Semiconductor Sensors:

Ch6: Gas Sensors

Resistive Gas Sensors- cont.

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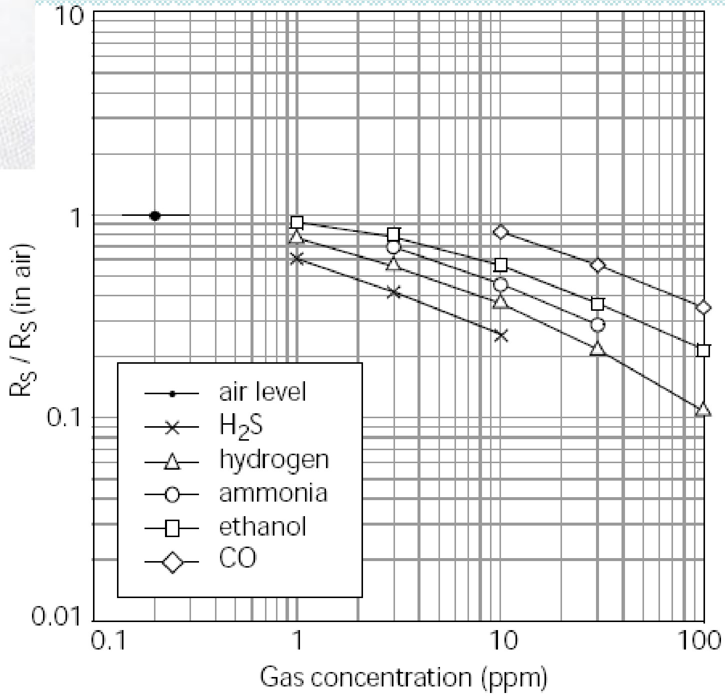
نمونه تجاری از حسگر گاز مقاومتی

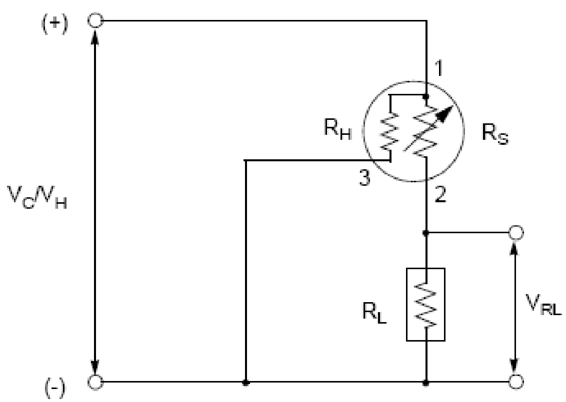


F. Parts and Materials

No.	Parts	Materials
1	Sensing element	Tin dioxide (SnO_2)
2	Substrate	Alumina (Al_2O_3)
3	Lead wire	Gold alloy (Au-Pd-Mo)
4	Heater	Ruthenium oxide (RuO_2)
5	Electrode	Gold (Au)
6 ①	Plastic housing	Polyamide resin
7 ③	Plastic base	Polyamide resin
8 ②	Stainless steel mesh	SUS 316 (100 mesh)
9 ④	Heater/electrode pins	Iron-nickel alloy

C. Sensitivity characteristics

Model	SP3-AQ2-01		
Symbol	Parameter	Specification	Conditions etc.
R_S	Sensor resistance	10 kΩ to 40 kΩ	in air
β	Sensitivity slope	0.2 -0.5	R_S at hydrogen 10 ppm / R_S in air
Standard Test Conditions:		Temp: 20 °C ± 2 °C Humidity:65% ± 5% (in clean air)	V_C : 5.0 V ± 1% V_H : 5.0 V ± 1% R_L : 10 kΩ ± 5%
Pre-heating time: more than 48 hours			



V_C : Circuit Voltage
V_H : Heater Voltage
R_L : Load Resistance
R_H : Heater Resistance

V_{RL}: Voltage across load resistance
$R_S = (V_C \times R_L) / V_{RL} - R_L$
Polarity of circuit voltage is important in the DC operation

MQ-4 GAS SENSOR

نمونه تجاری از حسگر گاز مقاومتی

FEATURES

* High sensitivity to CH_4, Natural gas.
* Small sensitivity to alcohol, smoke.
* Fast response . * Stable and long life * Simple drive circuit

	Parts	Materials
1	Gas sensing layer	SnO_2
2	Electrode	Au
3	Electrode line	Pt
4	Heater coil	Ni-Cr alloy
5	Tubular ceramic	Al_2O_3
6	Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7	Clamp ring	Copper plating Ni
8	Resin base	Bakelite
9	Tube Pin	Copper plating Ni

