Electronic Supplementary Information (ESI):

A Facile Method for Enhancing the Sensing Performance of Zinc Oxide Nanofibers Gas Sensors

Pei-Pei Wang[a], Qi Qi[a], Rui-Fei Xuan[a,b], Jun Zhao[a], Li-Jing Zhou[a] and Guo-Dong Li*[a]

[a]State Key Lab of Inorganic Synthesis & Preparative Chemistry, College of Chemistry, Jilin University, Changchun 130012, P.R. China.

[b]College of Materials Science and Engineering, China University of Mining and Technology, Xuzhou, 221116, P. R. China.

* To whom correspondence should be addressed (G. D. Li, lgd@jlu.edu.cn)

Experimental section

The preparation of ZnO nanoparticles sensors

ZnO nanoparticles were deposited on Al_2O_3 ceramic substrates (6 mm × 3 mm, 0.5 mm in thickness, supplied by Beijing Elite Tech Co., Ltd, China) using a RF sputtering system (JZCK-IVB, Shenyang) at room temperature (25 ^oC). There are four pairs of Ag-Pd inter-digitized electrodes (both width and distance were about 0.2 mm, and the thickness was about 500 nm) on the ceramic substrate, and the electrodes were calcinated at 900 ^oC during which no resistivity change was observed. A sintered ceramic ZnO target with purity of 99.99% and diameter of 54 mm was employed as source material in the sputtering system. The target-to-substrate separation was kept as 6 cm. High purity Ar (99.999%) and O_2 (99.999%) were introduced separately using mass flow controllers. The total pressure during sputtering was maintained at 1.0 Pa, and the O_2/Ar ratio was 1/10. The deposition power was fixed at 150 W with a frequency of 13.56 MHz. Before sputtering, the vacuum chamber was evacuated down to a base pressure of 1.0×10^{-3} Pa, and the target was pre-sputtered for 15 min to remove any impurity on the surface of the target, the treatment lasted about 30 minutes.

The preparation of ZnO nanoparticles-nanofibers sensors

The ceramic substrates coated with ZnO nanoparticles were placed on a flat aluminum foil in electrospinning equipment. Briefly, 3 g of zinc acetate aqueous solution (16.7 wt%, analytical grade, supplied by Beijing Chemical Co., China) was slowly dropped into an aqueous solution containing 7.6 g polyvinyl alcohol (PVA, MW=75,000, analytical grade, supplied by Beijing Chemical Co., China) and 0.01g Triton-X100 (surfactant, analytical grade, supplied by Tianjin Chemical Co., China). After stirring for 12 h, a gel was obtained. This gel was loaded into a glass syringe connected to a high-voltage power supply. An electric field of 18 kV was applied between cathode (a flat aluminum foil) and anode (syringe) with a distance of 20 cm. After spinning for about 4 h, collected electrospun nanofibers were calcinated (600 ^oC in air for 5 h) to remove PVA and also to convert amorphous zinc precursor to crystalline ZnO.

General characterization methods

Scanning electron microscopy (SEM) images were recorded on a SHIMADZU SSX-550 (Japan) instrument. Transmission electron microscopy (TEM) image were taken on a Hitachi S-570 microscope with an accelerating voltage of 200 kV. X-ray powder diffraction (XRD) data were collected on an X'Pert MPD Philips diffractometer (Cu Kα X-radiation at 40 kV and 50 mA). The thickness of nanoparticles film was measured by a step profiler (AMBIOS Technology INC XP-2).

Sensing performance testing

Sensor measurement was performed on a CGS-1TP (Chemical Gas Sensor-1 Temperature Pressure) intelligent gas sensing analysis system (Beijing Elite Tech Co., Ltd, China) with a static gas distribution unit. The analysis system offered an external temperature control (from room temperature to 500 ^{o}C), which could adjust the sensor temperature. During the measurement, the sensor was laid on the temperature control and pre-heated at different operating temperatures for about 30 min. Two probes were pressed on sensor electrodes by controlling the position adjustment in the analysis system. The electrical signals were collected in real time. When the resistance of the sensor was stable, saturated target gas was injected into the test chamber (18 L in volume) by a micro-injector through a rubber plug. The saturated target gas was mixed with air (relative humidity was about 25%) by two fans. After the sensor resistance reached a new constant value, the test chamber was opened to recover the sensors in fresh air.

The response value (R) is designated as R = Ra/Rg, where Ra is the sensor resistance in air (base resistance) and Rg is the sensor resistance in a mixture of target gas and air. The time taken for the sensor resistance to change from Ra to [Ra - 90%×(Ra-Rg)] is defined as sensor response time when the target gas is introduced to the sensor, and the time taken from Rg to [Rg + 90%×(Ra-Rg)] is defined as sensor recovery time when the atmosphere is changed to air.

