GRAPHENE IN SPAIN

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ICMM-CSIC
Outline

• Actors and Resources available
• On-going activity
  – Fundamental Research
    • Theory
    • Experimental & Applied
  – Industrial activity
• Future
Main Actors

• CSIC: Spanish Council for Scientific Research
  – 9 Institutes

• Universities
  – 10 Institutions

• Other Public R&D Laboratories
  – Regions: Madrid (2 IMDEA Institutes), Barcelona
    ICREA (ICFO,CIN2,ICN), San Sebastian (NanoGUNE),
    Zaragoza (INA), Asturias (ICO)

• Industrial labs
Resources

Funding sources active in graphene in Spain:

- National Agency: Ministry of Science and Innovation
- Regions: Cataluña, Basque Country, Madrid, Aragón
- EU Calls
- Institutions: CSIC, Universities
- Industrial partners
- Joint-ventures
Funding via National Plan for RD&I

• Current Plan: 2008-2011, Ministry as Funding Agency

• “Bottom-up” approximation + Excellence criteria: Peer review.

• Established (+20 years) Calls for Competitive funding for:
  ▪ 3-year Research Projects: funding for individual and co-ordinated groups
  ▪ 1-2 year Supporting Actions (networks, conferences, strategic issues)
  ▪ 5-year CONSOLIDER Projects (average 5 M€/5-year): large scale coordination

• Supplemented by:
  – Large Installations (ESRF&ILL)
  – International Cooperation :ERANets, NSF, Japan, Brazil, Portugal (Braga).

<table>
<thead>
<tr>
<th>Thematic Area</th>
<th>Average funding (k€/FTE/3-year)</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>12.0</td>
<td>70 %</td>
</tr>
<tr>
<td>Material Sciences</td>
<td>11.5</td>
<td>65 %</td>
</tr>
<tr>
<td>Chemistry</td>
<td>12.5</td>
<td>75 %</td>
</tr>
</tbody>
</table>
Graphene in the National Plan for RD&I

• Figures from MICINN for 3-year cycle 2008-2010

• 61 Research Projects funded with at least one objective related to graphene, total funding: 7.8 M€:
  – Physics: 18 (32% of funds)
  – Material Sciences: 31 (57%)
  – Chemistry: 8 (11%)
  – International Cooperation: 4

• 2 CONSOLIDER Projects active in Graphene
Theory groups

- ICMM-CSIC (Madrid):
  - F. Guinea, M. A. H. Vozmediano, L. Brey
  - Transport, Structure, Mesoscopics
- CIN2/CSIC (Barcelona):
  - P. Ordejón, R. Rurali
  - Transport, Defects, Large scale simulations
- UAM (Madrid):
  - J. J. Palacios, T. Stauber, G. Gómez-Santos
  - Magnetism, Mesoscopics
- DIPC, EHU (San Sebastián):
  - P. M. Echenique, A. Rubio, A. Ayuela
  - Large scale simulations, Chemistry
- UCM (Madrid):
  - F. Sols
  - Mesoscopics
- UA (Alicante):
  - J. Fernández-Rossier
  - Magnetism, Mesoscopics
- UAB (Barcelona):
  - David Jimenez, Xavier Cartoixa
  - Device simulation (RF), Nanomechanics, spintronics
- UPC (Barcelona):
  - A. Cabello, Josep Sole
  - Telecommunication Applications, Simulation
- ICN (Barcelona):
  - A. Bachtold, S. Roche
  - Transport, Disorder, simulations
Experimental groups

- ICN, Barcelona: A. Bachtold, Valenzuela Spintronics, Transport,
- ICFO, Barcelona: F. Koppen, V. Pruneri, Photonics
- CSIC/UCM, Madrid: J. Santamaría, M. Garcia-Hernandez, Spintronics
- IMDEA, Madrid: Surface science & Nanotech.: Rodolfo Miranda
- CSIC, INA, Zaragoza: R. Ybarra, J. M. de Teresa: Spintronics
- USAL, Salamanca: E Diez Transport, Wet Chemistry,
- UCM, Madrid: J. Gonzalez-Calbet, Solid State Chemistry: Laminar systems
- NanoGUNE, San Sebastián: Graphenea
- UCM, Madrid: M. Vallet Regí, Biomaterials
- UPM, Madrid: Nanotech.
- Inst. Carboquímica, Zaragoza: W. Maser
- Instituto del Carbón, Oviedo: R. Menéndez
- U. Alicante, Martín-Gullon: Chemical Synthesis & Scaling processes Graph
- UPC, TEC Group
- Universidad de La Rioja: Chemistry, Avanzare
- CSIC/CNM Barcelona: P Godignon, F Perez Synthesis and Devices
- ICN, Barcelona, A. Bachtold: NEMS, Spintronics, SEM, Chemistry
Outcome: Graphene Figures

