Supporting Information

In-situ Coupling of Multidimensional MOFs for Heterogeneous Metal Oxide Architectures: Toward Sensitive Chemiresistor

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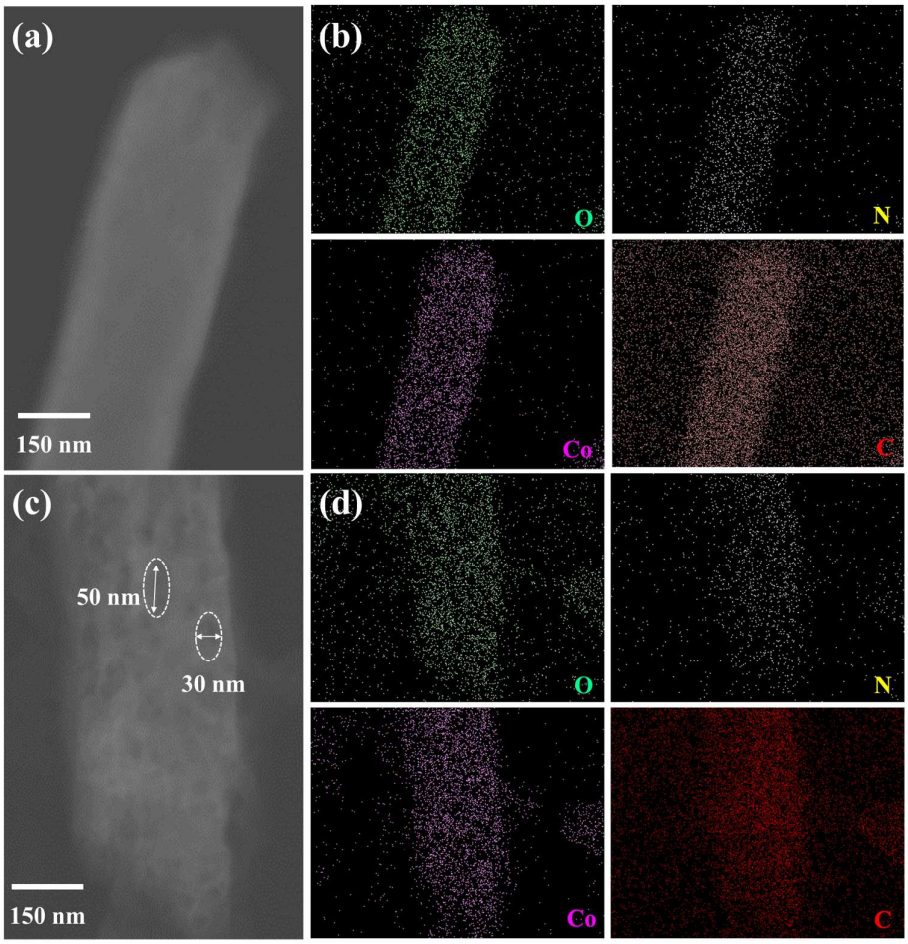

Figure S1. STEM images of (a) ZIF-67 rods and (c) ZIF-67 belts, EDS mapping images of (b) ZIF-67 rods and (d) ZIF-67 belts with Co, O, C, and N elements.

