Supplementary Information

Fast response ammonia sensors based on TiO_2 and NiO nanostructured bilayer thin films

*Arvind Kumar†, Amit Sanger†, Ashwani Kumar, Ramesh Chandra**

Nanoscience Laboratory, Institute Instrumentation Centre, Indian Institute of Technology Roorkee, Roorkee - 247667, India

*Corresponding author

Email: ramesfic@iitr.ac.in

FIGURE S1

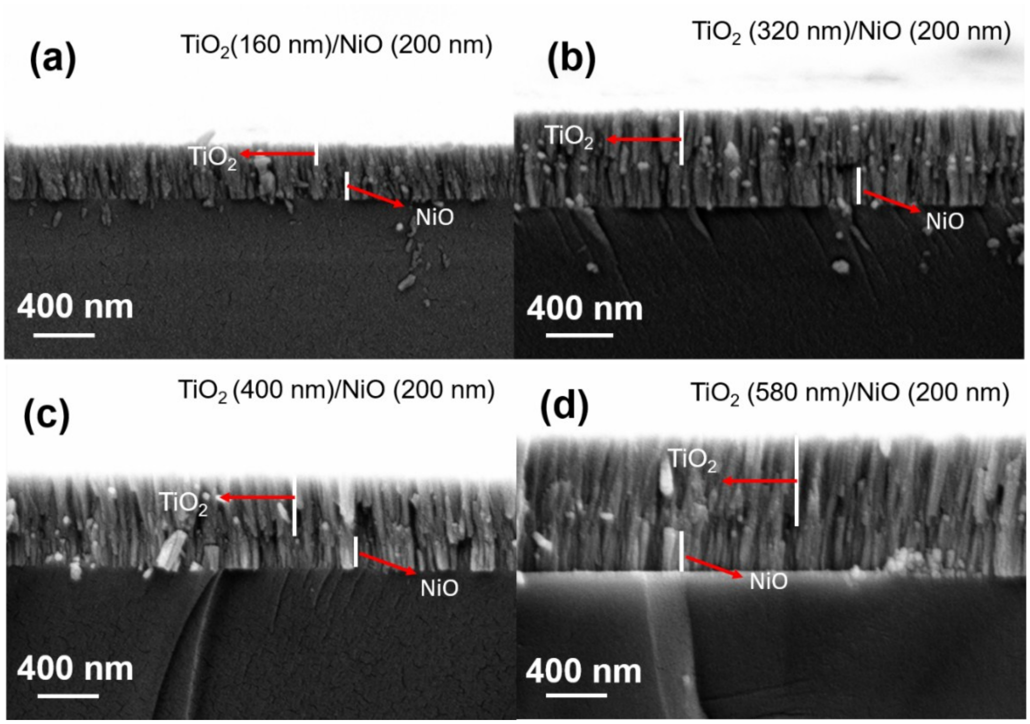

Figure S1. The cross-section micrographs of TiO_2/NiO bilayer sensor with different thickness of top TiO_2 layer

Figure S1 depicts the FE-SEM cross-sectional micrographs of four TiO_2/NiO bilayer sensing films. The results indicates that the bottom NiO film thickness was found to be fixed as 200 nm and the top TiO_2 film thickness was varied from 160 nm to 580 nm.

FIGURE S2

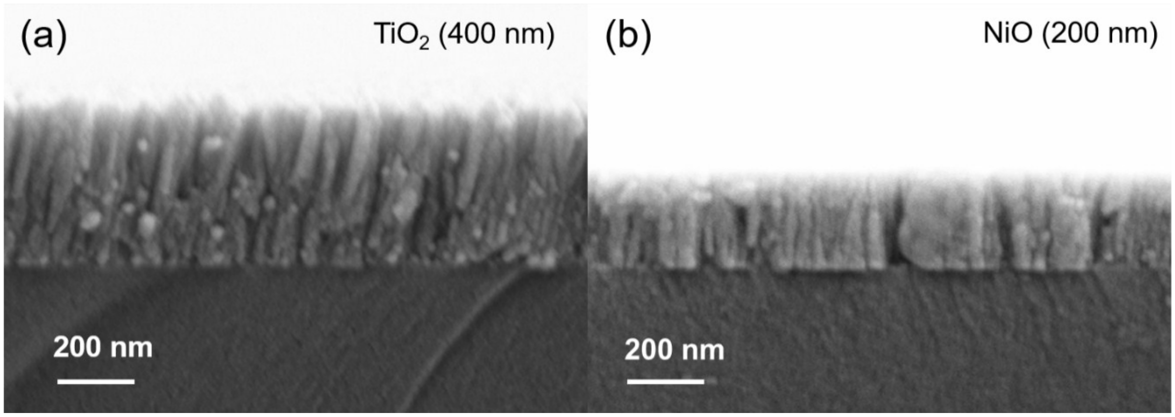

Figure S2. The cross-section micrographs of (a) pure TiO_2 of 400 nm and (b) pure NiO layer of 200 nm.