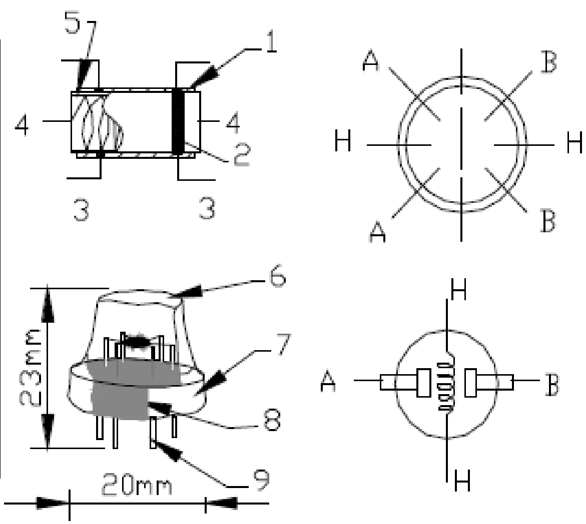


Fig. 1

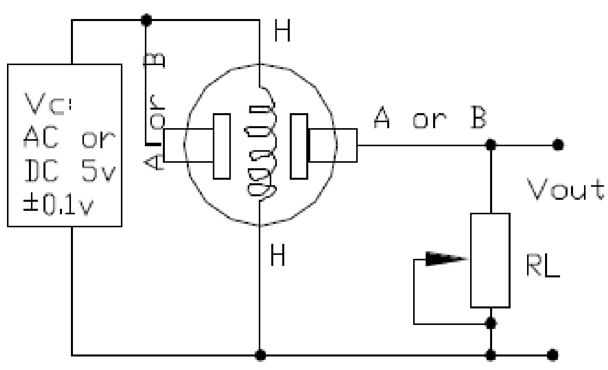


Fig.2

MQ-4 GAS SENSOR

نمونه تجاری از حسگر گاز مقاومتی

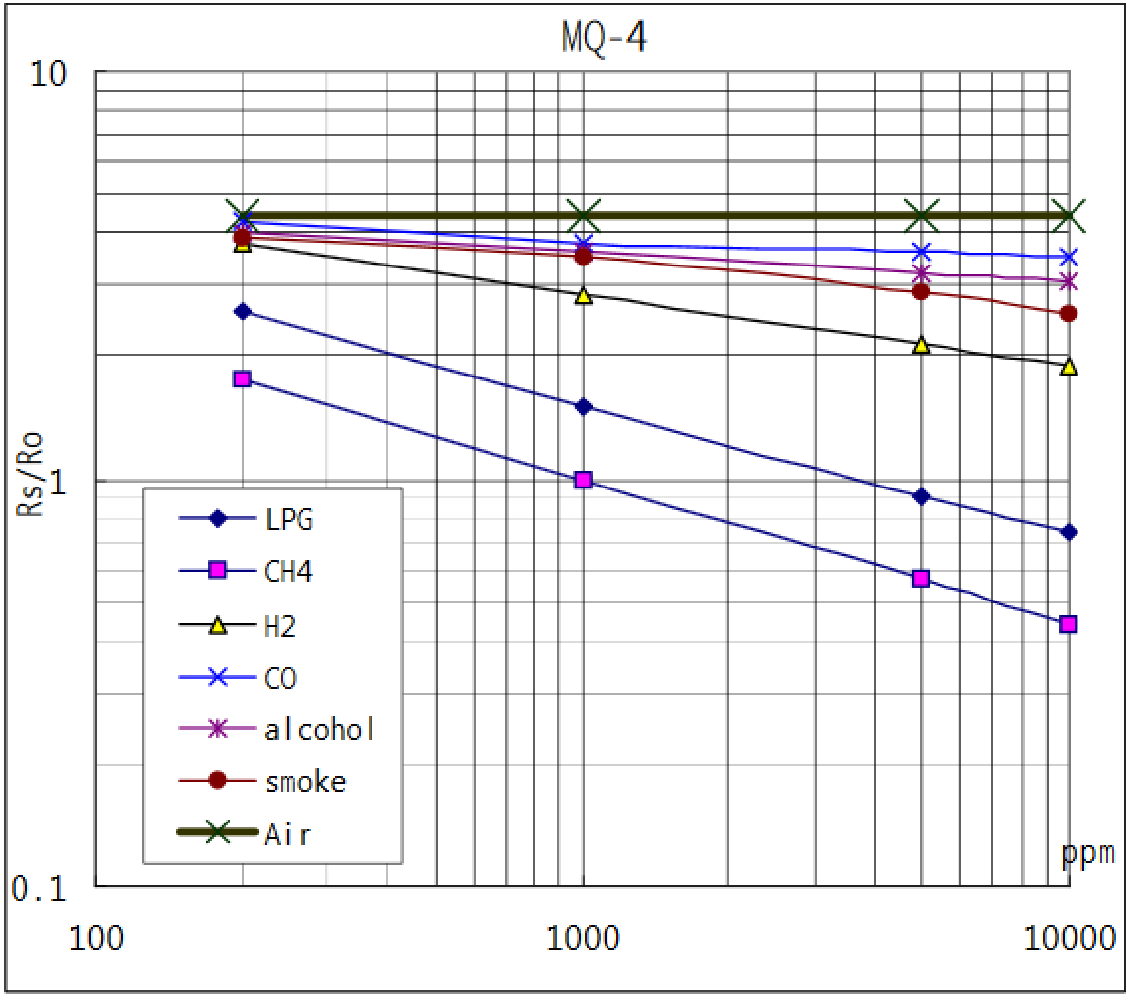


Fig.2 sensitivity characteristics of the MQ-4

Fig.3 is shows the typical sensitivity characteristics of the MQ-4 for several gases.

in their: Temp: 20℃、
Humidity: 65%、
O_2 concentration 21%
RL=20kΩ

Ro: sensor resistance at 1000ppm of CH_4 in the clean air.

Rs:sensor resistance at various concentrations of gases.