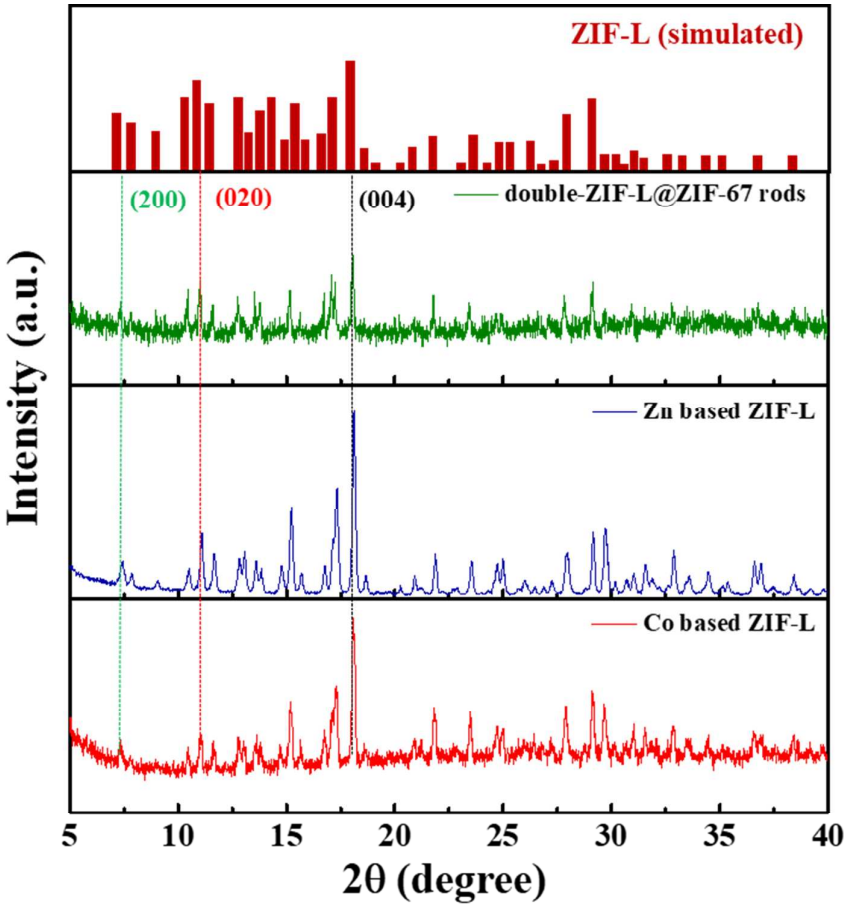

Figure S2. XRD analysis of Co based ZIF-L, Zn based ZIF-L, and double-ZIF-L@ZIF-67 rods.

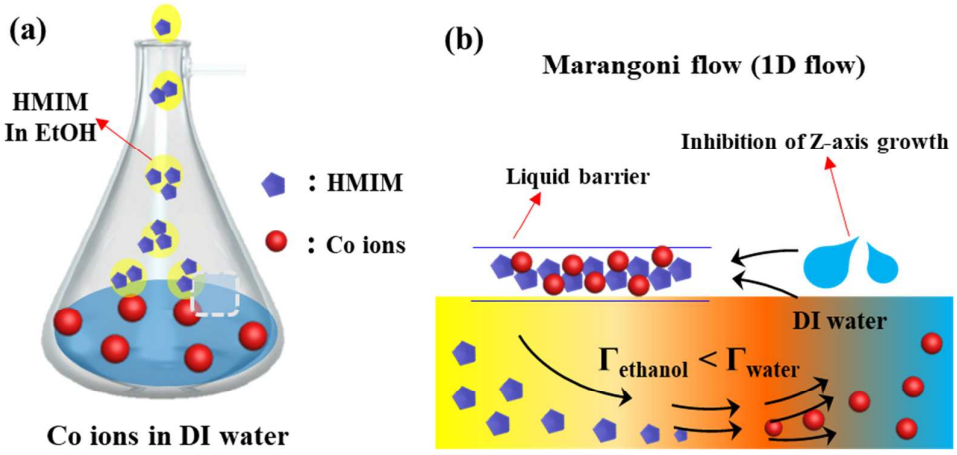

Figure S3. (a) Schematic image showing mixing process of HMIM dissolved solution and Co ions dissoved solution, (b) schematic illustration of Marangoni flow between HMIM-EtOH and Co ions-DI water solutions.