Figure S2 depicts the individual thickness of TiO_2 and NiO thin films to be nearly 400 nm and 200 nm respectively.

FIGURE S3

.

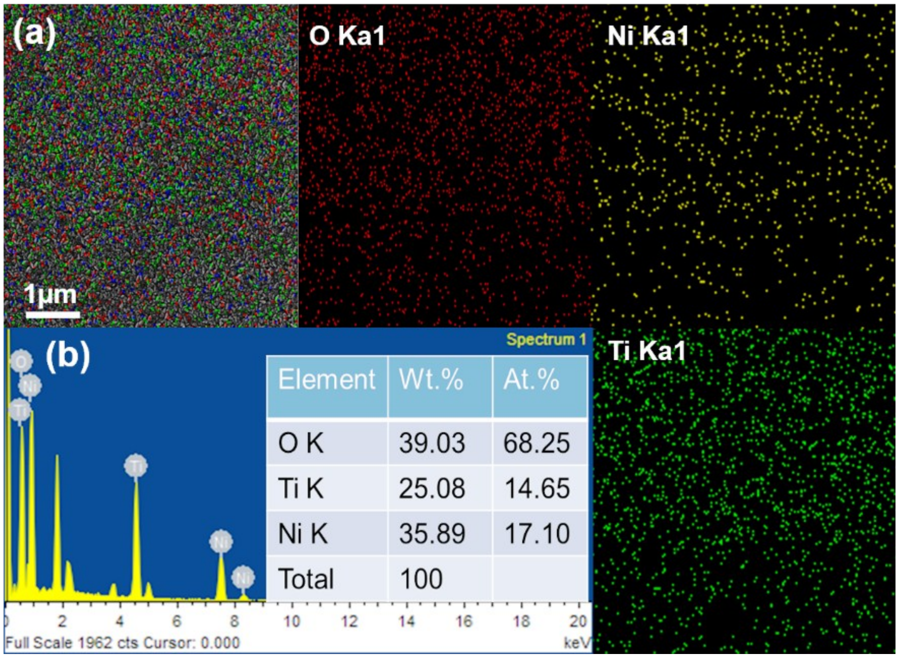

Figure S3. (a) Elemental mapping, and (b) EDS spectra of NiO/TiO_2 bilayer thin film.

Figure S3 shows the elemental mapping and EDS spectrum of NiO/TiO_2 bilayer sensor which indicate the uniform element distribution of titanium, oxygen and nickel elements. The red region of O, green region of Ti and yellow regions of Ni are typically overlapped.

FIGURE S4

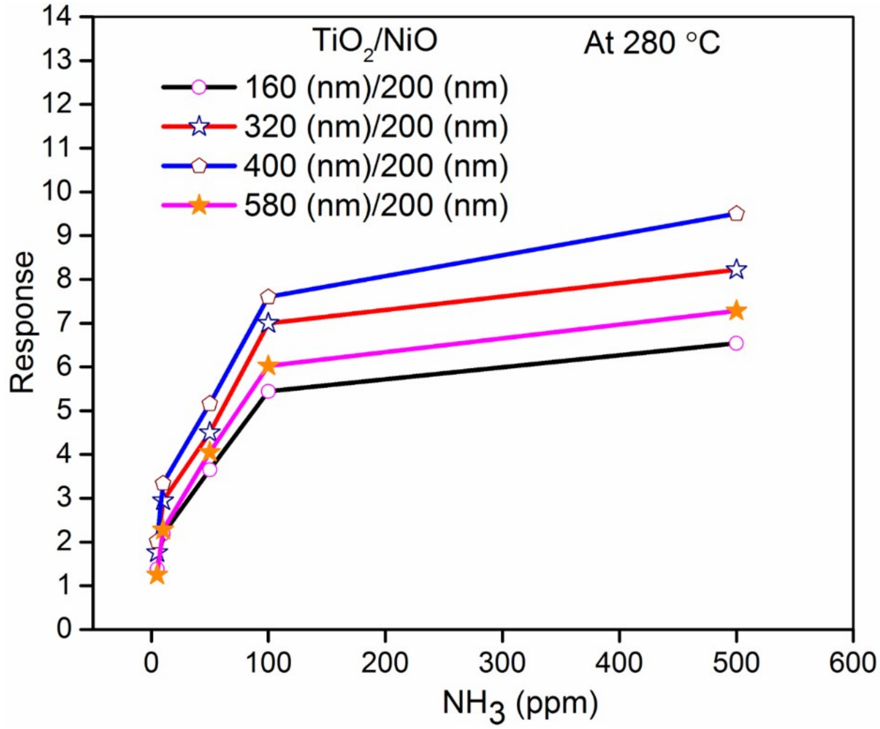

Figure S4. Variation of the response of TiO_2/NiO sensor with thickness of top TiO_2 layer using different ammonia concentrations at 280ºC.