اطلاعات عناصر جدول تناوبی مندلیف

Group	1	2	3	4	5	6	7	8	9	10	11	12
Period 1	1 H 1.008 Hydrogen											
2	3 Li 6.94 Lithium	4 Be 9.0122 Beryllium										
3	11 Na 22.990 Sodium	12 Mg 24.305 Magnesium										
4	19 K 39.098 Potassium	20 Ca 40.078 Calcium	21 Sc 44.956 Scandium	22 Ti 47.867 Titanium	23 V 50.942 Vanadium	24 Cr 51.996 Chromium	25 Mn 54.938 Manganese	26 Fe 55.845 Iron	27 Co 58.933 Cobalt	28 Ni 58.693 Nickel	29 Cu 63.546 Copper	30 Zn 65.38 Zinc
5	37 Rb 85.468 Rubidium	38 Sr 87.62 Strontium	39 Y 88.906 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.906 Niobium	42 Mo 95.95 Molybdenum	43 Tc ☢ [98.906] Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium
6	55 Cs 132.91 Caesium	56 Ba 137.33 Barium	71 Lu 174.97 Lutetium	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury
7	87 Fr ☢ [223.02] Francium	88 Ra ☢ [226.03] Radium	103 Lr ☢ [262.11] Lawrencium	104 Rf ☢ [267.12] Rutherfordium	105 Db ☢ [270.13] Dubnium	106 Sg ☢ [269.13] Seaborgium	107 Bh ☢ [270.13] Bohrium	108 Hs ☢ [269.13] Hassium	109 Mt ☢ [278.16] Meitnerium	110 Ds ☢ [281.17] Darmstadtium	111 Rg ☢ [281.17] Roentgenium	112 Cn ☢ [285.18] Copernicium

https://www.webelements.com/

1	12	13	14	15	16	17	18
							2 **He** 4.0026 Helium
		5 **B** 10.81 Boron	6 **C** 12.011 Carbon	7 **N** 14.007 Nitrogen	8 **O** 15.999 Oxygen	9 **F** 18.998 Fluorine	10 **Ne** 20.180 Neon
		13 **Al** 26.982 Aluminium	14 **Si** 28.085 Silicon	15 **P** 30.974 Phosphorus	16 **S** 32.06 Sulfur	17 **Cl** 35.45 Chlorine	18 **Ar** 39.948 Argon
9 **u** 546 per	30 **Zn** 65.38 Zinc	31 **Ga** 69.723 Gallium	32 **Ge** 72.630 Germanium	33 **As** 74.922 Arsenic	34 **Se** 78.971 Selenium	35 **Br** 79.904 Bromine	36 **Kr** 83.798 Krypton
7 **g** .87 ver	48 **Cd** 112.41 Cadmium	49 **In** 114.82 Indium	50 **Sn** 118.71 Tin	51 **Sb** 121.76 Antimony	52 **Te** 127.60 Tellurium	53 **I** 126.90 Iodine	54 **Xe** 131.29 Xenon
9 **u** .97 ld	80 **Hg** 200.59 Mercury	81 **Tl** 204.38 Thallium	82 **Pb** 207.2 Lead	83 **Bi** 208.98 Bismuth	84 **Po** ☢ [208.98] Polonium	85 **At** ☢ [209.99] Astatine	86 **Rn** ☢ [222.02] Radon
1 ☢ .17] enium	112 **Cn** ☢ [285.18] Copernicium	113 **Nh** ☢ [286.18] Nihonium	114 **Fl** ☢ [289.19] Flerovium	115 **Mc** ☢ [289.19] Moscovium	116 **Lv** ☢ [293.20] Livermorium	117 **Ts** ☢ [293.21] Tennessine	118 **Og** ☢ [294.21] Oganesson

اطلاعات عناصر جدول تناوبی مندلیف

*	57 **La** 138.91 Lanthanum	58 **Ce** 140.12 Cerium	59 **Pr** 140.91 Praseodymium	60 **Nd** 144.24 Neodymium	61 **Pm** [144.91] Promethium	62 **Sm** 150.36 Samarium	63 **Eu** 151.96 Europium	64 **Gd** 157.25 Gadolinium	65 **Tb** 158.93 Terbium	66 **Dy** 162.50 Dysprosium	67 **Ho** 164.93 Holmium	68 **Er** 167.26 Erbium	69 **Tm** 168.93 Thulium	70 **Yb** 173.05 Ytterbium
**	89 **Ac** [227.03] Actinium	90 **Th** 232.04 Thorium	91 **Pa** 231.04 Protactinium	92 **U** 238.03 Uranium	93 **Np** [237.05] Neptunium	94 **Pu** [244.06] Plutonium	95 **Am** [243.06] Americium	96 **Cm** [247.07] Curium	97 **Bk** [247.07] Berkelium	98 **Cf** [251.08] Californium	99 **Es** [252.08] Einsteinium	100 **Fm** [257.10] Fermium	101 **Md** [258.10] Mendelevium	102 **No** [259.10] Nobelium

*Lanthanoids

**Actinoids

با کلیک بر نام اختصاری عناصر در جدول تناوبی در آدرس **https://www.webelements.com** اطلاعاتی زیادی از هر عنصر در اختیار قرار می گیرد.