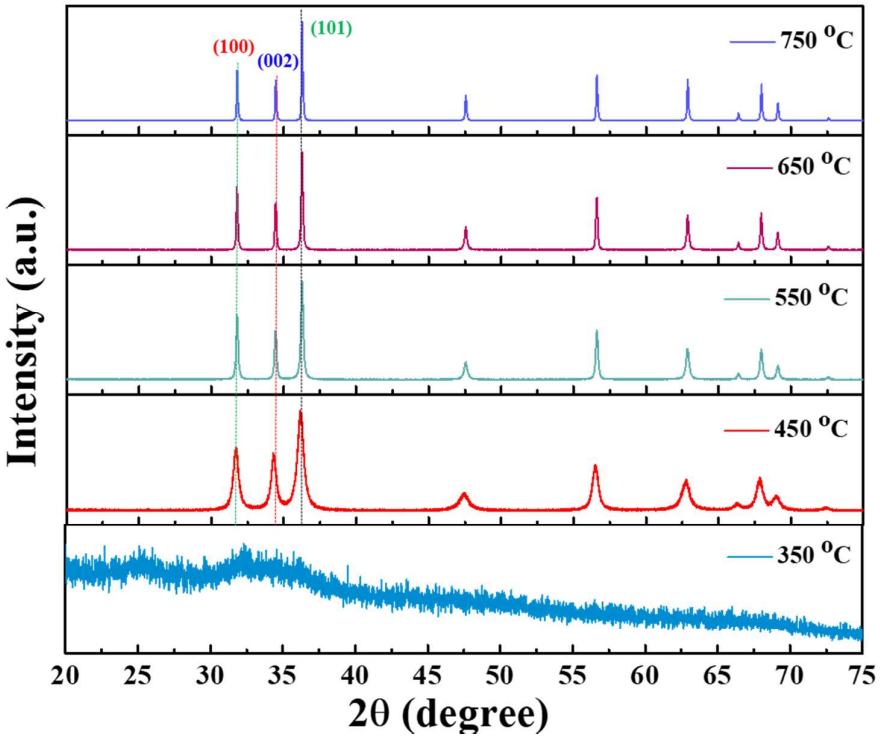

Figure S4. XRD analysis of various double-Co_3O_4 rods@ZnO sheets (e.g. 350 double-Co_3O_4 rods@ZnO sheet, 450 double-Co_3O_4 rods@ZnO sheet, 550 double-Co_3O_4 rods@ZnO sheet, 650 double-Co_3O_4 rods@ZnO sheet, and 750 double-Co_3O_4 rods@ZnO sheet)

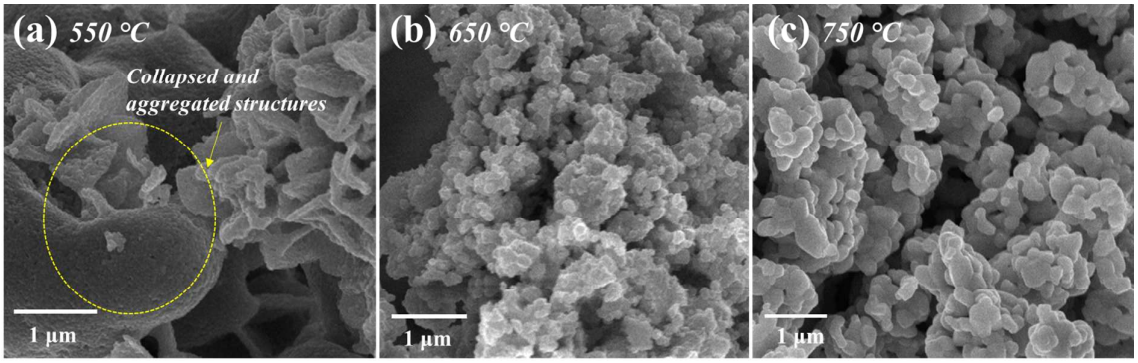

Figure S5. SEM image of (a) 550 double-Co_3O_4 rods@ZnO sheets, (b) 650 double-Co_3O_4 rods@ZnO sheets, and (c) 750 double-Co_3O_4 rods@ZnO sheets.

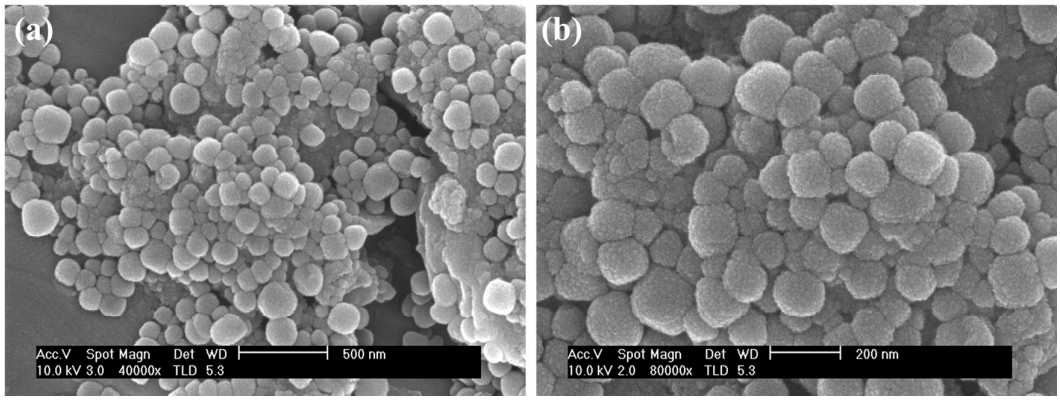

Figure S6. (a) SEM image of polyhedron ZIF-67 particles produced by using mixed solvent of DI water and EtOH. (b) Magnified SEM image of polyhedron ZIF-67.