Graphene papers and citations with at least one author in Spain:

- Published Items in Each Year
- Citations in Each Year
- Published Items in Each Year (EU)
Graphene research in Spain: a first analysis

Large gap between Theory and Experimental Groups

Publications and Citations ("graphene" & "Spain")

- Experimental
- Theory
Industry

- FIRST European exporter of graphene (Asia Market)
- Mechanical and thermal properties, polymer composites
- Electrical properties, polymer composites

Presently: 500Kg/year
Target 2012: 300 Kg/day
Fund injection: 12 MEuro (2011)

Technical Characteristics

<table>
<thead>
<tr>
<th>Index</th>
<th>No.</th>
<th>avan-nanographene</th>
<th>avan-nanographene/SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle morphology</td>
<td>plates</td>
<td>nanocomposite</td>
<td></td>
</tr>
<tr>
<td>Content ≥</td>
<td>98.5%</td>
<td>98.5% (SiO₂; C)</td>
<td></td>
</tr>
<tr>
<td>Particle size (observed by TEM and SEM)</td>
<td>1-1.5 microns and 20nm in thickness</td>
<td>60 nm // 1-1.5 microns and 20nm in thickness</td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>20,000 S/cm (plane)</td>
<td>≤800 S/cm</td>
<td></td>
</tr>
<tr>
<td>Density g/cm³</td>
<td>2.25</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>
**Industry**

(supplying grams/week end 2011)

www.GRANPHNANOTECH.com

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**GRA\text{n}PH**

High crystalline faceted single-layer graphene nanoplatelets

**Products**

Different GRA\text{n}PH grades available:

- GRA\text{n}PH oxide solution (on-line purchase):
  - Water
  - Acetone
  - Tetrahydrofuran
  - Isopropanol
  - Ethanol
  - Other polar solvents (under request)

- GRA\text{n}PH oxide chemically reduced (under request)
- GRA\text{n}PH oxide thermally reduced (under request)

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<table>
<thead>
<tr>
<th>Property</th>
<th>GRA\text{n}PH oxide</th>
<th>Reduced GRA\text{n}PH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raman, D/G Ratio</td>
<td>1.27</td>
<td>1.30</td>
</tr>
<tr>
<td>XPS, C/O Ratio</td>
<td>1.5</td>
<td>2.1</td>
</tr>
<tr>
<td>XPS, C=C (%)</td>
<td>45</td>
<td>73</td>
</tr>
<tr>
<td>XPS, C-O and epoxy (%)</td>
<td>32</td>
<td>24</td>
</tr>
<tr>
<td>XPS, C=O (%)</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>XPS, COOH (%)</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>TEM, Average length (µm)</td>
<td>-0.5-5</td>
<td>-0.5-5</td>
</tr>
<tr>
<td>Solution type</td>
<td>Aqueous/organic polar solvent</td>
<td>-</td>
</tr>
<tr>
<td>GRA\text{n}PH concentration (g/l)</td>
<td>0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

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**ANTOLIN GROUP:**

Global automotive supplier (modular solutions for interiors)

87 plants in 22 countries

Sales (2009): 1700 M€
• Start up 2010: Silicon wafers (CVD)
• Expectations: Larger production, lowering cost; Incorporate exfoliation (Physical and Chemical)
• 3 M€ investment (Joint venture capital) + Access to a 40M€ lab [NanoGUNE]
• 2 EU projects as partners & 2 National
• Interests: Graphene suppliers to Research Laboratory + Energy sector industries
Looking ahead

- **GRAPHeNE**
  - Nationwide network
  - To coach links:
    - Academics (Theory & Experiment)
    - Academics & Industrial Partners & Investors
  - To Report on progress to G-community & EU Initiatives.
  - Feedback on EU initiatives to GRAPHeNE community.
  - Coordinate Spanish actors to contribute to EU initiatives:
    - Graphene flagship & FP8 (2011)
  - Dissemination:
    - Non-graphene Researchers (new applications)
    - Education (High schools) & Broad Audience
  - To become a representative and reliable partner of the graphene research community vis-a-vis the Spanish Science Policy bodies
  - Increase visibility (Graphene, G-community, G-opportunities)
Roadmap

- Application for funding: MICCIN Supporting action, Nov 2010
- Already Working on Graphene Register: Researchers, Facilities, Industrial partners, Papers, Patents
- Exploratory meeting with Graphene CA representatives (March 2011)
- Kick-off meeting: May 2011
- Web platform (CSIC powered) (May-June 2011).
- Coordinate activities of Spanish community timely to contribute to Flagship CA & FP8 (Meeting agenda WP3-WP4-WP5)
- Outreach activities (ongoing: Radio, TV, major journals)
- Explore other mass media (June-July 2011)
- Contact with secondary education actors (ongoing)
- Contact with Women in Science groups (May 2011)