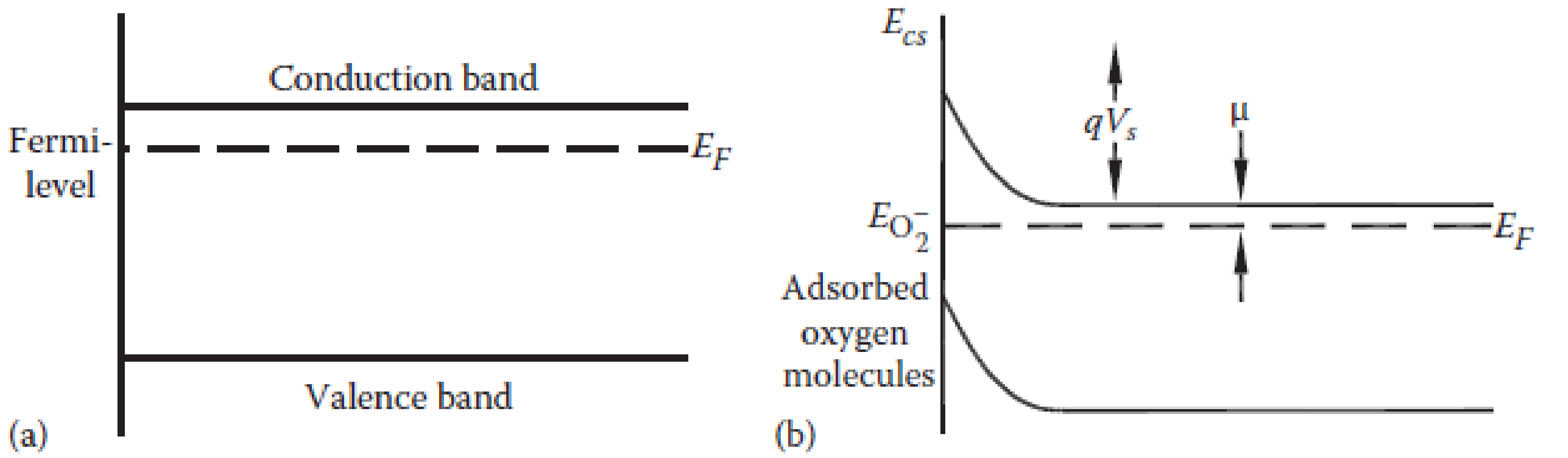


FIGURE 4.1
(a) Simple energy band diagram showing conduction band, valence band, and Fermilevel. (b) Band bending due to adsorption of oxygen species on the sensor surface altering its properties.

If we assume thermal emission as the dominant charge-transport mechanism, in this case, the conductivity *G* over such barriers depends on the energy barrier and is generally given as: $G \sim e^{-qV_s/kT}$

$$\sigma = C \exp\left(\frac{-E_a}{kT}\right) p_{O_2}^{1/m}$$

where

σ is the conductivity

C is proportionality constant

E_a is the activation energy for the bulk conduction

p_{O_2} is the oxygen partial pressure [24]

The constant *m*, the oxygen sensitivity, depends on the defects involved in the conduction mechanism. When the defects are represented by doubly ionized oxygen vacancies, $m = -6$, but if the defects are represented by metal vacancies, different values of *m* are found.

فشار جزئی یک گاز مشخص در یک ترکیب گازی

In a mixture of gases, each gas has a **partial pressure** which is the hypothetical pressure of that gas if it alone occupied the entire volume of the original mixture at the same temperature.

$$\frac{V_x}{V_{tot}} = \frac{p_x}{p_{tot}} = \frac{n_x}{n_{tot}}$$

- V_x is the partial volume of any individual gas component (X)
- V_{tot} is the total volume of the gas mixture
- p_x is the **partial pressure** of gas X
- p_{tot} is the total pressure of the gas mixture
- n_x is the amount of substance of gas (X)
- n_{tot} is the total amount of substance in gas mixture

Ex: Since inspired air is 21% **oxygen** and atmospheric **pressure** is 760 mmHg (at sea level), the **partial pressure of oxygen** is 0.21 x 760 mmHg = 160 mmHg.

Sensitivity of Resistive Gas Sensors حساسیت حسگر مقاومتی

Sensitivity, S, is defined as the ratio of change of resistance in test gas $\Delta R = R_a - R_g$, to the value of resistance in air R_a where R_g is the sensor resistance in the presence of the test gas:

$$S = \frac{\Delta R}{R_a} = \frac{\left|R_a - R_g\right|}{R_a}$$

Sensitivity is also defined by the formula $S = (R_0 - R_{gs})/R_{gs}$, where R_0 is the resistance of the sensor before passing gas and R_{gs} is after passing gas and reaching the saturation value. Others have defined this by $S = R_a/R_g$, where R_a and R_g express the resistance of the sensor in air and in detecting gas.

Eranna, G. Metal oxide nanostructures as gas sensing devices. CRC Press, 2016.

