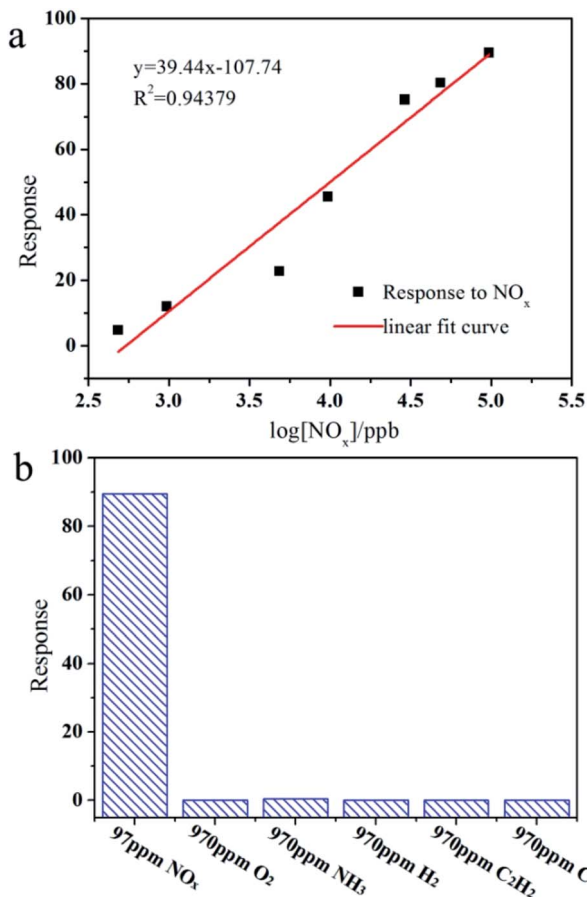
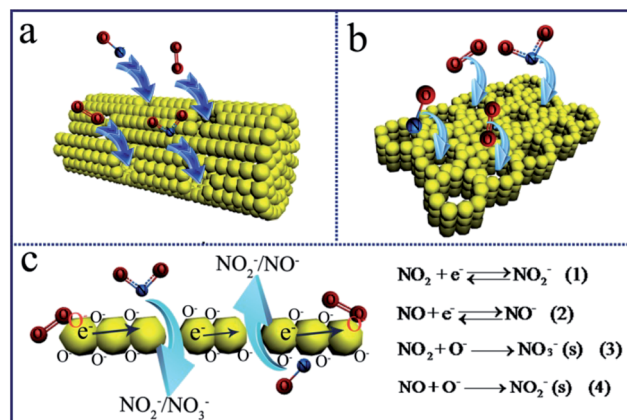


Fig. 6 (a) The histogram of the response for the ps-In<sub>2</sub>O<sub>3</sub> NS sensor to different gases at room temperature; (b) linear dependence relation between the response and relative NO<sub>x</sub> concentration for ps-In<sub>2</sub>O<sub>3</sub> NS sensor.

at room temperature. As shown in Fig. 6b, the ps-In<sub>2</sub>O<sub>3</sub> NS sensor exhibits an excellent selectivity for NO<sub>x</sub>, and no response to O<sub>2</sub>, NH<sub>3</sub>, H<sub>2</sub>, C<sub>2</sub>H<sub>2</sub> and CO. The ps-In<sub>2</sub>O<sub>3</sub> NS sensor thus is suitable for application to commercial NO<sub>x</sub> sensing systems.

When the N-type In<sub>2</sub>O<sub>3</sub> semiconductor is used in gas sensor and exposed in air, O<sub>2</sub> molecules will be chemisorbed and can trap the electrons of the In<sub>2</sub>O<sub>3</sub> to be changed into O<sub>2</sub><sup>-</sup>, O<sup>-</sup>, and O<sup>2-</sup> on the In<sub>2</sub>O<sub>3</sub> surfaces.<sup>39-41</sup> Such chemisorbed oxygen is suggested to act as an electron donor, which depend strongly on temperature and the nature of the material. The formation of numerous oxygen species (e.g. O<sub>2</sub><sup>-</sup>, O<sup>-</sup>, and O<sup>2-</sup>), which are known for their good catalytic activity in gas sensors, could improve the performance of NO<sub>x</sub> sensor.<sup>42,43</sup> After the oxidizing gas (e.g. NO<sub>x</sub>) is introduced, some oxygen species will be reduced and removed from the surfaces above a certain temperature, resulting in the variation of the resistance of In<sub>2</sub>O<sub>3</sub>. The surface area and the morphology of a sensing film can directly decide the adsorption quantity of the oxygen species and hence have important impacts on the variation of resistance and the relevant response of the sensors. The Schematic for sensing mechanism is shown in Scheme 2. When the sensor film is exposed to NO<sub>x</sub>, the NO<sub>x</sub> gas molecules could attract the electrons from which results in an increase of the



Scheme 2 The gas sensing mechanism of the different porous In<sub>2</sub>O<sub>3</sub> sensors.