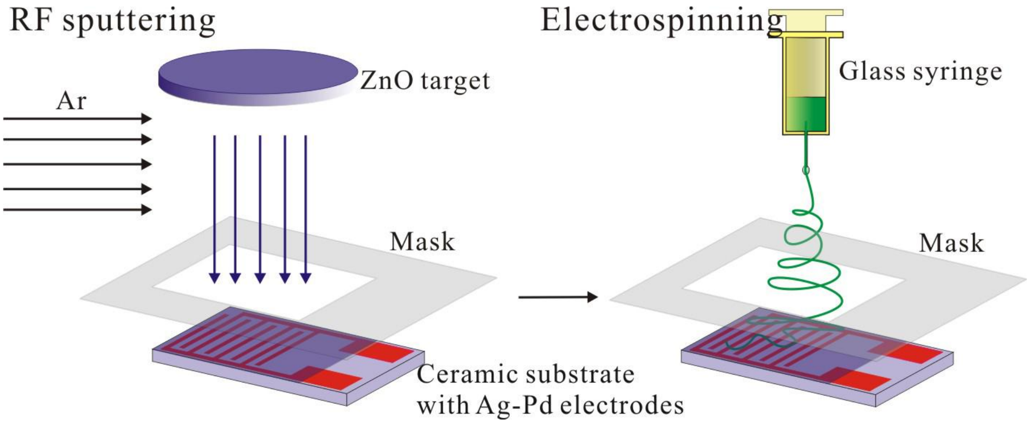

Fig. S1 Schematic diagram of the processing steps used to fabricate ZnO nanoparticles-nanofibers sensors.

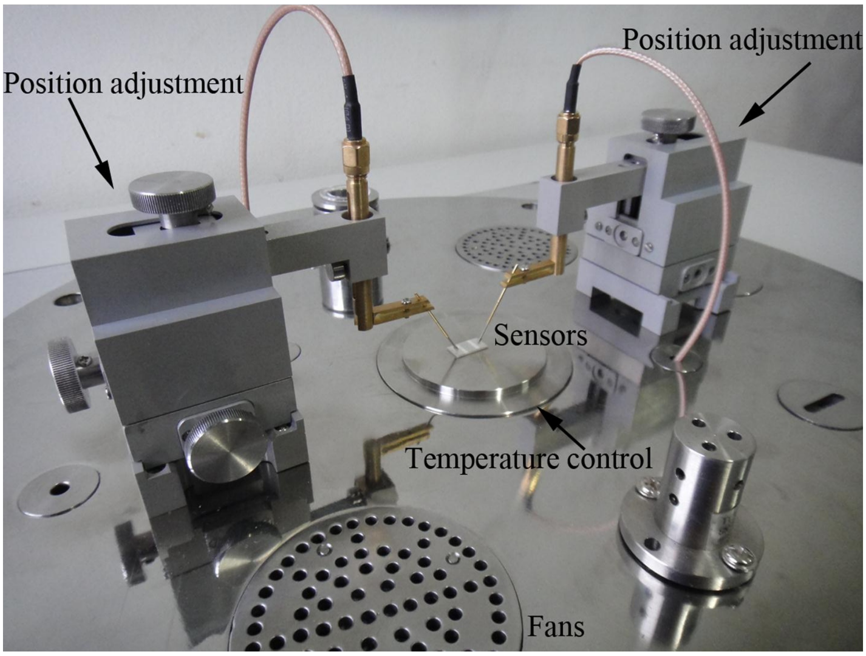

Fig. S2 A photograph of gas sensors in the sensing analysis system.

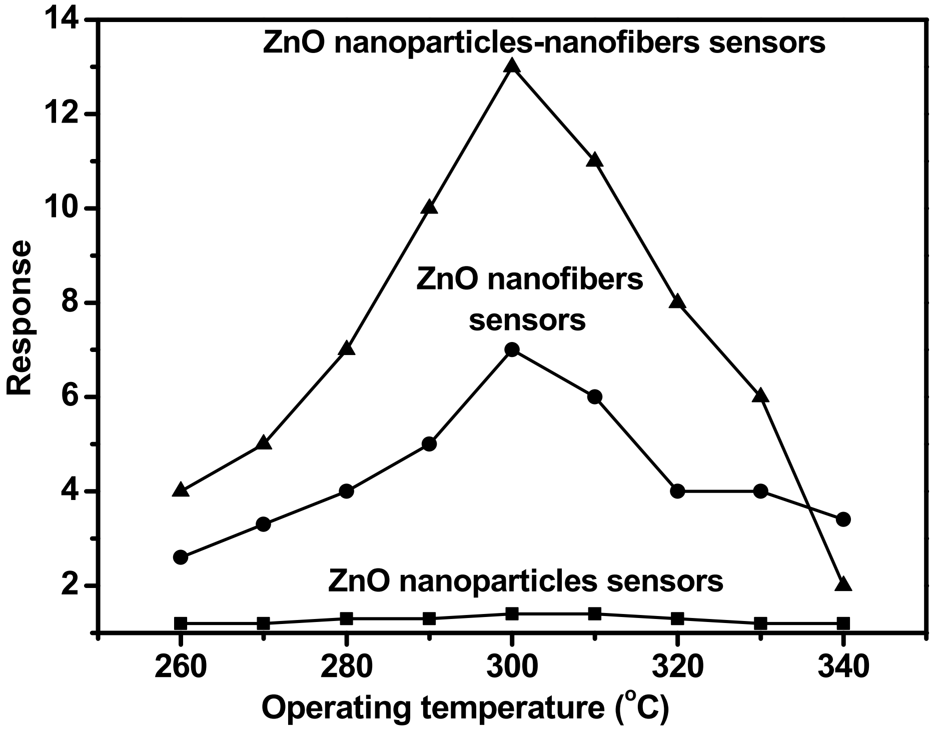

Fig. S3 Electrical responses of ZnO nanoparticles-nanofibers sensors, ZnO nanofibers sensors and ZnO nanoparticles sensors to 100 ppm ethanol at different operating temperatures.