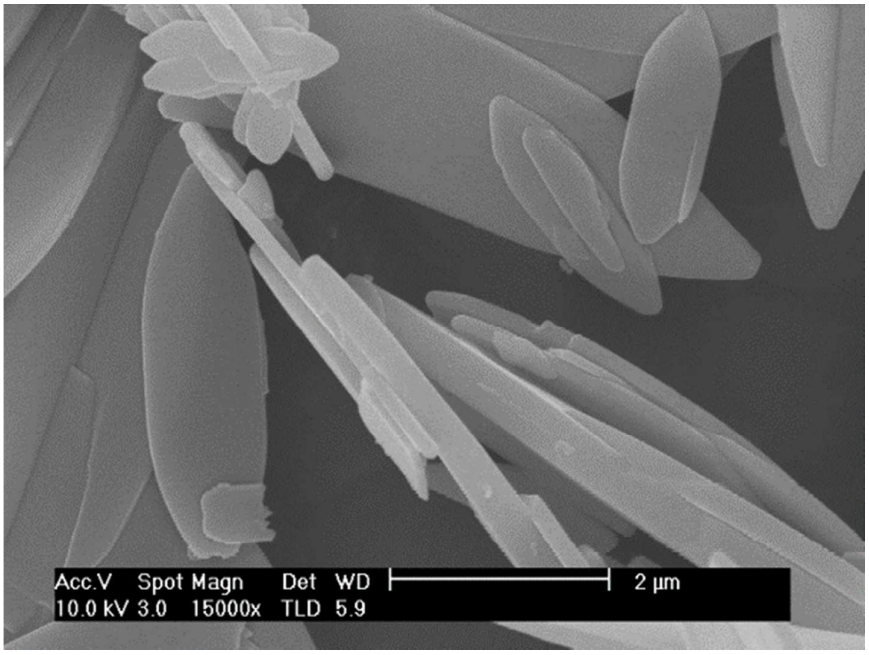

Figure S7. SEM image of Zn based ZIF-L structures.

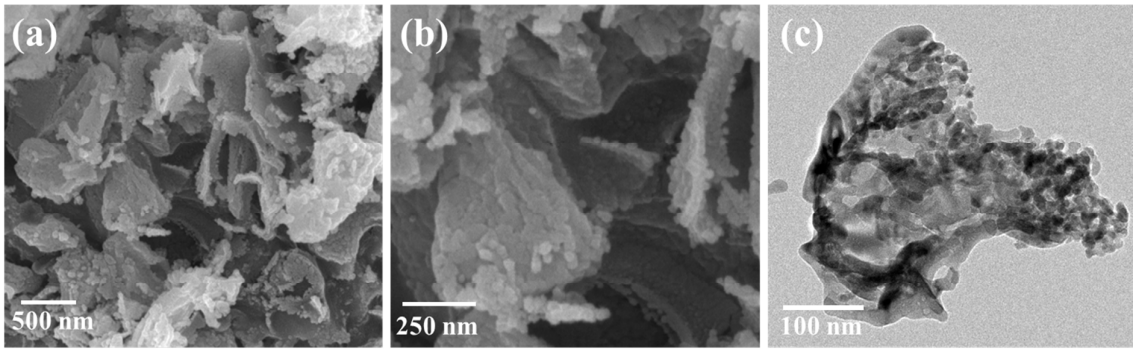

Figure S8. SEM images of (a, b) collapsed Co_3O_4 rods loaded ZnO sheet, and (c) TEM image of collapsed Co_3O_4 rods loaded ZnO sheet.

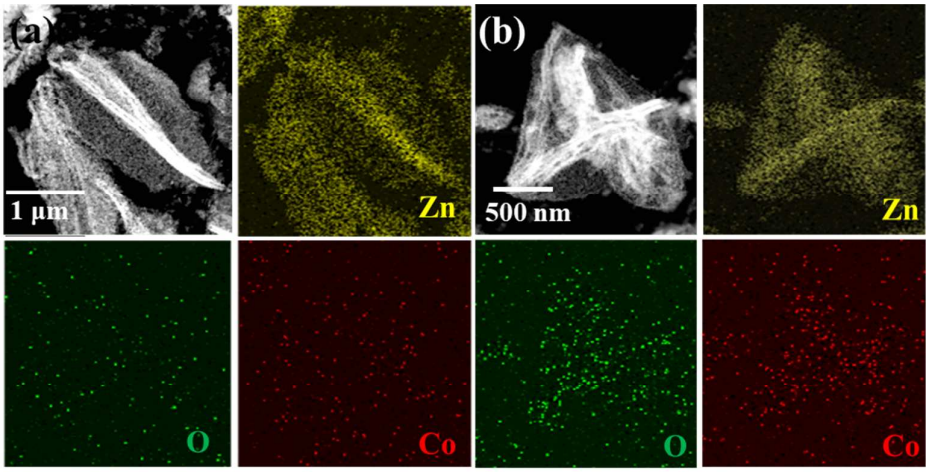

Figure S9. EDS mapping images of (a) single-Co_3O_4 rods@ZnO sheet, and (b) double-Co_3O_4 rods@ZnO sheet.