بهبود ویژگی حسگر گاز

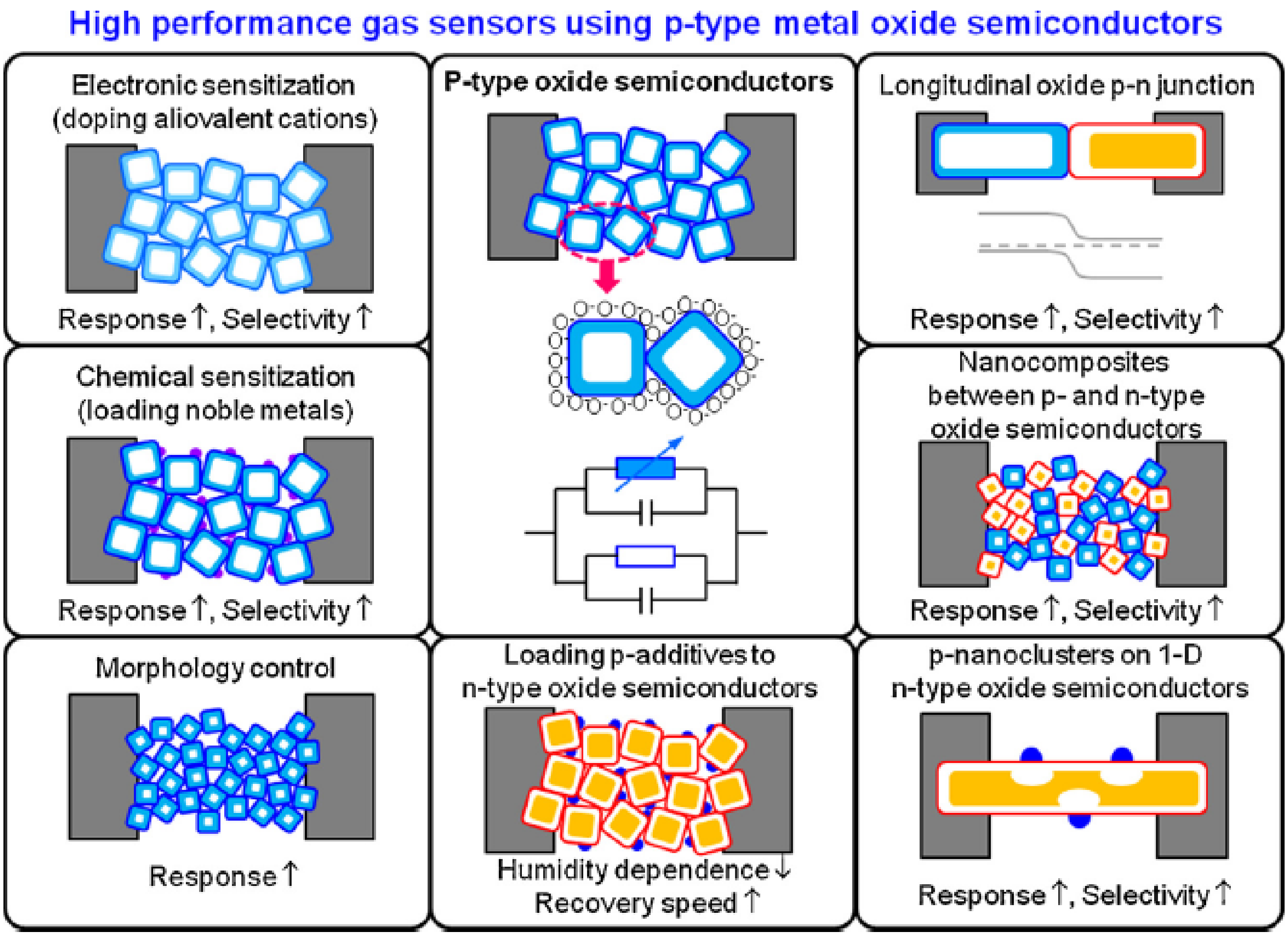


Fig. 2. High-performance gas sensors fabricated using p-type metal oxide semiconductors.

H. Kim, J.H. Lee. "Highly sensitive and selective gas sensors using p-type oxide semiconductors: overview." Sensors and Actuators B: Chemical 2014.

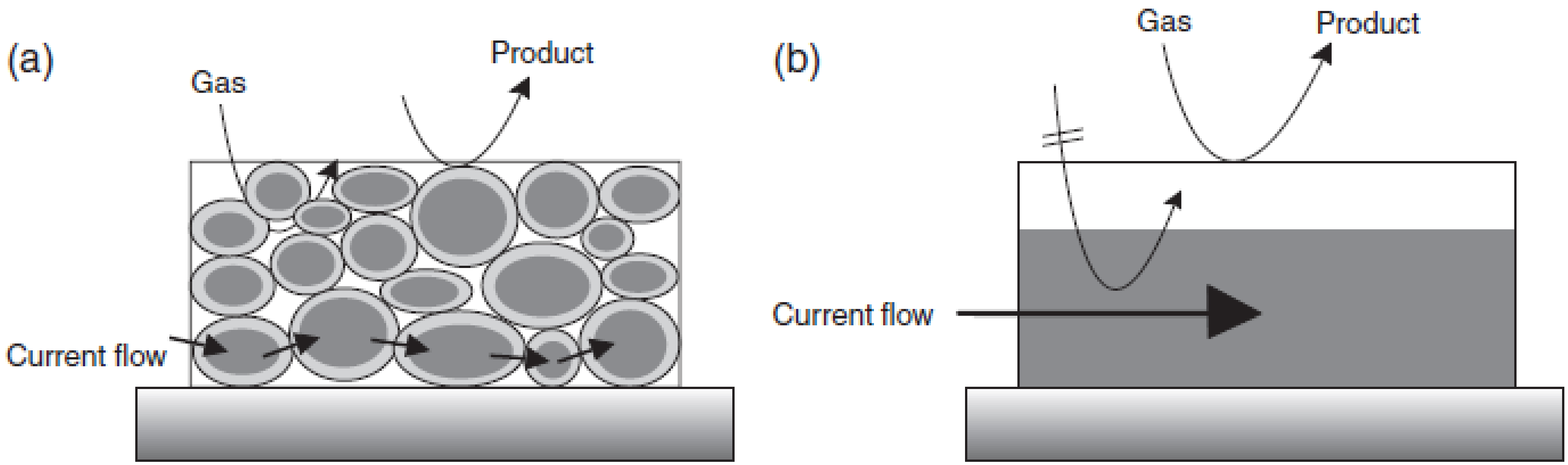
پارامترهای موثر در ویژگی‌های حسگری گاز

- جنس و ساختار قسمت حساسه
  - جنس ماده حساسه
  - اندازه دانه های کریستالی
  - سطح موثر تماس با گاز
  - ضخامت لایه
- دمای سطح حسگر
- آلایش حجمی
- آلایش سطحی

❖ آلایش به دو صورت شیمیایی و الکترونیکی میتواند بر ویژگیهای حسگری اثر گذارد.

Eranna, G. Metal oxide nanostructures as gas sensing devices. CRC Press, 2016.