In<sub>2</sub>O<sub>3</sub> sensor, because the In<sub>2</sub>O<sub>3</sub> sensor is a N-type semiconductor. It finally results in the rapid increase of the resistance (Scheme 2). The target gas molecules (NO<sub>2</sub>) directly adsorb onto In<sub>2</sub>O<sub>3</sub> and react with O<sup>-</sup> the In<sub>2</sub>O<sub>3</sub> because of the high electron affinity of the NO<sub>x</sub> molecules, which leads to electron transfer from the In<sub>2</sub>O<sub>3</sub> to the NO<sub>x</sub>. The adsorption of NO<sub>2</sub> on In<sub>2</sub>O<sub>3</sub> leads to NO<sub>2</sub><sup>-</sup> and the adsorption of NO on In<sub>2</sub>O<sub>3</sub> leads to NO<sup>-</sup>.<sup>44,45</sup> The process traps electrons from the conduction band or donor level of In<sub>2</sub>O<sub>3</sub>, and generate bidentate NO<sub>3</sub><sup>-</sup>.<sup>5,46</sup> The target gas molecules (NO) also can adsorb onto In<sub>2</sub>O<sub>3</sub> and react with O<sup>-</sup> and generate NO<sub>2</sub><sup>-</sup>.<sup>6</sup>

From all the above, the good gas sensing for NO<sub>x</sub> of the In<sub>2</sub>O<sub>3</sub> sensor can be ascribed to the following two factors. First, effective gas diffusion and contact from pores of the In<sub>2</sub>O<sub>3</sub> may also contribute to the good gas sensing. The porous structure can act as channels for gas diffusion, and thus provide more active sites for the reaction of NO<sub>x</sub> with surface-adsorbed oxygen ions. Second, the good gas sensing for NO<sub>x</sub> of the In<sub>2</sub>O<sub>3</sub> sensor can be ascribed to the single crystal In<sub>2</sub>O<sub>3</sub> and its own nanosheet structure which have a beneficial effect on the performance of the In<sub>2</sub>O<sub>3</sub> sensor.<sup>47,48</sup> The ideal structure is considered to be single crystal, because such gas sensing materials can exhibit high electron conductivities, and have abundant interfacial active sites and excellent stability.<sup>49,50</sup> When the porous coupled with single crystallinity provides for the ease of gas diffusion and more active sites for the formation of reactive oxygen species.<sup>51</sup> Then the oxygen species are benefit to the gas sensing performance. So the single crystal structure will lead to good gas sensing performance. These factors improve the performance of the ps-In<sub>2</sub>O<sub>3</sub> NS sensor together.

## Conclusions

In summary, we have demonstrated that the porous single-crystal In<sub>2</sub>O<sub>3</sub> nanosheet *via* a liquid reflux method. The ps-In<sub>2</sub>O<sub>3</sub> NS have gas sensing properties towards NO<sub>x</sub> and gas sensing data shows this porous single-crystal In<sub>2</sub>O<sub>3</sub> nanosheet exhibit an excellent response (89.48), fast response time (16.6 s) and low testing limit to the NO<sub>x</sub> at room temperature,



respectively. The good gas sensing is attributed to the effective gas diffusion and contact by the pore cannals on the surface of the  $\text{In}_2\text{O}_3$  nanosheet.

## Acknowledgements

We gratefully acknowledge the support of this research by the National Natural Science Foundation of China (No. 21601018, 21401012, 51573023, 51572034, 21501104, 21501014), the Natural Science Foundation of Heilongjiang Province (B2015014), the Natural Science Foundation of Changchun University of Science and Technology (No. XQNJJ-2015-07), the University Nursing Program for Young Scholars with Creative Talents in Heilongjiang Province (UNPYSCT-2016088), the Open Project Foundation of Key Laboratory of Functional Inorganic Material Chemistry (Heilongjiang University).

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