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Detection of NO_2 down to ppb Levels Using Individual and Multiple In_2O_3 Nanowire Devices

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ABSTRACT

We demonstrate detection of NO_2 down to ppb levels using transistors based on both single and multiple In_2O_3 nanowires operating at room temperature. This represents orders-of-magnitude improvement over previously reported metal oxide film or nanowire/nanobelt sensors. A comparison between the single and multiple nanowire sensors reveals that the latter have numerous advantages in terms of great reliability, high sensitivity, and simplicity in fabrication. Furthermore, selective detection of NO_2 can be readily achieved with multiple-nanowire sensors even with other common chemicals such as NH_3, O_2, CO, and H_2 around.

Chemical sensing based on various nanostructures[1−11] has attracted enormous attention, as this is widely perceived as one of the most promising areas for nanotechnology to generate significant impact. Among the chemicals studied, NO_2 is one of the most dangerous air pollutants, which plays a major role in the formation of ozone and acid rain. Continued or frequent exposure to NO_2 concentrations higher than the air quality standard (53 ppb) may cause increased incidence of acute respiratory illness in children.[12] The detection and measurement of NO_2 gas are thus of great importance in both environmental protection and human health. Solid-state sensors for NO_2 detection have been under development based on both conventional metal oxide thin films and one-dimensional nanostructures, however, with various limitations. For instance, most existing metal oxide thin-film sensors work at elevated temperatures with sensing limitations around 1 ppm or even higher.[13−17] Nanowires or nanobelts made of metal oxides can deliver better performance because of their enhanced surface-to-volume ratios, and SnO_2 nanobelts have been demonstrated to detect 3 ppm NO_2 at room temperature.[5] In addition, by operating SnO_2 nanobelt sensors at 400 °C, detection down to 0.5 ppm NO_2 has been successfully achieved.[7] These represent significant advance in the field of solid-state chemical sensing; however, the detection limit does not satisfy the requirement of 53 ppb NO_2 set by the U.S. Environmental Control Agency. On the other hand, carbon nanotube mat samples have been reported to reliably detect NO_2 down to 1 ppb or less, with the aid of functional polymer coating to enhance the sticking coefficient.[3]

In this letter we report the detection of NO_2 down to ppb levels for the first time with metal oxide nanowire transistors. Two types of devices have been studied based on both single and multiple In_2O_3 nanowires operating at room temperature and without the help of functional polymer coating. This represents orders-of-magnitude improvement over previously reported metal oxide film or nanowire/nanobelt sensors, and rivals the performance of the best nanotube chemical sensors. While single In_2O_3 nanowire devices exhibited strong gate dependence and nice transistor behavior, sensors based on multiple In_2O_3 nanowires displayed numerous advantages in terms of great reliability, high sensitivity down to 5 ppb, and simplicity in fabrication. Furthermore, selective detection of NO_2 among other common chemicals has been observed with multiple-nanowire sensors without the extra step of polymer coating. These novel devices are a proven new generation of NO_2 sensors that could replace the conventional devices, and even surpass the carbon nanotube (CNT) NO_2 sensors[2,3] in terms of their great simplicity in device fabrication.

In_2O_3 nanowires were synthesized by a laser ablation method, and details can be found in our previous publication.[18] This method typically produced single-crystalline In_2O_3 nanowires with diameters ~10 nm and lengths ~5 μm. These nanowires are wide band gap semiconductors with bixbyte crystal structure, as shown in Figure 1a. The conductance of In_2O_3 nanowires is directly related to the carrier concentration inside, which in turn can be altered by

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