Korean Graphene Research Activities and Roadmap

April 10, 2012

Byung Hee Hong

Seoul National University
Recently, Korean government has approved a plan for commercializing graphene technologies, including:

1) graphene-based touch panels
2) organic light-emitting diodes (OLEDs)
3) electro-chromic smart windows
4) secondary batteries for electronic vehicles
5) high-voltage high-power supercapacitors
6) ultra-light and strong composites
7) high-performance gas barrier films,
8) electro-magnetic interference shielding, and
9) environmentally friendly anti-oxidation steel plates.

These items have been carefully selected considering economic efficiency and technological feasibility. In addition, Korea is also planning a “Korean Graphene Hub” project that is focusing on the fundamental sciences of graphene and related 2D materials, separately.

In this talk, the brief history, recent status, and prospect of Korea’s graphene projects will be introduced, and discuss how we can harmonize the world-wide graphene projects based on international collaboration rather than competition.
Contents

1. Introduction

2. Korean Graphene Research Society (KGRS)

3. Korean Greaphene Research Hub

4. Greaphene Materials and Components Commercialization Project

5. Summary and Prospect
Introduction

- Korean Graphene Research Society
- Number of Research Papers/Patents
- Governmental Research Budgets
- University-Related Research Activities
- Sep. 1, 2008, **First Korean Graphene Meeting** hosted by Prof. B. J. Cho at KAIST
- Jun. 29-Jul. 2, 2009 **1st Recent Progress in Graphene Research (RPGR)** held at KIAS, organized by **Y. W. Son** and **A. Castro Neto et al.**
- Aug. 2-6, 2010, During 2nd RPGR, Korean graphene researchers planned monthly meetings at SKKU.
- Sep. 30, 2010, Seminar by H. Cheong (Sogang U.)
- Oct. 28, 2010, Seminar by H. S. Shin (UNIST)
- Nov. 25, 2010, Seminar by B. J. Cho (KAIST)
- Dec. 9, 2010, Seminar by I. Oh (KAIST) …

**Conference organized by KGRS**
- Nov. 10-12, Dasan Conference on Graphene, Jeju
- Jan. 21, 2011, 1st KGRS Meeting, UNIST
- Apr. 1, 2011, 2nd KGRS Meeting, KAIST
- Jun. 28, 2011, 3rd KGRS Meeting, POSTECH
- Apr. 8, 2011, National Assembly Forum on Graphene
- Oct. 3-6, 2011, **3rd RPGR, SKKU, Suwon**
Korean Graphene Research Society (KGRS)

http://www.graphene.or.kr

Steering Committee

H.-J. Lee (Chair, POSTECH)
K. Cho (POSTECH)
H. Cheong (Sogang U.)
Byung Jin Cho (KAIST)
S. Y. Choi (KAIST)
S. Hong (Sejong U.)
B. Kim (Dongjin Semichem)

Secretary

B. H. Hong (SNU)
H. S. Shin (UNIST)
S. W. Jeon (KAIST)
T. Lee (POSTECH)
S. Seo (Sejong U.)
H. J. Chung (SAIT)
Y. W. Son (KIAS)

Organization Meeting of KGRS
April 1st, 2011, KAIST
대한민국 그래핀 육성 방안 토론회
2011년 4월 6일 (금) 오전 9:30 / 국회의원회관 소회의실

발표자
노선영 교수 (세계대학 행사, 2004 노벨상, 이사, 그래핀 연구에 업계) 노현주 교수 (대한형국, MD, 사상, 기업, 그래핀 연구에 업계) 노현주 교수 (대한형국, MD, 사상, 기업, 그래핀 연구에 업계)

로고

Apr 8, 2011
National Assembly Building, Seoul
Oct. 3-6, 2011, SKKU, Suwon
Oct. 3-6, 2011, SKKU, Suwon
## Research Highlights from Korea

### Synthesis & Patterning
- **Sejong Univ.**: MBE method
- **SKKU**: Large-area graphene by CVD
- **Samsung Electronics**: Catalyst-free PECVD
- **SKKU**: Room-temperature reduction of graphene oxide
- **POSTECH**: Graphene synthesis using solid sources
- **KAIST**: Nanopatterning via block copolymer lithography
- **UNIST**: Chemical exfoliation using edge functionalization

### Property Characterization
- **POSTECH**: Quantum Hall effect and nanoribbon characterization
- **Univ. of Seoul**: THz characteristics
- **SKKU**: Chemical Doping
- **Sogang Univ.**: Polarized Raman spectroscopy
- **Kunkuk Univ.**: Friction anisotropy in graphene domain structures
- **Sejong Univ.**: Nitrogen doping and defect structure analysis
- **KAIST**: TEM imaging of liquid samples using graphene membranes

