micro-hotplate-sensors

Karsten Henkel, 2001

micro hotplate metal oxide semiconductor sensor
  sensing principle
  history/need
  fabrication
  setup of parts
  power consumption
  sensing layers
  principle of measurements
  example of publication
  others
  new material
  other sensing principles
  other heating principle
sensing principle of metal oxide semiconductor (n-type)

depletion area at the surface
(adsorption of atmospheric oxygen)

decreasing by reducing gases (CO, H₂) => increasing of conductivity

increasing by oxidising gases (NO₂) => decreasing of conductivity

typical materials
SnO₂, ZNO, TiO₂, WO₃

typical temperatures
200-400 °C
Taguchi sensor (1970)

Taguchi-type sensor (a) Sensor Element: the heater is embedded in an alumina ceramic tube and the semiconductor material is mounted on the tube with two printed gold electrodes. The heater is needed to achieve the typical sensor working temperatures in 200±400°C range and the two electrodes allow the measurement of gas sensitive changes in electrical conductivity. (b) Packaged Sensor: the heated sensor element is mounted such that thermal contact between substrate and element is only given via the connecting wires. [1]

Applications

**industrial**
- gas monitoring systems
- gas leak detectors in factories
- analysis equipment
- fermentation control
- fire and toxic gas detector

**domestic**
- gas leak alarm
- ventilation control
- cooking for microwave oven
- breath alcohol detector
- humidity control in tape recorders

nowadays

screen print technique on ceramic substrates

Gas sensor prepared by screen-printing on a ceramic substrate of size 6 mm x 8 mm. The sensor element consists of a CO- and a NOx-sensitive layer. The platinum structures (heater, electrodes and contact pads) and the two sensitive layers are manufactured in screen-printing technology. The sensitive layers consist of specifically doped and coated tin dioxide. Their electrical resistance is measured by interdigitated platinum electrodes located below the sensitive layers and the necessary sensor working temperature of about 300°C is achieved by a heater located on the backside of the ceramic. With help of the platinum contact pads the sensor is fixed to a steel lead frame by parallel gap welding and mounted in the housing. [1]
Why?

power consumption of screen printed devices 200mW - 1 W
bad selectivity of metal oxide semiconductor sensor
difficult mounting of the overall hot ceramic elements

battery, automobile
sensor arrays
thermal isolation
driving electronic too hot

Integration

combination of standard microelectronic and micromachining
=> micromachined metal oxide sensor

thin membrane of low thermal conductivity
(isolation between active area and substrate)

Advantages

power consumption 30-150 mW
(substrate nearly at ambient temperature)
fast thermal response
signal processing electronic on the same chip
sensor arrays
interdigitated electrodes
reproducibility of preparation much better
lower costs per unit
Schematic process flow for the formation of a closed-membrane type gas sensor. [1]

In literature mostly 4-6 masks

- Silicon, ~ 400 µm thick
- Dielectric layer deposition, e.g. SiO₂, Si₃N₄
  - sputtering and structuring of metal (Pt, Au,...) to form heater and electrodes
  - passivation
  - backside processing
  - anisotropic KOH-etch
- metal oxide deposition
**closed membrane**

silicon oxide and/or silicon nitride

(1-2 µm)

nitrides porous silicon

(25-30 µm)

double side etching

factor $2^{0.5}$ larger (may be plasma etching vertical walls)

**suspended membrane (spider type)**

silicon oxide and/or silicon nitride

selective formation of porous silicon in p-type silicon wafer => undercut profile below implanted n-type silicon regions

=>$5 \mu m$ thick n-type silicon membrane hanging on suspension beams (silicon nitride)

=>$ Silicon$: good temperature uniformity

excellent mechanical stability
### Thermal conductivity and capacity of substrate materials and air