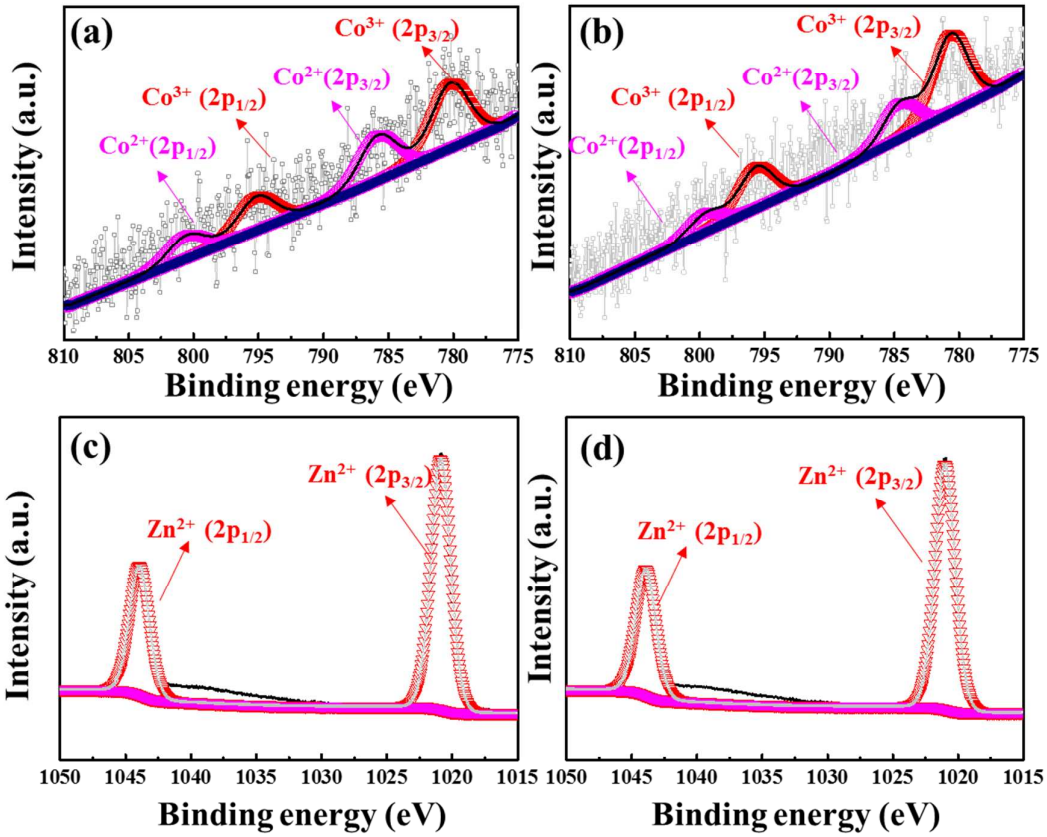

Figure S10. XPS spectra of single-Co_3O_4 rods@ZnO sheet: (a) Co 2p and (c) Zn 2p, and XPS spectra of double-Co_3O_4 rods@ZnO sheet: (b) Co 2p and (d) Zn 2p.

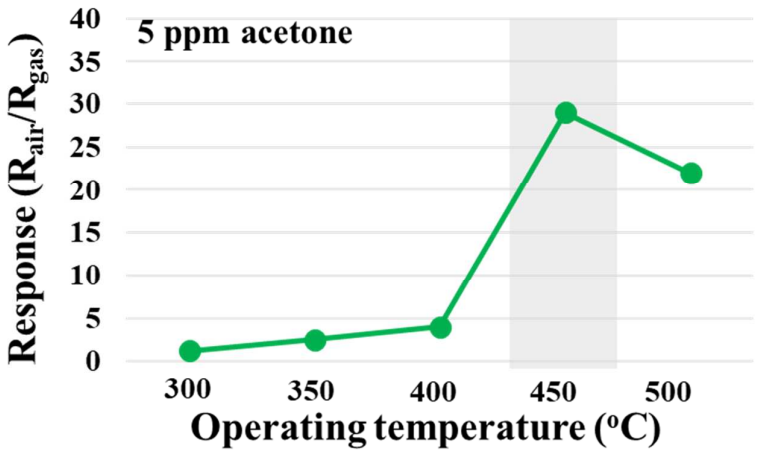

Figure S11. Acetone sensing response of double-Co_3O_4 rods@ZnO sheet at various sensing temperatures.

