Outline

• What is Graphene?
• Introduction to Graphenea
• A market overview
• Graphene wafer scale integration allows many applications
• Wafer Scale Integration
• Graphenea Roadmap
Graphene has outstanding electronic, optical, thermal and mechanical properties
Graphenea is a high-quality graphene producer...

- Geim & Novoselov publish Science paper
- First funding round closed $1.8 m
- First Graphene produced in Graphenea
- Moving to a larger laboratory
- Sigma-Aldrich selects Graphenea as supplier
- Repsol Energy Ventures joins Graphenea €1 m
- US branch opened
- €1 m sales milestone
- 2.2M € investment for scale up secured
- Jesus de la Fuente writes first Business Case
- Graphenea founded
- First commercial order
- Graphene Flagship approved €1 B 10 years project
- Global Top 100 Ones to Watch
Graphenea Sites

Headquarters & Research (San Sebastian, Spain)

GO Production Lab @ Miramon Technology Park

App Laboratory (Cambridge, MA)
...and key Scientific talent involved...

Dr. Luis Hueso
CIC nanogune
Scientific Advisor
2010-

Prof. Manish Chhowalla
Rutgers New Jersey
Scientific Advisor
2010-

Dr. Jing Kong
MIT Boston
Scientific Advisor
2011-2012

Dr. Tomas Palacios
MIT Boston
Scientific Advisor
2011-

Dr. Andreas Berger
CIC nanoGune
Scientific Advisor
2009-2010

Dr. Alexander Balandin
University of California Riverside
Scientific Advisor
2014-

Private and confidential

Dr. Amaia Zurutuza
Graphenea’s
Scientific Director
Graphenea is working with industrial-scalable technology
CVD and GO

Graphene synthesis technologies comparison

Mechanical exfoliation

Chemical exfoliation

SiC Sublimation

CVD

Graphene is working with industrial-scalable technology
CVD and GO
Graphenea is working with industrial-scalable technology
CVD and GO

<table>
<thead>
<tr>
<th>FORMAT</th>
<th>RAW MATERIAL</th>
<th>PROPERTIES</th>
<th>POTENTIAL</th>
<th>MAIN APPLICATIONS</th>
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<tbody>
<tr>
<td>CVD (Chemical Vapour Deposition)</td>
<td>CH₄</td>
<td>High electron mobility</td>
<td>High</td>
<td>Electronics</td>
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<td>Sensors/Biosensors</td>
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<td>Membranes</td>
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<td>Flexible Electrodes</td>
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<td>GO (Graphene Oxide)</td>
<td>Graphite</td>
<td>Versatility Functionalization</td>
<td>Medium</td>
<td>Advanced Polymers</td>
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Graphenea Intellectual Property


4. Equipment and Method to Automatically Transfer a Graphene Monolayer to a Substrate, EP14382148, filing date 24 Apr 2014

5. Method of Manufacturing Graphene Monolayer on Insulating Substrates, EP2679540, filing date 29 June 2012
We are expanding our global presence
Graphenea has a growing customer base and distribution network...

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<tr>
<th>INDUSTRIES</th>
<th>RESEARCH CENTERS</th>
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Note: Partial list – illustrative only
Market Overview
Each application requires a specific type and grade of graphene.
Graphene market is very small and driven by Research-related demand.

Global Graphene market forecast ($M)

Research-related demand

Early-stage applications demand

BCC has reduced its market expectation in 2017 from 270 MM$ to 122.9 MM$, fully aligned with IDTechEx forecasted market of 100 MM$ in 2018, Lux Research estimates $126 in 2020.

Source: BCC, IDTechEx, Lux Research, Graphenea elaboration
Quantum dots... How things can change dramatically

IDTechEx Research

Graphenea
Graphene wafer scale integration allows many applications
Nanowires on graphene enables UV LEDs

By growing AlGaN (aluminium gallium nitride) nanowires on graphene, graphene will be used both as a substrate and as a UV transparent electrode in order to achieve a high external efficiency.

Water Disinfection  Air Purification  Food Processing
Flexible WiFi receivers

- 2.4 GHz receiver circuits on plastic
- Ideal for IoT and flexible electronics

Source: McKinsey
Flexible Hall sensor

- High sensitivity, linearity and flexibility
- The key factor determining sensitivity of Hall effect sensors is high electron mobility

Source: Honeywell
Ultra-sensitive and low-cost Graphene Quantum-Dot Photodetector

Non-invasive health monitoring applications

- Flexible and transparent
- Blood volume
- Heart rate
- Ultra-sensitive with a gain of $10^8$ carriers per absorbed photon
- Sensitive to both visible and infrared light
- No cooling required

ICFO
Wafer Scale Integration
CMOS-Fab Integration

- CVD growth on Cu foil
- Transfer on a carrier substrate
- Automated transfer of graphene on CMOS wafer
- Patterning of Graphene structures and contact metals
- Functional material deposition and encapsulation
- Pick and Place assembly
- Final testing and calibration

✓ Graphenea allows integration for graphene
Graphene on a carrier substrate

Important factors to consider

• Transfer method selection
• Substrate type
• Semiconductor industry requirements: metal impurities, contamination, wafer uniformity
• Large scale quality control method
Wafer Scale Integration

Graphene on catalyst

• Quality of the transfer
• Substrate supporting the graphene
• Quality of the interface between graphene & substrate

Graphene on the desired substrate

Large impact on graphene properties & device performance
Graphene on a carrier substrate to facilitate integration

Graphenea

End user

Wet method

Dry method

Catalyst

Graphene

Carrier Polymer

Substrate

Graphene
Wafer Scale Integration

There is non standard process for all the substrates and applications

- Wet Transfer
- Dry Transfer
- Semi-dry Transfer
Wafer Scale Integration

Conventional wet transfer process
Wafer Scale Integration

Dry transfer process
Wafer Scale Integration

Semi-Dry transfer process

Alternative to Cu etching – electrochemical delamination

Graphene Wafer In-line quality control

Imaging spectroscopic ellipsometry

- Micromapping of Delta and Psi at 480nm related with the thickness of the material and refractive index
- Thickness
- Impurities
- Defects

1x1cm², 7min at 10x objective
Roadmap
Graphenea CVD production capacity roadmap

<table>
<thead>
<tr>
<th>Phase</th>
<th>2010-2012</th>
<th>2013-2014</th>
<th>2015-2016</th>
<th>2018-...</th>
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<tbody>
<tr>
<td><strong>PHASE 0</strong></td>
<td>1 cm x 1 cm/2 hour</td>
<td><strong>PHASE 1</strong></td>
<td>4” wafer/ 2 hour</td>
<td><strong>PHASE 2</strong></td>
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<td><strong>310 €/cm²</strong></td>
<td><strong>5 €/cm²</strong></td>
<td><strong>0.80 €/cm²</strong></td>
<td><strong>0.25 €/cm²</strong></td>
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**Notes:**
- **AUTO TRANSFER**
- **RESEARCH**
- **DEVELOPMENT**
- **COMMERCIAL**