<table>
<thead>
<tr>
<th>Material</th>
<th>Modification</th>
<th>$T$ (K)</th>
<th>Thermal conductivity ($W \text{ m}^{-1} \text{ K}^{-1}$)</th>
<th>Thermal capacity ($10^8 \text{ J m}^{-3} \text{ K}^{-1}$)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>Undoping</td>
<td>300</td>
<td>150</td>
<td>1.63</td>
<td>[87]</td>
</tr>
<tr>
<td>Doping ($10^{19}$ atoms per cm$^3$)</td>
<td>n.s.</td>
<td>50, 70</td>
<td>–</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td>Nitrided porous silicon</td>
<td>55% Porosity</td>
<td>n.s.</td>
<td>0.74–4.09</td>
<td>–</td>
<td>[17]</td>
</tr>
<tr>
<td>Silicon oxide</td>
<td>n.s.</td>
<td>300</td>
<td>1.4</td>
<td>1.61</td>
<td>[40]</td>
</tr>
<tr>
<td>Silicon nitride</td>
<td>n.s.</td>
<td>300</td>
<td>9–30</td>
<td>1.86–2.48</td>
<td>[40]</td>
</tr>
<tr>
<td>Polysilicon</td>
<td>(10$^{20}$ atoms per cm$^3$)</td>
<td>n.s.</td>
<td>29–34</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td>n-Doping ($10^{20}$ atoms per cm$^3$)</td>
<td>n.s.</td>
<td>16–24</td>
<td>–</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td>p-Doping ($10^{20}$ atoms per cm$^3$)</td>
<td>n.s.</td>
<td>17–20</td>
<td>–</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td>Platinum</td>
<td></td>
<td>293</td>
<td>70</td>
<td>2.85</td>
<td>[88]</td>
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<tr>
<td>Diamond</td>
<td>n.s.</td>
<td>300</td>
<td>1000, 2000</td>
<td>–</td>
<td>[29,40]</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>n.s.</td>
<td>300</td>
<td>121–500</td>
<td>–</td>
<td>[40]</td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td>293</td>
<td>0.026</td>
<td>–</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>593</td>
<td>0.044</td>
<td>–</td>
<td>[35]</td>
</tr>
</tbody>
</table>

*Thermal conductivity and capacity of substrate materials and air. Modifications and temperatures are listed as specified in the cited references; n.s. stands for not specified.

### Thermal characteristics of micromachined gas sensors in comparison to a screen-printed ceramic sensor

<table>
<thead>
<tr>
<th>Type</th>
<th>Membrane edge length (mm)</th>
<th>Heater edge length (µm)</th>
<th>Temperature (°C)</th>
<th>Power consumption (mW)</th>
<th>Thermal time constant (ms)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si$_3$N$_4$/SiO$_2$-membrane</td>
<td>1.7</td>
<td>900</td>
<td>500</td>
<td>130</td>
<td>10</td>
<td>[12]</td>
</tr>
<tr>
<td></td>
<td>1–1.5</td>
<td>–</td>
<td>400</td>
<td>30</td>
<td>–</td>
<td>[15]</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>~500</td>
<td>450</td>
<td>230</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>~500</td>
<td>450</td>
<td>190</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>~500</td>
<td>450</td>
<td>160</td>
<td>–</td>
<td>[32]</td>
</tr>
<tr>
<td>NPS-membrane</td>
<td>1.5</td>
<td>–</td>
<td>400</td>
<td>170</td>
<td>56</td>
<td>[17]</td>
</tr>
<tr>
<td>Spider (anisotropic etch)</td>
<td>~0.1</td>
<td>~0.1</td>
<td>300</td>
<td>12</td>
<td>3</td>
<td>[18]</td>
</tr>
<tr>
<td></td>
<td>~0.1</td>
<td>~0.1</td>
<td>350</td>
<td>20</td>
<td>0.2</td>
<td>[10]</td>
</tr>
<tr>
<td></td>
<td>~0.1</td>
<td>~0.1</td>
<td>320</td>
<td>40</td>
<td>2–5</td>
<td>[23]</td>
</tr>
<tr>
<td>Spider (sacrificial etch)</td>
<td>0.1</td>
<td>0.1</td>
<td>200</td>
<td>15</td>
<td>–</td>
<td>[20]</td>
</tr>
<tr>
<td>Ceramic</td>
<td>–</td>
<td>–</td>
<td>330</td>
<td>1</td>
<td>~10</td>
<td>[89]</td>
</tr>
</tbody>
</table>