Figure S4 shows that during the sensing measurements, the sensor response increases as the TiO_2 layer thickness increases from 160 nm to 400 nm but it decreases when the TiO_2 thickness further increases to 580 nm. It means the TiO_2/NiO bilayer sensor with 400 nm TiO_2 layer (at top) and 200 nm NiO layer (at bottom) exhibited the best sensing response towards ammonia at 280℃.

FIGURE S5

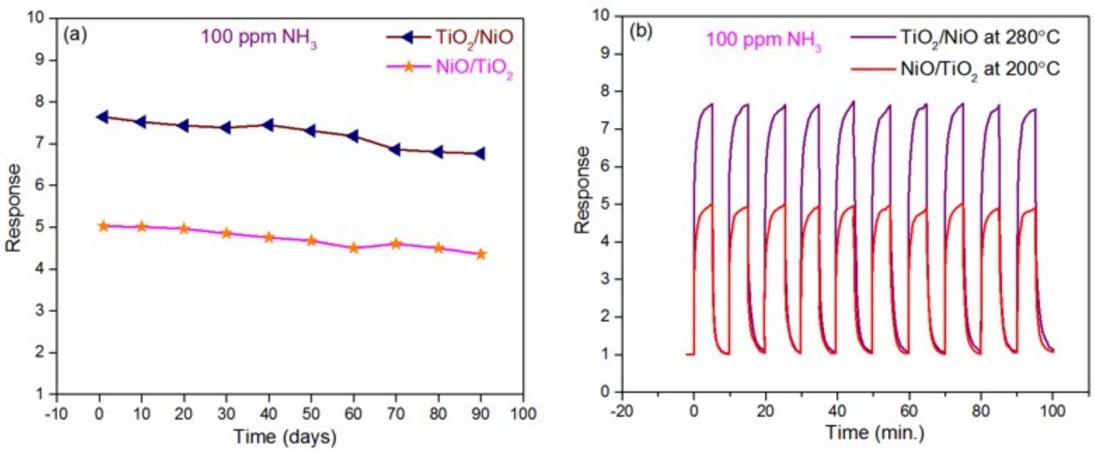

Figure S5. (a) Stability test for 90 days and (b) Stable response up to 10th cycles of TiO_2/NiO and NiO/TiO_2 bilayer sensors towards100 ppm NH_3 at 280ºC and 200ºC, respectively.

Figure S5 (a) and (b) shows the stability characteristics of TiO_2/NiO and NiO/TiO_2 bilayer sensors towards 100 ppm NH_3 at 280°C and 200°C respectively. During the measurements, the TiO_2/NiO and NiO/TiO_2 bilayer sensors exhibits nearly constant response signal (∼10% changes) and (∼12% changes) respectively, indicating the significant long term stability of the sensor. Therefore, we concluded that the above-mentioned stability test will contributes to establish both the bilayer sensors as potential candidate for NH_3 gas sensing application.

FIGURE S6

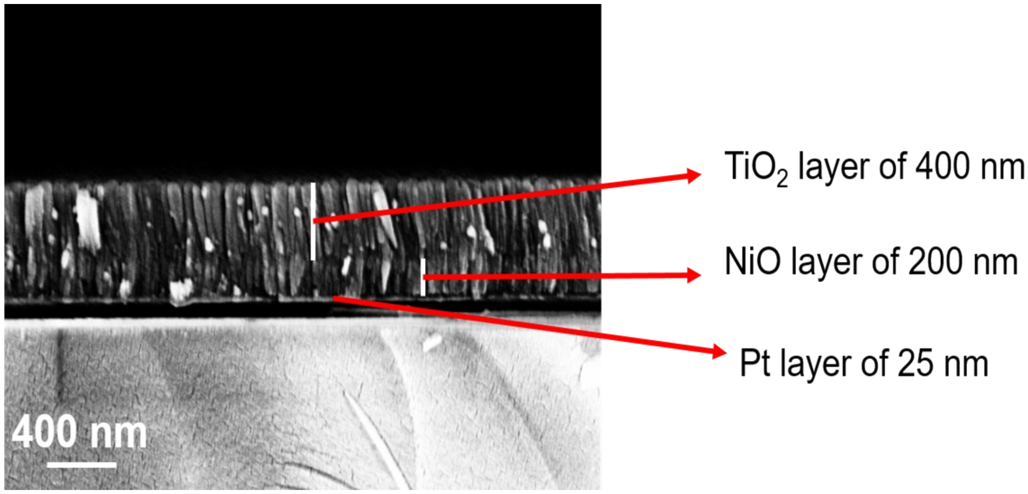

Figure S6. The cross-section micrographs of TiO_2/NiO bilayer sensor with Pt layer of 25 nm thick as bottom electrode.

