High sensitive CVD graphene-based gas sensors operating under environmental conditions

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Introduction

- Fast response and recovery
- Long operating life
- High sensitivity
- Small size
- Large scale and low production cost
- Good selectivity

GAS SENSOR
GRAPHENE-BASED GAS SENSOR

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- High sensitivity
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Research activity
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- Wafer scale production
- Small size (device~2, 5, 10 μm)
- Selectivity to NO₂
- High sensitivity (LOD~100ppb @RT)

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EU warning for NO₂ emissions (last February)
- France
- Italy
- Germany
- Spain
- Great Britain
Why graphene in gas sensing?

2D MATERIAL

- Highest surface volume ratio (2600 m²g⁻¹)
- Surface atoms interaction, no bulk
- **Strong stability @ RT**

CANDIDATE FOR GAS-SENSORS

IDEAL CANDIDATE FOR GAS-SENSORS IN ENVIRONMENTAL CONDITIONS
Transfer process after CVD growth
Transfer-free process

Mo/SiO₂/Si

Graphene/Mo/SiO₂/Si

Graphene/SiO₂/Si

Contacts/Graphene/SiO₂/Si

😊 Growth substrate = target substrate

😊 No damages

😊 No polymer residues at interface

😊 Wafer scale process with high yield (>97%)
Graphene characterizations

Raman (50X, N.A. 0.50)
100 spectra, area=100 μm x 100 μm
Graphene characterizations

Raman (50X, N.A. 0.50)

Few-Multi Layer Graphene

AFM
Devices

- Metal contacts
- Graphene bar
- Packaging
- Bonding
I-V measurements

<table>
<thead>
<tr>
<th>Graphene bar dimensions (μm)</th>
<th>Length</th>
<th>Width</th>
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</thead>
<tbody>
<tr>
<td>Device 1A</td>
<td>206</td>
<td>10</td>
</tr>
<tr>
<td>Device 1B</td>
<td>206</td>
<td>10</td>
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<tr>
<td>Device 2A</td>
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<td>5</td>
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<tr>
<td>Device 2B</td>
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<td>Device 3A</td>
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<td>2</td>
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Metal contacts

Graphene bar
Experimental set-up

TEST CHAMBER

- Stainless steel testing chamber
- Environmental conditions (RT=25°C, RH=50%, p=p_{atm})
- Carrier: N\textsubscript{2}
Experimental set-up

TEST CHAMBER

- Stainless steel testing chamber
- Environmental conditions (RT=25°C, RH=50%, p=p_{atm})
- Carrier: N_2

Baseline: carrier gas

Recovery: carrier gas
RH test

- Drift of base conductance
- Slow kinetics
- RH: 30% -> 70% \(|\Delta I/I_0| \approx 1.3\%\)
RH tests
RH tests

- Slow kinetics
- Drift of base conductance
- Repeatability
- Current variation <2%
- Real environment: RH slower variations

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Tests towards NO$_2$

**Test protocol**

1. Baseline: 20 min N$_2$
2. Exposure: 4 min NO$_2$ @ 0.1-1.5 ppm
3. Recovery phase: 10 min N$_2$

- Real environment: no drastic RH variation
- @RH=50%: separated contributions
- LOD~ 100 ppb
Conclusions

FABRICATION PROCESS

• Transfer-free graphene-based gas sensors
• Wafer scale production (>700 devices/wafer)
• High yield of working devices (>97%)

SENSORS

• Distinguishable RH effects on NO₂ sensing
• Repeatability on 2-5-10 μm devices
• High sensitivity in 0.1-1.5 ppm
  ➢ LOD ~ 100 ppb @ RT

From LAB…

…to FAB
Acknowledgment

Enabling new technology

Italian national agency for new technologies, energy and sustainable economic development

...Thanks!

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