*NPS = nitrided porous silicon.*
electrodes

**Au, Pt, Al, W**

Al standard IC-process metallization but bad contact properties to sensing film and limit to 500°C

Ti as adhesion layer (in range of 20 nm)

horizontal setup in case of Au or Pt heater in the same layer as electrodes
vertical setup more freedom

heater and thermometer

polysilicon IC-compatible, sheet resistance adjustable by n-type doping and negative temperature coefficient, hot spots

Pt (not compatible)
or p++ doped structures

thermometers also from Al plates for four-point temperature measurement

(improve additionally the uniformity of temperature, but limit of 500 °C)
or forward biased pn-junctions

Sometimes Si-plugs for temperature uniformity

(a) Vertical and (b) horizontal approach.

![Diagram](image)
SEM of MHP[2]

Photo of a bonded MHP gas sensor [3]

SEM of MHP

Sensorarray [4]

Fig. 2. Distribution of sensor array on the Si-chip. S1 = S3: Sensors with large membrane and heater with meander shape. S2: Sensor with large membrane and heater with loop shape. S4 = S8: Sensors with small membrane and heater with loop shape. S6 = S7 = S9: Sensors with small membrane and heater with meander shape.

[5]
Heat transfer - power consumption

\[ Q_{\text{tot}} = G_m \lambda_m (T_{\text{hot}} - T_{\text{amb}}) + G_{\text{air}} \lambda_{\text{air}} (T_{\text{hot}} - T_{\text{amb}}) + G_{\text{rad}} \sigma \epsilon (T_{\text{hot}}^4 - T_{\text{amb}}^4) \]

\( \epsilon \) .. emissivity \( \delta \) ... Stefan - Boltzmann constant

suspended membrane
(conduction perpendicular neglected, basically along the suspension beams, one dimensional)

\[ G_m = \frac{4A_{\text{beam}}}{l} \]

[1]

closed membrane

\[ G_m = \frac{2\pi d}{\ln \frac{r_a}{r_i}} \]

Ratio b:a for square geometry 3:1

air

conduction and fluid motion simulations show fluid motion is about 5%
=> simple model
only conduction
concentric spheres (layer and ambient)

\[ G_{\text{air}} = \frac{4\pi}{1 - \frac{1}{r_a/r_i}} \approx 4\pi r_i \]

Convection simulation

radiation (only some %)

gray emitter \( G_{\text{rad}} = 2A \)

backside coating
comparison heat suspended and closed membrane

\[ \lambda_m = 10 \text{Wm}^{-1}\text{K}^{-1} \quad d = 2 \mu m \quad (T_{hot} - T_{amb}) = 300K \]

suspended : \( l = 100 \mu m, w = 20 \mu m \Rightarrow 4.8 \text{mW} \)

closed \( (r_a / r_i) = 2,5,8 \Rightarrow 54,23,18 \text{mW} \)

**conclusion, requirements**

constructing thin membranes consisting of materials of low thermal conductivity;

use of suspension beams with high length-to-width ratio adjusting the heater size (edge length a) to the size of the closed membrane (edge length b) as b:a 3:1;

decreasing the heated area choosing a large pit depth of the suspended membrane thin gold coating at the backside of the membrane.

