

Synthesis and characterization methods

The details of FSP for metal oxide nanoparticle synthesis have been described elsewhere¹. Precursor solutions ammonium tungstate hydrate (Aldrich, purity > 97%) diluted (0.4 M of tungsten ions) in a 3:2 (volume ratio) mixture of diethylene glycol monbutyl ether (Fluka, > 98.5%) and ethanol (Fluka, > 99.5%) were fed at 5 ml/min through the inner reactor capillary. Chromium (III) acetyl-acetonate (Aldrich, purity > 97%) was added to the precursor solution at concentrations to result in 1, 2 and 10 at% Cr doping in the product powder, respectively. Through the surrounding annulus, 5 l/min of oxygen (Pan Gas, purity > 99%) were fed dispersing the precursor solution into a combustible spray. The methane and oxygen flow rates in the FSP-supporting premixed flame were 1.5 and 3.2 l/min, respectively. The as-synthesized powders were annealed in air at 500 °C for 8 h prior to sensing tests.

X-ray diffraction (XRD) patterns were obtained with a Bruker AXS D8 Advance diffractometer (40 kV, 40 mA, Karlsruhe, Germany) operating with Cu K_α radiation. Phase analysis based on XRD data is accomplished using the software DIFFRAC^{plus} EVA and DIFFRAC^{plus} TOPAS. The BET powder specific surface area (SSA) of the synthesized particles was measured by nitrogen adsorption at 77K (Micromeritics Gemini 2375) after degassing the sample, at least, for 1h at 150°C in nitrogen. The BET equivalent average diameter (d_{BET}) was calculated as $d_{\text{BET}} = 6/(\text{SSA} \cdot \rho_p)$, where ρ_p is the density of WO₃ (7.16g/cm³). Raman scattering spectra were recorded by Renishaw InVia Reflex Raman Spectrophotometer with the excitation laser length of 514.5 nm, laser

(1) Madler, L.; Stark, W. J.; Pratsinis, S. E., *J. Mater. Res.* **2002** 17, 1356.

power of 300 mW and exposure time of 30s at RT. The morphology of the powders were observed by transmission electron microscopy (TEM; CM30ST microscope, FEI (Eindhoven), LaB₆ cathode, operated at 300 kV, SuperTwin lens with point resolution ~ 2Å). Thermogravimetric analysis (TGA) and differential thermal analysis (DTA) were accomplished on a Linseis STA PT1000 thermal analyzer under static air. The sample was heated to 800 °C at a rate of 5 °C/min. Calcined alumina was taken as the reference material.

These heat treated powders were suspended into 1-heptanol, ultrasonically stirred and drop-coated onto Au-electrode integrated alumina substrates to fabricate the sensors. The substrates were then dried in an oven at 75 °C for at least 1 hour. Sensing tests were carried out in a gas flow bench setup. The gases used in the sensing setup were UHP nitrogen (Praxair), UHP oxygen (Praxair) and different tested gases in synthetic air (10 ppm). Concentrations of tested gases were varied by changing its flow rate in conjunction with nitrogen/oxygen (4:1) flow rates. The definition of normalized sensitivity was used to calculate the sensitivity. In detail, for reducing gases, e.g., acetone, ethanol, methanol, NH₃ and CO, $S=R_0/R_g$; and for oxidizing gases, e.g., NO and NO₂, $S=R_g/R_0$. Here R_0 is the ratio of baseline resistance to R_g is gas-responding resistance.