تفاوت حسگری مقاومتی در ساختار متراکم و متخلخل

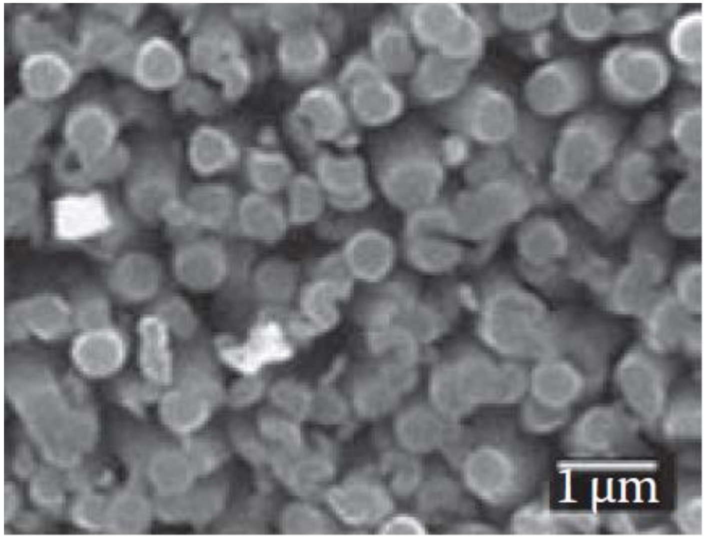


2.3 Diagram showing the difference between (a) a porous and (b) a compact layer.

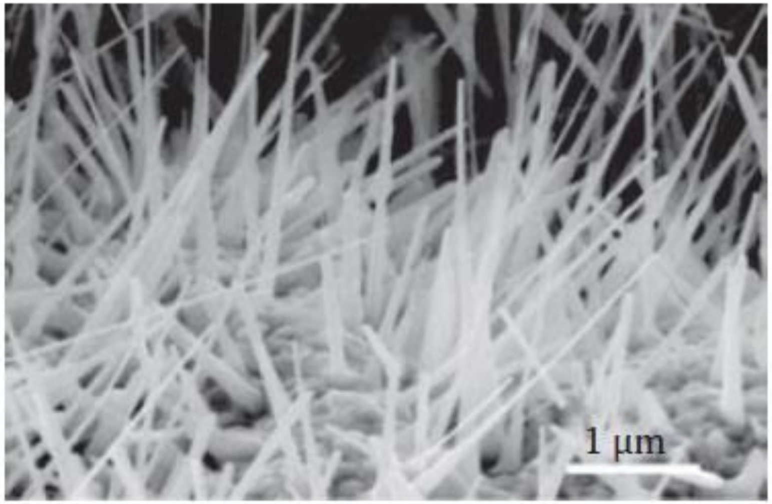
In the case of a compact layer, gas interaction only takes place on the geometric surface; the flow of current is only influenced by the thickness of the depletion layer on the surface of the layer. For porous layers, the gas can penetrate into the entire layer and, in that way, each individual grain is affected by the surrounding gaseous composition. The current is consequently determined by the barriers between all the grains.

Eranna, G. Metal oxide nanostructures as gas sensing devices. CRC Press, 2016.

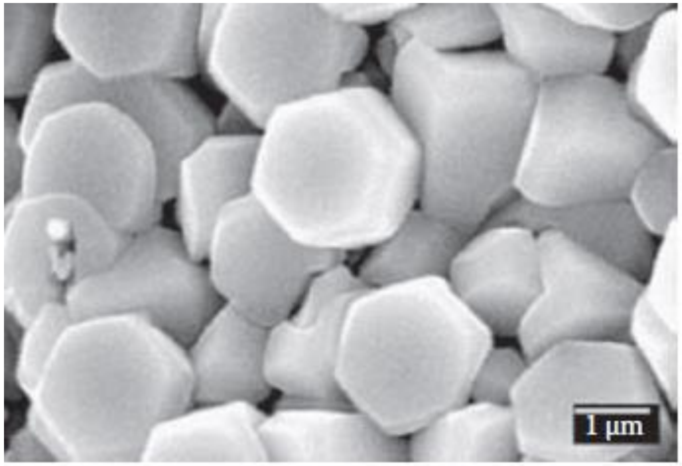
ساختارهای متخلخل مورد استفاده در حسگرها



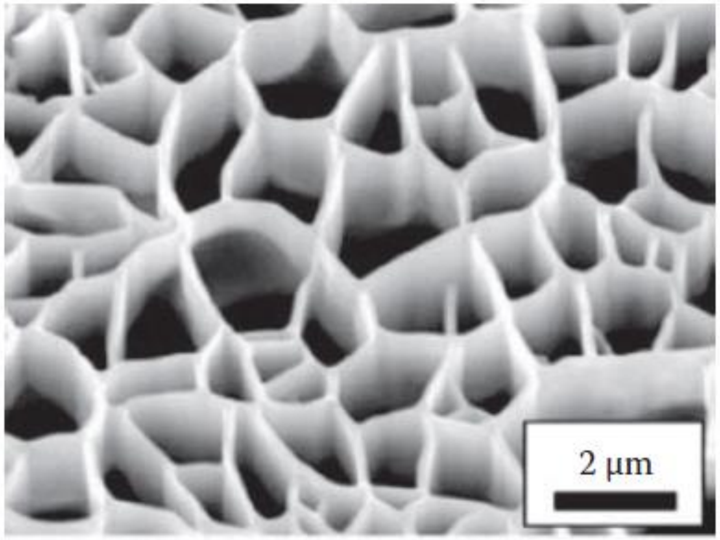
SEM images of ZnO nanorod arrays



FE-SEM morphologies of ZnO nanowire arrays.