### Theoretical Works
- **KIAS**: Electronic structure of graphene on SiC and Strain effect
- **POSTECH**: Giant magnetoresistance near defects in graphene
- **POSTECH**: DNA sequencing device using graphene nanoribbon
- **KIAS**: Work function of bilayer graphene under mechanical strain
- **KAIST**: Doping effect of graphene on dielectric

### Device Applications
- **SKKU**: Transparent electrodes for solar cells and display
- **GIST**: Electrodes for solar cells, fuel cell, and molecular devices
- **KAIST**: Field emission from graphene-CNT hybrid material
- **SNU**: Graphene substrate for LED
- **KAIST/ETRI**: Nonvolatile flexible memory using graphene oxide
- **KAIST**: Supercapacitor using doped graphene
- **KAIST**: 20 nm flash memory using graphene
Korean Graphene Research Activities

Number of Graphene-Related Papers Published in 2000~2010

Analysis by L. Colombo
Number of Graphene-Related Papers Published in 2011

Korean Graphene Research Activities

“Report on Korean Graphene Hub (2011) by KGRS”
### Governmental Research Budget in Korea (2007~2010)

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<th>Institution</th>
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<th>2009</th>
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“Report on Korean Graphene Hub (2011) by KGRS”

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<td>14.4</td>
<td>68.8</td>
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"Report on Korean Graphene Hub (2011) by KGRS"
University-related research activities in Korea

Table 1: Top 10 ranking of university-related inventors by number of patents

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name</th>
<th>Number of patents</th>
<th>Organizational affiliations in inventor's graphene patents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jae-young Choi</td>
<td>62</td>
<td>Korea Institute of Science and Technology; Samsung; Sungkyunkwan University</td>
</tr>
<tr>
<td>2</td>
<td>Hyeon-jin Shin</td>
<td>43</td>
<td>Samsung; Sungkyunkwan University</td>
</tr>
<tr>
<td>3</td>
<td>Seon-ma Yoon</td>
<td>39</td>
<td>Samsung; Sungkyunkwan University</td>
</tr>
<tr>
<td>4</td>
<td>Ilhan A. Aksay</td>
<td>35</td>
<td>Battelle Memorial Institute; Princeton University; Vorbeck Materials Corporation</td>
</tr>
<tr>
<td>5</td>
<td>Hyun-jong Chung</td>
<td>34</td>
<td>Samsung; Seoul National University; Sungkyunkwan University</td>
</tr>
<tr>
<td>6</td>
<td>Sun-ae Seo</td>
<td>33</td>
<td>Sungkyunkwan University; Leiden Stanford University</td>
</tr>
<tr>
<td>7</td>
<td>Byung Hae Hong</td>
<td>28</td>
<td>Samsung; Sungkyunkwan University</td>
</tr>
<tr>
<td>8</td>
<td>Yun-sung Woo</td>
<td>21</td>
<td>Samsung; Seoul National University; Sungkyunkwan University</td>
</tr>
<tr>
<td>9</td>
<td>Robert K. Prudhomme</td>
<td>21</td>
<td>Princeton University; Vorbeck Materials Corporation</td>
</tr>
<tr>
<td>10</td>
<td>Rodney S. Ruoff</td>
<td>20</td>
<td>Graphene Energy; Northwestern University; Texas Instruments; University of Texas</td>
</tr>
<tr>
<td>11</td>
<td>James M. Tour</td>
<td>20</td>
<td>University of Texas; William Marsh Rice University</td>
</tr>
<tr>
<td>12</td>
<td>John S. Lettow</td>
<td>18</td>
<td>Princeton University; Vorbeck Materials Corporation</td>
</tr>
</tbody>
</table>

Nature Mat. 11 (2012)
1. Introduction:

Korean Graphene Research Activities

University-Company Cooperative Research Activities in Korea

Nature Mat. 11 (2012)
Nature Outlook Special Issue on Graphene

**GROWING GRAPHENE FILMS**

Researchers make large (centimetre-scale) graphene films by depositing carbon atoms from a vapour onto a copper surface. Roll-to-roll processing then transfers the graphene film from copper to another substrate.

Copper foil is heated to 800-1000°C in a furnace, where hydrogen (H₂) and methane gas (CH₄) are piped through. Carbon atoms grow as graphene film on top of the copper.

Adhesive 'thermal release' tape is attached on top of the graphene, by applying pressure between heavy rollers.

The copper is eaten away in a plastic bath filled with etchant (such as ammonium persulfate, a bleaching agent and oxidant).