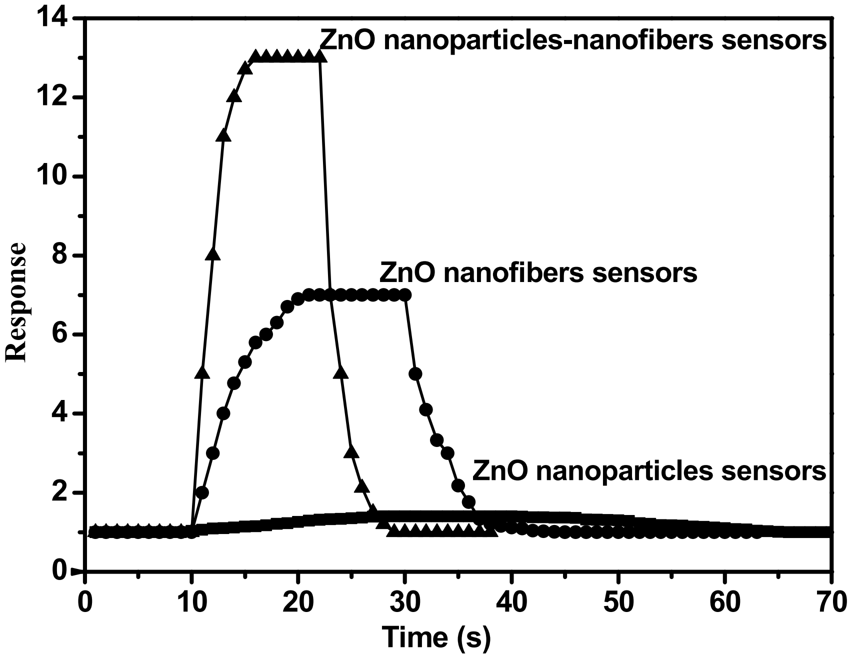

Fig. S4 Response-time curves of ZnO nanoparticles-nanofibers sensors, ZnO nanofibers sensors and ZnO nanoparticles sensors to 100 ppm of ethanol at 300 °C.

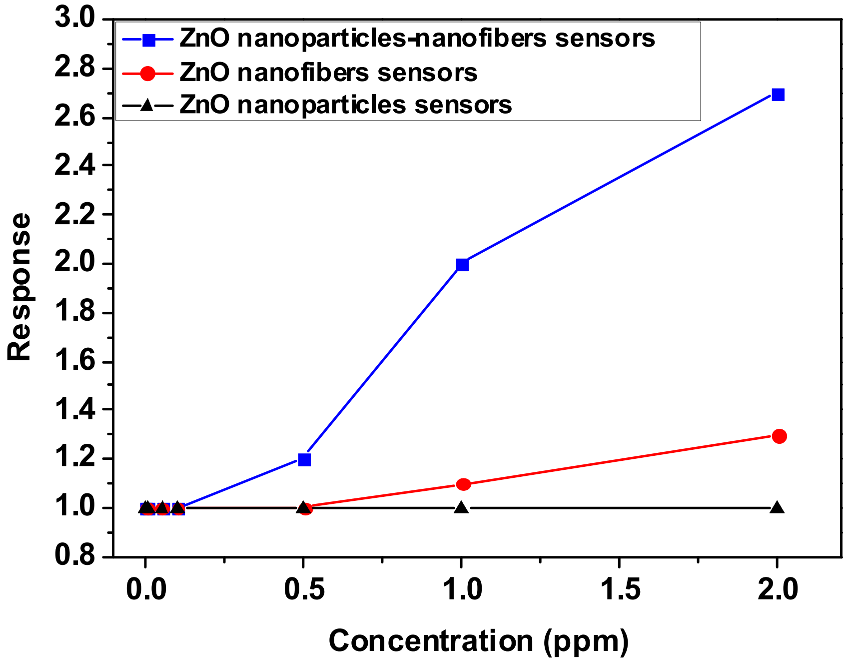

Fig. S5 Concentration-response curve to ethanol of the ZnO nanoparcitles-nanofibers sensors, ZnO nanofibers sensors and ZnO nanoparcitles sensors.

Table S1. Information of all the three samples.

Sample name	Sensing film	Depositing process
ZnO nanoparticles sensors	ZnO nanoparticles	RF sputtering
ZnO nanofibers sensors	ZnO nanofibers	Electrospinning
ZnO nanoparticles-nanofibers sensors	ZnO nanoparticles and ZnO nanofibers	RF sputtering and electrospinning