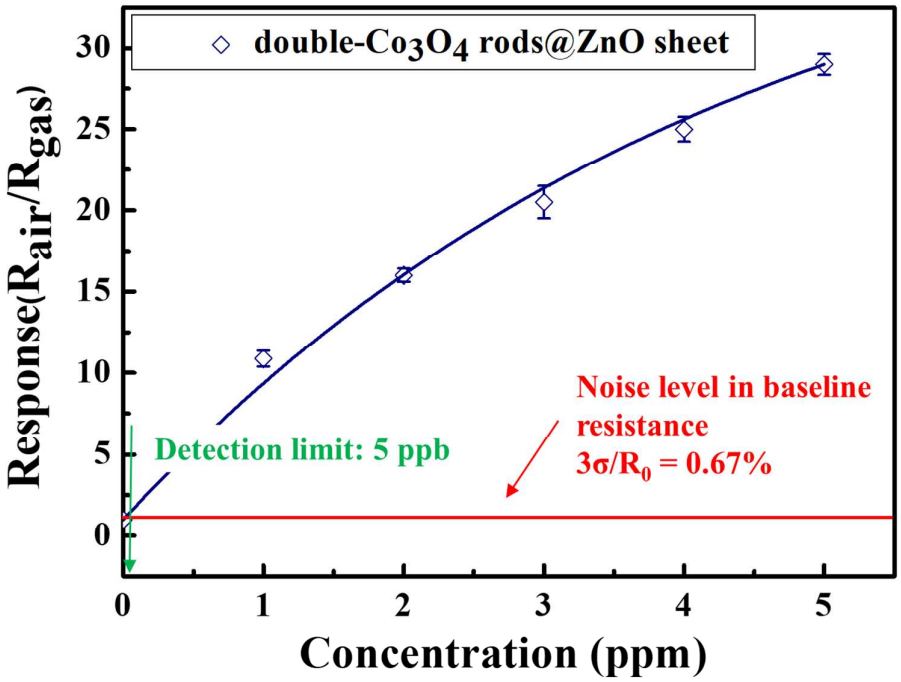

Figure S12. Extrapolation of the double-Co_3O_4 rods@ZnO sheet's detection limit toward acetone gas at 450 □

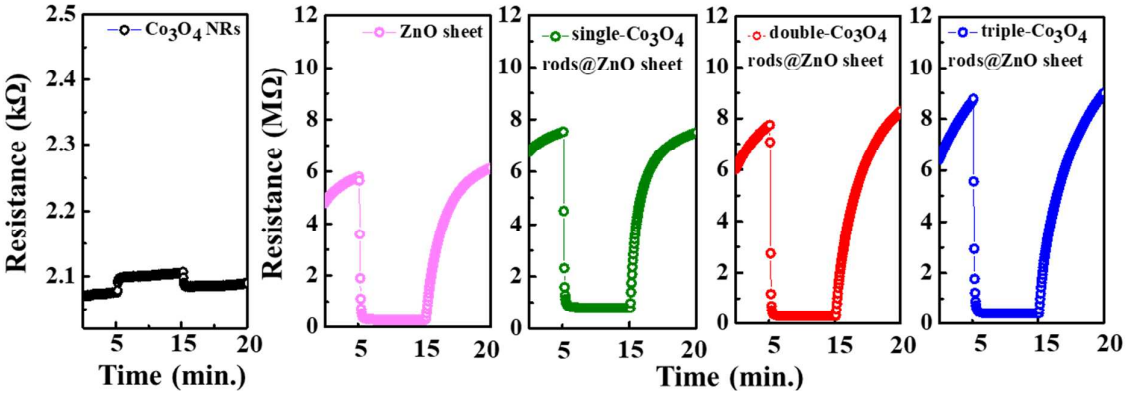

Figure S13. Resistance variation of Co_3O_4 rods, ZnO sheet, single-Co_3O_4 rods@ZnO sheet, double-Co_3O_4 rods@ZnO sheet, and triple-Co_3O_4 rods@ZnO sheet upon exposure to 5 ppm of acetone at 450 □.

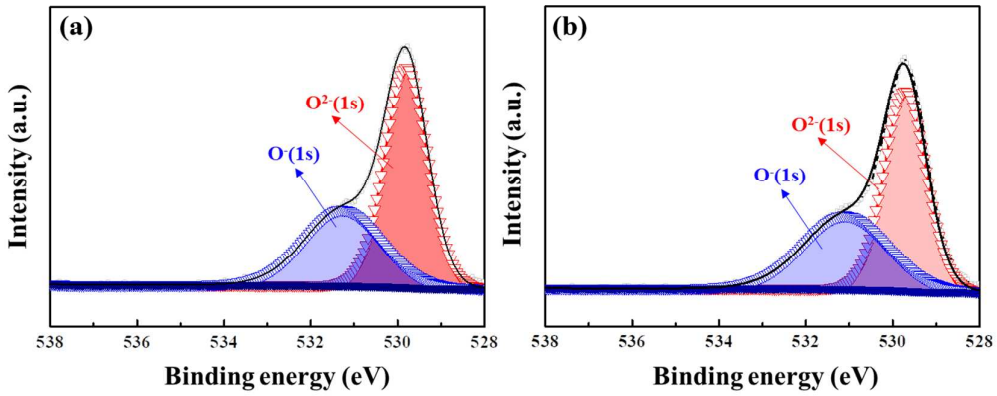

Figure S14. XPS spectra of oxygen in (a) single-Co_3O_4 rods@ZnO sheet, and (b) triple-Co_3O_4 rods@ZnO sheet.