Supporting figures

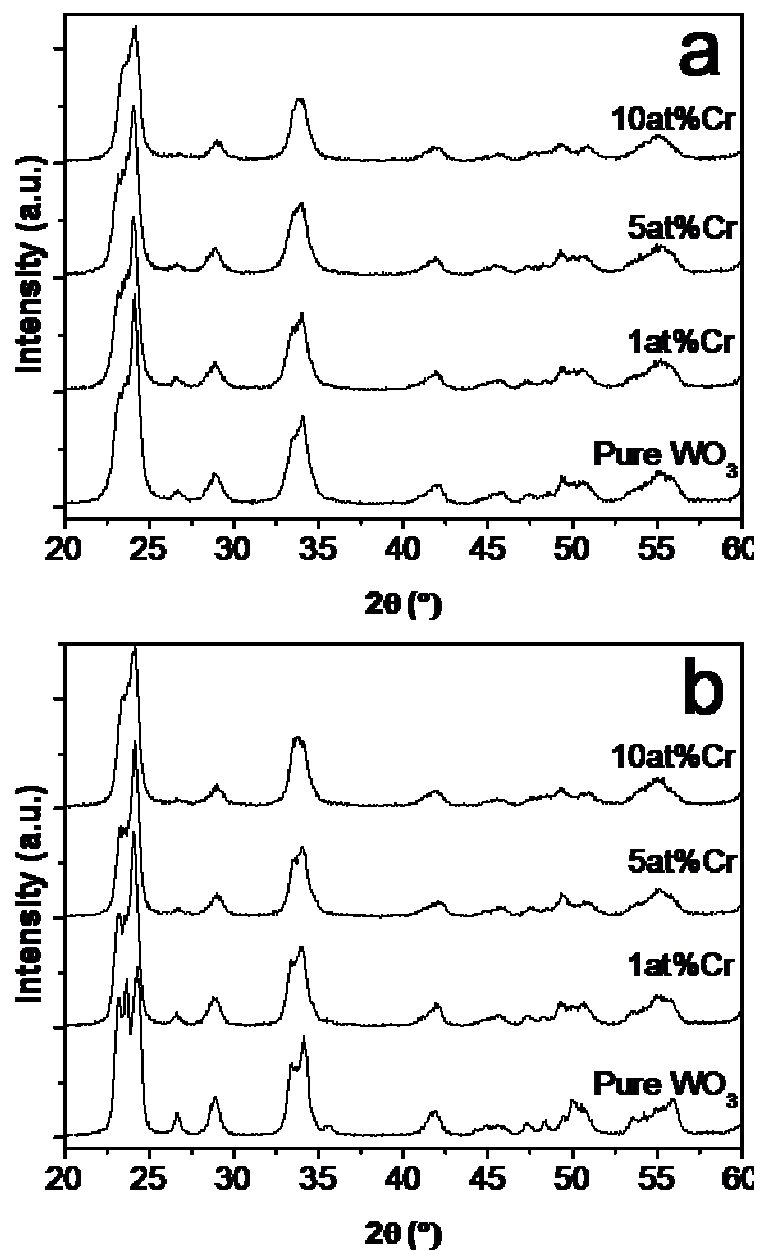


Figure S1 XRD spectra of (a) as-synthesized and (b) heat-treated pure and Cr-doped WO_3 .