**but**

need of large area to make measurement of resistance possible

mechanical stability

=> compromise

---

**temperature uniformity**

Si-plugs two heater for compensation

**thermal transient response**

response to step function

\[ T(t) - T_{amb} = P_{el} \times R_{therm} \times (1 - e^{-\frac{t}{\tau}}) \]

\[ \tau = R_{therm} \times C \]

Reducing of R increase power consumption

=> trade off thermal capacity differs scarcely

=> reduction of heated mass (A,d minimal)

=> suspended membranes better

---

Fig. 1. Thermal response of the Micro-hotplate (MHP).
Sensing layer deposition

large intrinsic or thermal-induced membrane stress leading to membrane deformation/breaking of the membrane
plastic deformation at the metal±SnO2 contact area
deformation/breaking of the membrane due to deposition of sensing layer;
stress in the metallization sandwich structure
thermometer-resistance shift due to mechanical and thermal stresses.

| Deposition techniques used for the preparation of metal oxides such as SnO2 [90]a |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Paste/slurry deposition         | Chemical vapor deposition (CVD) | Physical vapor deposition (PVD) | Evaporation                     |
| Screen-printing                 | Thermal CVD                     | Sputtering                      | Molecular beam epitaxy          |
| Drop deposition                 | Plasma activated CVD            | Reactive sputtering             | Thermal evaporation             |
| Dip coating                     | Laser induced CVD               | Cathode sputtering              | Reactive evaporation            |
| Spray deposition                | Electroless plating             | With bias voltage               | Ion plating                     |

thick films several microns     
large extra thermal mass         
thermal response increase
larger thermal conductivity     
smoothing of temperature profile
over active area, additional heat losses

thin films 20 ...1000nm

compact layers      
only surface interaction=> two parallel resistances for current flow
porous layers       
each grain posses a surface depleted area, series of resistances=> higher sensitivities

RGTO (rheotaxial growth and thermal oxidation) leads to thin porous films
principles of measurements
resistance
most at constant temperature and by DC measurement

thick film sensors for reducing gases much better while for oxidizing gases in the same range like thin films

modification of electrode material, working temperature, geometry

\[ \Rightarrow \text{better sensitivity and selectivity of single sensor} \]
\[ \Rightarrow \text{design of arrays} \]

application of electric fields perpendicular to the sensing film may improve the sensitivity
CO sensor signals of various thick and thin film sensors

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>CO concentration (ppm)</th>
<th>CO sensor signals</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thick film sensors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TGS 2201 thick film ceramic sensor</td>
<td>10–100</td>
<td>1.7–3.3</td>
<td>[93]</td>
</tr>
<tr>
<td>Taguchi-type from IPC</td>
<td>50</td>
<td>9</td>
<td>[94]</td>
</tr>
<tr>
<td>Screen-printed thick-film ceramic sensor from IPC</td>
<td>50</td>
<td>10</td>
<td>[94]</td>
</tr>
<tr>
<td>Different microstructured sensors with drop deposited thick film from IPC</td>
<td>50</td>
<td>8, 21, 40</td>
<td>[94]</td>
</tr>
<tr>
<td><strong>Thin film sensors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MGS1100 from Motorola, RGTO thin film on micromachined substrate</td>
<td>10–1000</td>
<td>1.05–11</td>
<td>[74]</td>
</tr>
<tr>
<td>Micromachined sensor with RGTO thin film</td>
<td>10–100</td>
<td>1.1–2</td>
<td>[66]</td>
</tr>
<tr>
<td>Thermally activated, CVD-deposited thin film on micromachined substrate</td>
<td>5–45</td>
<td>1.05–1.6</td>
<td>[23]</td>
</tr>
<tr>
<td>Micromachined sensor with 60 nm thick sputtered thin film</td>
<td>50</td>
<td>1.3</td>
<td>[94]</td>
</tr>
</tbody>
</table>

aData values are obtained under constant operation temperature except for the Motorola sensor which is temperature pulsed due to the manufacture’s proposed operating conditions.