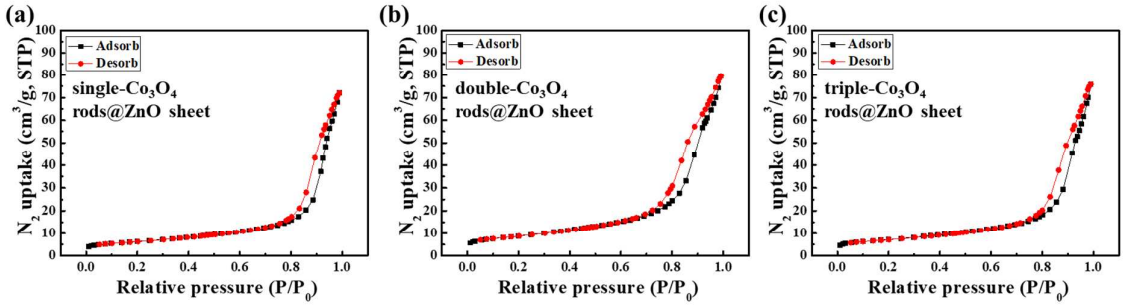

Figure S15. N_2 adsorption/desorption isotherms of (a) single-Co_3O_4 rods@ZnO sheet, (b) double-Co_3O_4 rods@ZnO sheet, and (c) triple-Co_3O_4 rods@ZnO sheet.

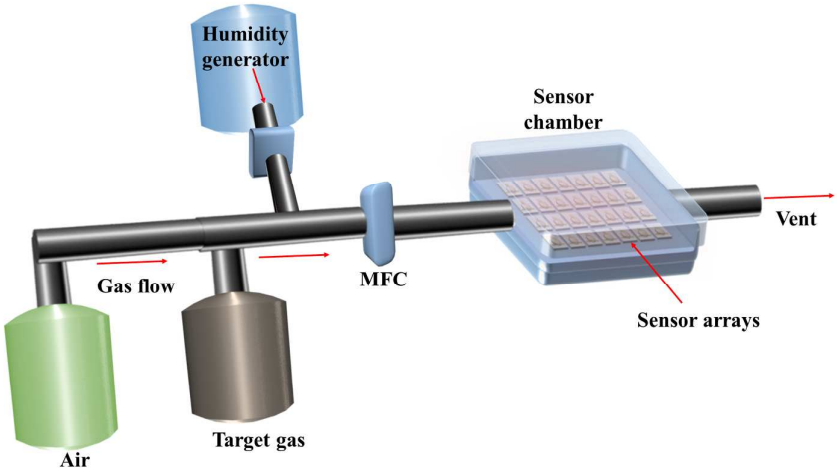

Figure S16. Schematic image of sensing measurement system.

Table S1. The pH values of 4 ZIFs solutions

Solution	pH
DI water+Co ions + HMIM	8.47
Methanol+Co ions + HMIM	7.59
DI water/EtOH (2/1) + Co ions + HMIM, belt	8.22
DI water/EtOH (1/2) + Co ions + HMIM, rod	8.05

Table S2. Grain sizes of samples based on the (100), (002), and (101) peaks.

	450 double-Co_3O_4 rods@ZnO sheet	550 double-Co_3O_4 rods@ZnO sheet	650 double-Co_3O_4 rods@ZnO sheet	750 double-Co_3O_4 rods@ZnO sheet
(100)	**30.7 nm**	**54.6 nm**	**71.9 nm**	**92.5 nm**
(002)	**35 nm**	**55.6 nm**	**71.3 nm**	**94.4 nm**
(101)	**29.5 nm**	**50.5 nm**	**65.2 nm**	**91.2 nm**
Aver.	**31.7 nm**	**53.6 nm**	**69.5 nm**	**92.7 nm**

Table S3. ICP results of single-Co_3O_4 NRs@ZnO NSs, double-Co_3O_4 NRs@ZnO NSs, and triple-Co_3O_4 NRs@ZnO NSs

ICP analysis		
Samples	**Co (%)**	**Zn (%)**
single-Co_3O_4 NRs@ZnO NSs	0.27	80.0
double-Co_3O_4 NRs@ZnO NSs	0.71	79.6
triple-Co_3O_4 NRs@ZnO NSs	1.82	78.4

Table S4. The surface area under XPS spectra of O 1s in single-Co_3O_4 rods@ZnO sheet, double-Co_3O_4 rods@ZnO sheet, and triple-Co_3O_4 rods@ZnO sheet.