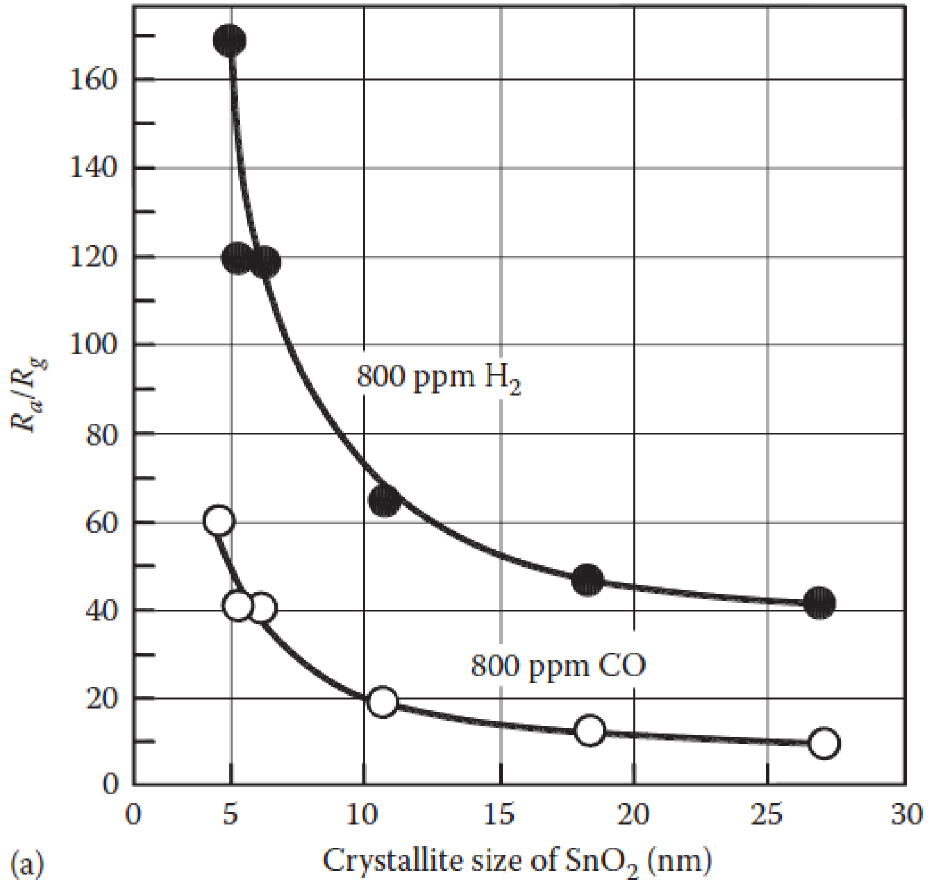
SEM image of hexagonal ZnO rods



FE-SEM images of grown ZnO nanowall networks.

Temperature-Dependent Sensitivity

اثر اندازه کریستالی بر حساسیت



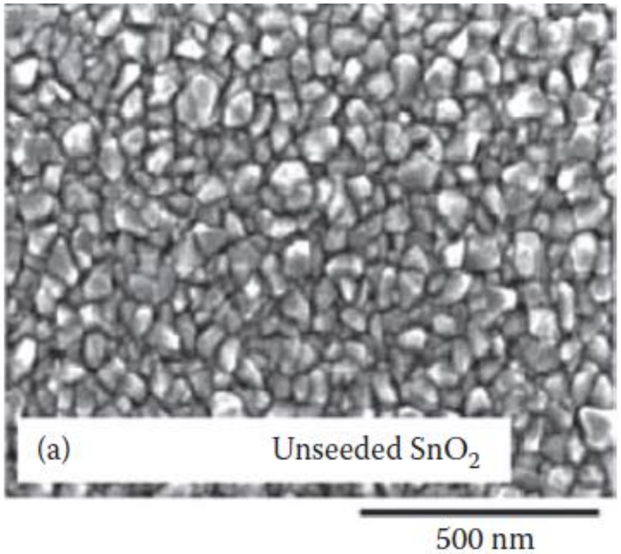
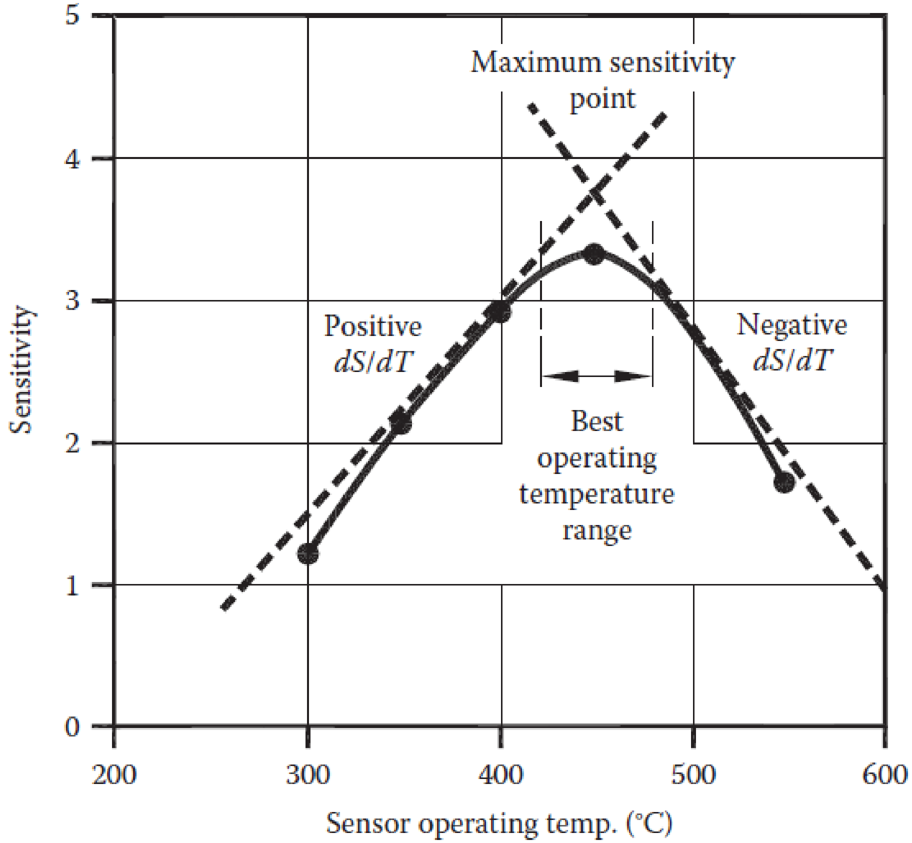