Table 8

NO₂ sensor signals of various thick and thin film sensors

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>NO₂ concentration (ppm)</th>
<th>NO₂ Sensor signals</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thick film sensors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TGS 2201 thick film ceramic sensor</td>
<td>0.1–1</td>
<td>1.5–10</td>
<td>[93]</td>
</tr>
<tr>
<td>Screen-printed thick-film ceramic sensor from Bosch</td>
<td>1–5</td>
<td>1.4–2.9</td>
<td>[89]</td>
</tr>
<tr>
<td>Screen-printed thick-film ceramic sensor optimized for NO₂-detection</td>
<td>0.2–5</td>
<td>40–200</td>
<td>[91]</td>
</tr>
<tr>
<td><strong>Thin film sensors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 nm thick sputtered thin film</td>
<td>1–5</td>
<td>4–11</td>
<td>[62]</td>
</tr>
<tr>
<td>Micromachined sensor with RGTO thin film</td>
<td>0.25–5</td>
<td>6–20</td>
<td>[66]</td>
</tr>
<tr>
<td>60 nm sputtered thin film</td>
<td>5–50</td>
<td>~2–4</td>
<td>[60]</td>
</tr>
<tr>
<td>60 nm sputtered thin film with electrode configuration featuring a JFET-like transducer mechanism</td>
<td>0.01–1</td>
<td>2–100</td>
<td>[58]</td>
</tr>
</tbody>
</table>
temperature modulations

increasing of selectivity, sensitivity
reduce of heating power

Fig. 3. Conductance response of a Pd-dosed SnO₂ film to the 20°C saturated vapors of (a) acetone, (b) formaldehyde (c) ethanol, and (d) methanol during the repetitive temperature sequence schematically illustrated in (a). The temperature-pulse sequence actually was much denser in time, consisting of 100 ns pulses ranging from 20 to 450°C with a 5°C temperature increment. The curves were scaled to fit on one graph as follows: (a) 20°C + 0.2 kΩ⁻¹, (b) 10°C + 0.27 kΩ⁻¹, (c) G, and (d) 0.7G - 0.05 kΩ⁻¹.

Fig. 4. Conductance response of a Pd-dosed SnO₂ film to the 20°C saturated vapors of (a) acetone, (b) formaldehyde (c) ethanol, and (d) methanol during the repetitive temperature sequence schematically illustrated in (a). The temperature-pulse sequence consisted of ten 100 ns pulses at each of eight temperatures ranging from 20 to 170°C with a 50°C temperature increment. The conductance curves were scaled to fit on one graph as follows: (a) 70°C + 0.6 kΩ⁻¹, (b) 17°C + 1 kΩ⁻¹, (c) G, and (d) G.

Fig. 5. Conductance response to methanol and ethanol vapor (as labeled) during a temperature-pulse sequence consisting of ten 100 ns pulses at each of 11 temperatures ranging from 20 to 520°C. Solid and dashed curves are data collected 5 and 200 ns, respectively, after the pulse.
temperature modulations

Results from [72] on sinusoidal temperature modulations of a micromachined thick film sensor in synthetic air (50% RH) and during exposure to 50 ppm CO, 1.0 ppm NO2 and a mixture of 50 ppm CO and 1.0 ppm NO2.

Fig. 24. Results from [72]. Polar plot representation of a fast Fourier transformation of the sensor signal shown in Fig. 23. The amplitudes of the fundamental frequency and of the first five harmonics are used as coordinates in the polar plot. Their values are normalized to the values in air and plotted in the figure for synthetic air (50% RH), 50 ppm CO, 1 ppm NO2 and a mixture of 50 ppm CO and 1 ppm NO2.
thermovoltage (Seebeck)

thermovoltage is generated in case of non-uniform temperature distribution across the sensing layer

\[ V_s = \alpha_s \Delta T \quad \lambda_s \ldots \text{gas sensitive seebeck coefficient} \]

two electrodes with different but constant temperature (constant \( \Delta T \))

Results show

\[ V_s \sim \ln c \]

\[ V_s = A + B \ln R_s \]

Picture from [76] showing the possibility for discrimination of methane to propane by combination of Seebeck and resistance measurements. Line A, ethanol and acetone; line B, hydrogen; line C, carbon monoxide; line D, propane; line E, methane. [1]

catalytic treatment of one electrode (use catalytic effect of combustible gases)\(\Rightarrow\) local temperature rise (combination of gas induced change of seebeck coefficient and catalytic effect)

this methods have not been carried out for MHP-devices
M.C. Horrilloe et al. Detection of low NO2 concentrations with low power micromachined tin oxide gas sensors, Sensors and Actuators B 58 1999 325–329