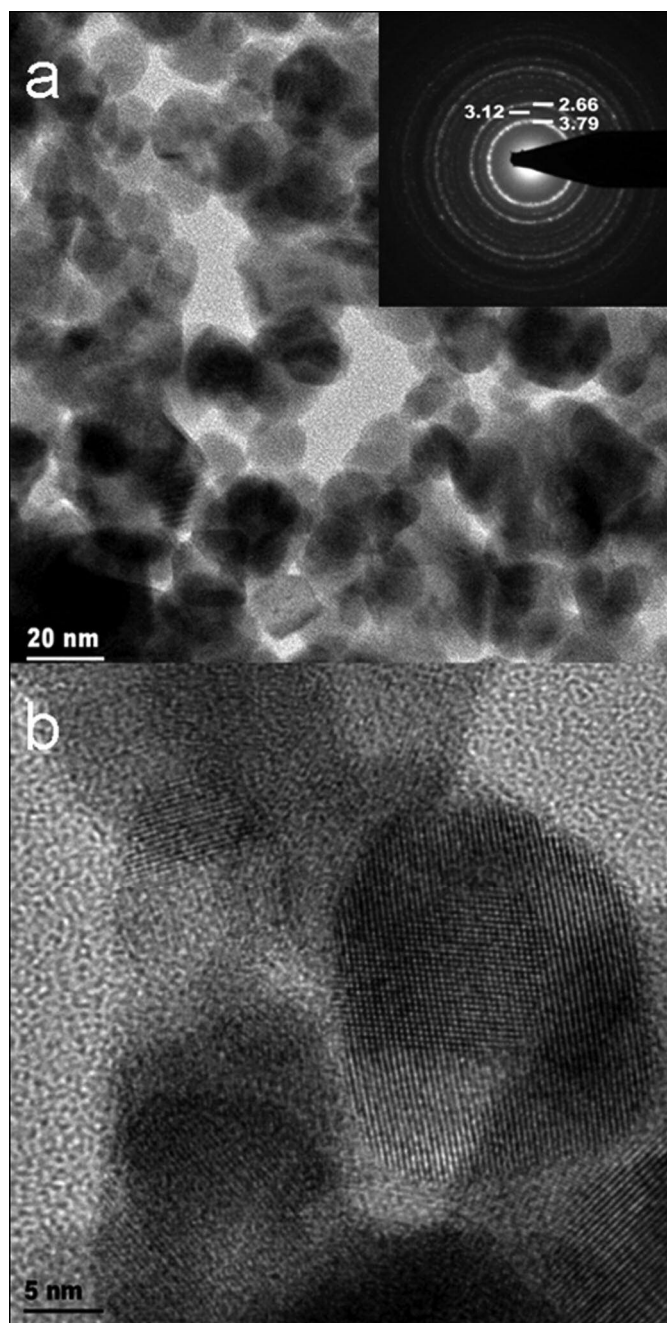


Figure S2 (a) TEM (inset: SAED pattern) and (b) HRTEM images of heat-treated 10at% Cr-doped WO_3 . The first three diffraction rings in the pattern correspond to (002)+(110), (012)+(102) and (112)+(200)+(020) planes of ϵ - WO_3 phase (JCPDS No.: 872386).

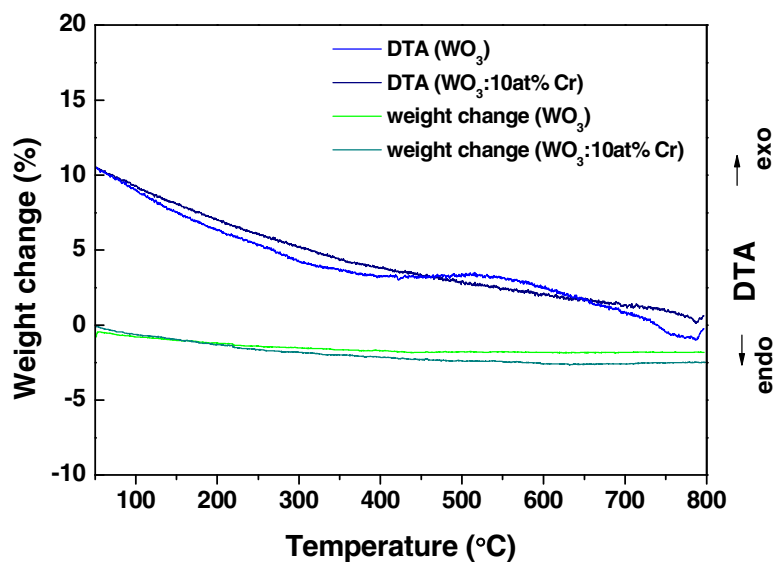


Figure S3 TG-DTA curves of heat-treated pure WO_3 and 10at% Cr-doped WO_3 . A small sharp endothermal peak at around 780°C appears on both DTA curves corresponding to the formation of $\alpha\text{-WO}_3$ phase. On the DTA curve of pure WO_3 , there is also an endothermal peak around 350°C most likely corresponding to the phase transition from $\gamma\text{-WO}_3$ to $\beta\text{-WO}_3$. Such results indicate that the Cr-doped sample didn't undergo any obvious phase transition up to 700°C .

Supporting Tables

Table S1 Dipole moments and sensitivities of 10 at% Cr-doped WO₃ to different gases.

	dipole moment ²	sensitivity		
		0.2ppm	0.5ppm	1ppm
acetone	2.88D	1.55	2.05	2.90
ethanol	1.69D	1.08	1.15	1.32
methanol	1.70D	1.03	1.10	1.23
NO	0.159D	1	1.05	1.09
NO ₂	0.316D	1	1.04	1.07
NH ₃	1.471D	1.02	1.03	1.05
CO	0.112D	1	1	1

(2)Dean, J. A., *Lange's Handbook of Chemistry* (McGraw-Hill, New York, 15th Edition, 1999), Table 5.17, 5.18