Figure S6 shows the required FE-SEM cross section view of TiO_2/NiO bilayer with the Pt bottom contact (electrode) thickness of about 25 nm.

FIGURE S7

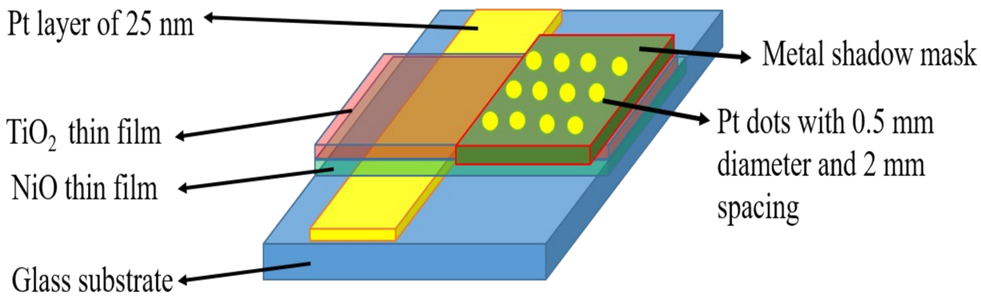

Figure S7. The schematic view of the TiO_2/NiO bilayer sensor with the platinum (Pt) as bottom and top electrodes

Figure S7 shows the schematic view of TiO_2/NiO bilayer sensor with the top and bottom Pt contacts (electrodes). For electrical measurements, the bottom contact layer and top dots of platinum (Pt) of 25 nm thickness were prepared using metal shadow mask on glass substrates via DC sputtering technique. The diameter of Pt dot is 0.5 mm and space between the two dots is 2 mm, approximately.

Table S1: Brief summary of previous reported literature on several semiconductor oxide based ammonia gas sensor prepared by various deposition techniques.

Sensor (metal oxide)	Fabrication technique	NH_3 ppm	Operating Temp.(°C)	Sensing response	Response/ recovery time	Ref.
Co_3O_4/SnO_2 composite	Hydrothermal route	100	200	13.6	4 sec/--	1
Pd/WO_3	hydrothermal	1000	300	2.2	15 sec/76 sec	2
α-Fe_2O_3	Sol-gel	100	RT	39%	27 sec/46 sec	3
NiO nanoparticles	Hydrothermal process	30	RT	20%	29 sec/150 sec	4
TeO_2 thin films	Sputtering	500	170	58%	3.1 min/5.6 min	5
Hierarchical SnO_2	Thermal evaporation	300	200	6	16 sec/25 sec	6
Pd doped WO_3	Screen printing	200	350	10	----	7
ZnO	Hydrothermal	4.6	100	3.96%	-----	8
h-WO_3	Annealing	50	30	6	1.3 min/3.8 min	9
NiO-ZnO	Hydrothermal route	50	RT	40%	27 sec/155 sec	10
TiO_2/NiO bilayer thin film	DC sputtering	100	280	7.6	24 sec/45 sec	Present work

References

1. L. Wang, Z. Lou, R. Zhang, T. Zhou, J. Deng and T. Zhang, *ACS Applied Materials & Interfaces*, 2016, 8, 6539-6545.

2. P. Van Tong, N. D. Hoa, N. Van Duy, D. T. T. Le and N. Van Hieu, *Sensors and Actuators B: Chemical*, 2016, 223, 453-460.

3. D. K. Bandgar, S. T. Navale, M. Naushad, R. S. Mane, F. J. Stadler and V. B. Patil, *RSC Advances*, 2015, 5, 68964-68971.

4. J. Wang, F. Yang, X. Wei, Y. Zhang, L. Wei, J. Zhang, Q. Tang, B. Guo and L. Xu, *Physical Chemistry Chemical Physics*, 2014, 16, 16711-16718.

5. T. Siciliano, M. Di Giulio, M. Tepore, E. Filippo, G. Micocci and A. Tepore, *Sensors and Actuators B: Chemical*, 2009, 138, 550-555.

6. L. V. Thong, L. T. N. Loan and N. Van Hieu, *Sensors and Actuators B: Chemical*, 2010, 150, 112-119.

7. V. Srivastava and K. Jain, *RSC Advances*, 2015, 5, 56993-56997.

8. I. Rawal, *RSC Advances*, 2015, 5, 4135-4142.

9. I. M. Szilágyi, L. Wang, P.-I. Gouma, C. Balázsi, J. Madarász and G. Pokol, *Materials Research Bulletin*, 2009, 44, 505-508.

10. J. Wang, P. Yang and X. Wei, *ACS Applied Materials & Interfaces*, 2015, 7, 3816-3824.