Spectral Feature Table			
Element/Transition	**Peak Energy (eV)**	**Peak Area (eV counts)**	**O^-/O^{2-}**
O^{2-} (1s) in Single-Co_3O_4 NRs@ZnO NSs	530.2	60693.83	0.615
O^- (1s) in Single-Co_3O_4 NRs@ZnO NSs	531.0	37325.69	
O^{2-}(1s) in Double-Co_3O_4 NRs@ZnO NSs	530.2	47322.30	1.203
O^- (1s) in Double-Co_3O_4 NRs@ZnO NSs	531.0	56943.89	
O^{2-}(1s) in Triple-Co_3O_4 NRs@ZnO NSs	530.2	54250.09	0.727
O^-(1s) in Triple-Co_3O_4 NRs@ZnO NSs	531.0	39428.26	

Table S5. Recent publications on MOF derived SMOs based chemiresistive acetone sensors.

Gas species	Materials	Optimal temperature	Limit of detection	Response	Reference
Acetone	ZnO@ZIF-CoZn nanowire	260 °C	1.9 ppb	12–13.5 @ 5 ppm	[1]
	MOF templated Cu_2O/CuO cages	150 °C	N/A	2.6–3 @ 200 ppm	[2]
	MOF templated ZnO nanocages	300 °C	100 ppb	2.2 @ 0.1 ppm	[3]
	MOF templated PdO-ZnO loaded SnO_2 nanotubes	400 °C	10 ppb	10 @ 5 ppm	[4]
	MOF templated ZnO/$ZnCo_2O_4$ hollow spheres	250 °C	N/A	1.7 @ 5 ppm	[5]
	MOF derived PdO loaded Co_3O_4 cubes	350 °C	0.1 ppm	2.51 @ 5 ppm	[6]
	MOF templated ZnO/$ZnFe_2O_4$ nanospheres	290 °C	1 pm	10 @ 25 ppm, 5 @ 5 ppm	[7]
	MOF derived Co_3O_4/$NiCo_2O_3$ double-shelled cages	228.9 °C	N/A	3.09 @ 100 ppm	[8]
	MOF derived Co_3O_4-PdO loaded n-SnO_2 HNCs	450 °C	5 ppb	22.8 @ 5ppm	[9]
	HMOF template double-Co_3O_4 rods@ZnO sheet	450 °C	5 ppb	29@5 ppm	this work

Table S6. Recent publications on MOF based chemiresistive sensors.

Gas species	Materials	Optimal temperature	Detection limit	Response	Reference
H_2S	ZIF-8	Room temperature	N/A	3 @ 1ppm	[10]
n-butanol	SNNU-50	Room temperature	N/A	1.56 @ 100 ppm	[11]
H_2S	Cu(bdc) xH_2O	Room temperature	N/A	1–2 @ 1ppm	[10]
H_2S	Fumarate based fcu-MOF	Room temperature	5.4 ppb	12–15 @ 10 ppm	[10, 12]
$N(CH_3)_3$ (Trimethylamine)	$Co(im)_2$ MOF	75 ^oC	2 ppm	14 @ 100 ppm	[13]
MeOH Acetone	$Cu_3(HTTP)_2$	Room temperature	N/A	1.08 @ 200 ppm (EtOH), ~1.02 @ 200 ppm (acetone)	[14]
EtOH Acetone	$Ni_3(HITP)_2$	Room temperature	N/A	1.03–1.04 @ 200 ppm (EtOH), ~1.02 @ 200 ppm (acetone)	[14, 15]
MeOH	MIL-53-NH_2 (Al)@polymer	Room temperature	N/A	2.49 @ 5000 ppm	[16, 17]
Formaldehyde Acetone	ZIF-67	150 ^oC	5 ppm	13 @ 100 ppm (Formaldehyde) 7 @ 100 ppm (acetone)	[18]
Acetone	MOF derived Co_3O_4-PdO loaded n-SnO_2 HNCs	450 ^oC	5 ppb	22.8 @ 5ppm	[9]
Acetone	HMOF template double-Co_3O_4 rods@ZnO sheet	450 ^oC	5 ppb	29@5 ppm	this work

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