<table>
<thead>
<tr>
<th>Microsensor</th>
<th>Heater</th>
<th>Membrane dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Meander</td>
<td>1100 ( \mu \text{m} \times 1100 \mu \text{m} )</td>
</tr>
<tr>
<td>S2</td>
<td>Loop</td>
<td>1100 ( \mu \text{m} \times 1100 \mu \text{m} )</td>
</tr>
<tr>
<td>S7</td>
<td>Meander</td>
<td>900 ( \mu \text{m} \times 900 \mu \text{m} )</td>
</tr>
<tr>
<td>S8</td>
<td>Loop</td>
<td>900 ( \mu \text{m} \times 900 \mu \text{m} )</td>
</tr>
</tbody>
</table>

Fig. 4. Response to very low NO\(_2\) concentrations obtained from S1 and S2 at 250°C.

600 nm, for low concentrations no significant difference

Fig. 5. Sensitivity to 1 ppm at different temperatures of the sensors: S2 and S8.

Fig. 6. Power consumption vs. operating temperature for the two types of membrane dimensions.
new material

F. Solzbacher et al.:  
A modular system of SiC-based microhotplates for the application in metal oxide gas sensors; Sensors and Actuators B 64 2000 95–101 [4]  
A new SiC/HfB$_2$ based low power gas sensor; Sensors and Actuators B 77 2001 111–115 [8]

**membrane** (closed)  
SiC (3C lower thermal conductivity than 4H ;6H )

**heater**

HfB$_2$  
N-implantation in SiC  
battery operation (1-2 V)  
automotive application

up to 700°C, at 400°C 35mW

![Mounting on TO8 carrier](image)

**sensitive layer**

In$_2$O$_3$  
(250°C 20 mW), time constant 50 s
other sensing principle


Sintered ceramics

for SO₂ detection: Pt/Na₂SO₄, BaSO₄, Ag₂SO₄/Ag
for NO₂ detection: Pt/NaNO₃, Ba(NO₃)₂, Ag₂SO₄/Ag
and for CO₂ detection: Pt/Na₂CO₃, BaCO₃, Ag₂SO₄/Ag.

Comparison between the performance of the integrated micropotentiometric sensor and its bulk form at 250°C

<table>
<thead>
<tr>
<th></th>
<th>Bulk sensor</th>
<th>Micro-sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>15 W</td>
<td>5 mW</td>
</tr>
<tr>
<td>Sensitivity and resolution</td>
<td>50 mV</td>
<td>45 mV</td>
</tr>
<tr>
<td>Response time</td>
<td>60 to 300 s</td>
<td>10 to 30 s</td>
</tr>
<tr>
<td>Recovery time</td>
<td>900 s</td>
<td>60 s</td>
</tr>
</tbody>
</table>
other sensing principle


Pt, Ir, Pd as gate sensitive materials
one al may used as reference

Top view photograph and cross section schematic of the low power array gas sensor: M MOSFET; D diode
H heater, G ground

heating characteristics
at 170°C operating temperature
80 mW for the array
65 ms rising, 100 ms cooling

sensing characteristic at 140 °C

<table>
<thead>
<tr>
<th></th>
<th>20 ppm NH₃</th>
<th>250 ppm H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt</td>
<td>182 mV</td>
<td>60 mV</td>
</tr>
<tr>
<td>Ir</td>
<td>165 mV</td>
<td>103 mV</td>
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</tbody>
</table>
other sensing/heating principle


SOI (silicon on insulator)

SOI chemoresistive gas sensor

SOI microcalorimeter sensor
<table>
<thead>
<tr>
<th></th>
<th>Authors</th>
<th>Journal Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I. Simon et al.</td>
<td>Sensors and Actuators B 73 (2001), 1-26</td>
</tr>
<tr>
<td>5</td>
<td>M.C. Horillo et al.</td>
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