FIGURE 7.46
(a) The effect of crystallite size on resistance of nanoporous SnO_2 elements upon exposure to 800 ppm of H_2 and CO in air at an operating temperature of 300°C.

Temperature-Dependent Sensitivity   وابستگی دمایی حساسیت حسگر مقاومتی

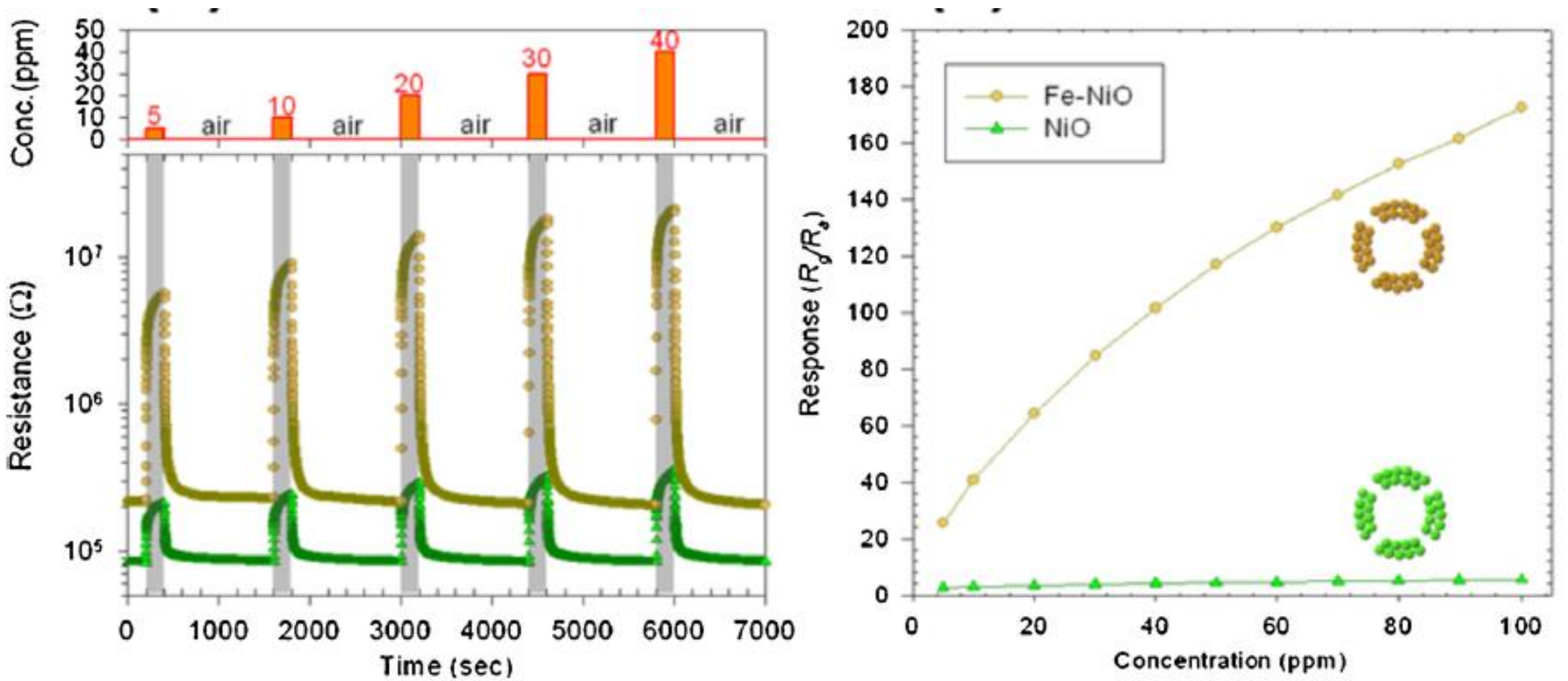


Response of SnO_2 sensor to 100 ppm of CH_4 gaseous species in dry air as a function of sensor operating temperature. Sensor sensitivity with temperature changes from positive value to negative value. Best operating range is indicated here for sensor operation. (Experimental data points are from *Prog. Solid State Chem.*, 33, Niederberger, M., Garnweitner, G., Pinna, N., and Neri, G., Non-aqueous routes to crystalline metal oxide nanoparticles: Formation mechanisms and applications, 59–70, Copyright 2005, with permission from Elsevier.)

Eranna, G. Metal oxide nanostructures as gas sensing devices. CRC Press, 2016.

Doping-Dependent Sensitivity

اثر آلایش برحساسیت حسگر مقاومتی



C_2H_5OH-detection characteristics of pure and 0.3 at% Fe-doped

H. Kim, J.H. Lee. "Highly sensitive and selective gas sensors using p-type oxide semiconductors: overview." Sensors and Actuators B: Chemical 2014.