On the fabrication of a graphene resonator and detection of a resonance via electrical read-out towards a graphene gas filter
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Motivation

Research towards a sustainable future

Need for new energy sources:

Hydrogen

Problems:

• Purification
• Storage

Possible solution purification:

Graphene membrane
Membrane

Performance: • productivity • selectivity • mechanical stability

➔ Thinner membranes have higher productivity

Graphene thickness: 0.34 nanometer
Graphene

2 Dimensional material

Single atomic layer of carbon atoms

Extraordinary properties:
- High electrical conductivity
- Stronger than steel
- High elasticity
- Impermeable for all gases

Control permeability:
- Pores
- Strain engineering

Permeability assessment

Scarselli 2012 Journal of Physics: Condensed Matter
Permeability measurement

- Driving force: pressure
- Leak rate is proportional to pressure change in time

Challenge:
- Small size of membrane
- Limited number of molecules

Measure pressure change over time
Graphene Resonator

- A resonator is a device that oscillates at specific frequencies
- Example of a resonator: musical instruments

- Resonance frequency:
  - Geometry
  - Mass
  - Tension: \textit{pressure, electrostatic force, temperature, fabrication}

- Resonance frequency: 10-100 MHz
Summary introduction

- The thinner a membrane, the higher its productivity
- Graphene thickness 0.34nm, controlled permeability
- Graphene is a potential gas filter
- Permeability assessment is necessary

**Goal:** Design and Fabrication of a Graphene Resonator and Read-out of the Resonance Frequency
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  o Read-out setup
    o Results read-out
    o Evaluation resonance measurement

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Actuation Principle

- Electrostatic force:
  - Attractive
  - Repulsive

- Switching electrostatic force induces vibration

Resonance detection in graphene membrane

Sazanova 2004
Detection Principle

Resonance peak current:
- Conductance changes during vibration
- Graphene and gate form capacitor

Capacitance: \[ C = \frac{\varepsilon A}{d} \]
- \( \varepsilon \): permittivity
- \( A \): area
- \( d \): distance plates
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Resonator Design

Chip requirements:
- Permeability measurement
- Electrical read-out
- Graphene

Numbers:
1. Gas inlet
2. Back gate
3. Hole for graphene
4. Source electrode
5. Drain electrode
6. Graphene membrane
7. Bond pad back gate
8. Insulation layer
Resonator Fabrication: photo’s
Evaluation Fabrication

<table>
<thead>
<tr>
<th>Issues</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misalignment</td>
<td>Deeper alignment marks</td>
</tr>
<tr>
<td>Wire bonding</td>
<td>Thicker adhesion layer</td>
</tr>
<tr>
<td>Oxide deterioration</td>
<td>Control wafer bonding process</td>
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Electrical read-out scheme

AC signal 10; 100 MHz

Graphene

Drain
Back
Gate Chip

Vacuum chamber

Current amplifier

Bias Tee

DC voltage

Frequency Mixer

lock in amplifier 1 kHz
Electrical Read-out Setup
Results model & experiment

Carrier mobility:

\[ \mu = 1100 \frac{cm^2}{Vs} \]
Results experiment

Output current as function of frequency sweep

Current (pA) vs. Frequency (MHz)
Evaluation Resonance Detection

Chip Design & Fabrication

Problem:
• Sensitivity chip

Improvements:
• Decrease gate-graphene distance
• Increase membrane area
• Increase permittivity

Solutions:
• Nitride membrane
• Top gate

<table>
<thead>
<tr>
<th>Resonator</th>
<th>Sensitivity (aF/nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip Chen 2009</td>
<td>1.3</td>
</tr>
<tr>
<td>Chip #1</td>
<td>0.04</td>
</tr>
<tr>
<td>Chip nitride</td>
<td>0.64</td>
</tr>
<tr>
<td>Chip top gate</td>
<td>1.97</td>
</tr>
</tbody>
</table>
Evaluation Resonance Detection

Electrical Read-out Circuit

**Issues current amplifier:**
- Input capacitance
- Sensitive to disturbance environment

**Solutions:**
- Noise box
- Current amplifier

**Data acquisition and processing:**
- Read-in frequency signal generator
- Matlab script search for peaks
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Conclusions

• A graphene resonator is designed and fabricated
  • Graphene transfer
  • Functionality successful
  • Fabrication issues solved

• Read-out setup is designed and built
  • Output signal modelled
  • Shielding essential
  • Current amplifier weak link

• No resonance is detected:
  • Chip Batch 2 nitride membrane and top gate
  • Noise box or change current amplifier
  • Data acquisition and processing
Future outlook

• Permeability measurement
  • Sealing back gate to enclose gas
  • Incorporate bulging in model
  • Feedback loop
    • Match tension of pressure and electrostatic force

• Development gas separation membrane

Wang 2012
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Mechanical exfoliation

The scotch-tape method

Pictures: Minkel 2008
Chip Fabrication 1/2
Chip Fabrication 2/2
Graphene Transfer

1. Coat polymer solution on chip with graphene flake
2. Wedge the polymer in water while graphene adheres to polymer
3. Polymer floats on water with graphene facing down
4. Position chip under flake
5. Drain water to bring chip and polymer in contact
6. Align flake by controlling x- and y position of polymer
7. Dissolve polymer

Schneider 2010
(a) Laser spot shows locations of obtained Raman spectra.

(c) Single layer graphene spectrum obtained from chip #2 at location 1

(d) Bilayer graphene spectrum obtained from chip #2 at location 2
Sealing concept

1. Copper coating
2. Helium supply
3. Soldering iron supplies heat
4. Solder closes gas cavity
Top gate concept

- Support second chip with gate above membrane
- Golden pillars and bondpad