On heating to 90-120°C, the adhesive tape unsticks, leaving the graphene clinging to a target substrate.

*Nature* 483 S29-42 (15 March 2012)
Korean Graphene Research Hub
by Ministry of Edu. Sci. & Tech.

- Background
- Purpose
- Organization
- Budget
Backgrounds

- There is a nation-wide criticism that Korea has been too much focus on near-term application and commercialization.

- Korea is one of the countries paying the most royalties for the use of fundamental technologies. (ex. CDMA technology by Qualcomm, 6 billion USD a year).

- Korea is No. 1 in display industry, but 90% of transparent electrodes are imported from Japan.

- The competitiveness of final set products are strong, but fundamental technologies for materials and components are very weak.
Purpose

• To support individual researchers by providing the most advanced research facilities dedicated to graphene and related 2D materials researches.

• To minimize duplicated investment and internal competitions.

• Fair distribution of governmental research budgets

• To educate general people to understand the importance of graphene researches

• To promote the international and company-university collaborations.
Demand Analysis & Planning Project by KGRS (2011)

- Option 1. **Independent Governmental Institute** (200~300 mil USD/year)
  - Takes long time for legalization process
  - Good for many researchers

- Option 2. (A branch of) **Institute of Basic Science** (~100 mil USD/year)
  - Budget has been already secured at least for 10 years.
  - Director-oriented program (~ Max-Plank Institute).
  - Good for only 4~5 PIs

- Option 3. **Central Fab. Facility & Funding controlled by KGRS**
  - Limited budget
  - Duplication with existing Fabs.
Organization

National Graphene Institute

Facility Support
- Public Facilities
- Specialized Facilities

Research Budget Control
- Plan and Search Selection & Evaluation

Education Collaboration
Examples

Specialized Facility

Finding and Supporting New Research Topics

Biological Applications of Graphene
Research Areas

2D Single Crystals

Theory group
- Atomic structure & phase change
- Electron-magnetic structure simulation
- Low dimensional quantum ordering

Characterization group
- Spectroscopic/Optical characterization
- Device physics
- Atomic Imaging

Synthesis group
- CVD growth
- Chemical synthesis & functionalization

Application group
- Electronic Devices
- Energy Storage
- Smart Composite Materials
# Research Budget (mil USD)

<table>
<thead>
<tr>
<th>Category</th>
<th>Years</th>
<th>1st Stage</th>
<th>2nd</th>
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<td>2013</td>
<td>2014</td>
<td>2015</td>
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<td>18</td>
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<td>25.2</td>
<td>53.5</td>
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</table>
Graphene Materials and Components Commercialization Project
by Ministry of Knowledge and Economy
Backgrounds

• Many companies are interested in graphene materials, but suffering from the lack of information.

• More and more graphene researches are moving toward applications. However, they don’t exactly know the demand and the technological details to be used in real applications.

• Even big companies don’t want to take the initial risks of investing on graphene materials.
Purpose

- To promote the collaboration between big, medium sized companies and university/institution researchers.

- To minimize duplicated investment and internal competitions.

- Government takes the risk of initial investment, and draws more investments from non-governmental institutes and companies.
# Mass production

<table>
<thead>
<tr>
<th>Company</th>
<th>Items</th>
<th>Status</th>
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<tr>
<td>Samsung Techwin</td>
<td>Large-are CVD Graphene</td>
<td>2nd generation pilot plant to be completed in 2012</td>
</tr>
<tr>
<td>POSCO, Hanwha Chemial</td>
<td>Graphene Nanoplatelets For energy electrodes and composites</td>
<td>Co-investment with XG Science 200 tons / year in 2014</td>
</tr>
<tr>
<td>Envirotech.</td>
<td>Graphene Nanoplatelets For energy electrodes and composites</td>
<td>1 Kg/day 70 tons / year in 2014</td>
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<tr>
<td>SSCP</td>
<td>Graphene Nanoplatelets For Heat Dissipation</td>
<td>300 tons /year</td>
</tr>
</tbody>
</table>
Recent R&D Status

Tech/Market Portfolio

Biz Opportunity

Revenue ($B)

Technology Realization (Prediction)

TCF: Transparent Conductive Film

mass production
mass production

1st generation pilot line of Samsung Techwin
Recent R&D progress for mass production

Investment to XG Science
POSCO & Hanwha Chemical

Pilot plant, Envirotech.
3. Commercialization Projects (2011)

Gas barriers For displays packaging
Conductive Ink EMI
Nano-inks
CVD Graphene & Graphene Nanoplatelets
Transparent electrodes
Bars
Heat Dissipation
Energy Electrodes
Ultra-light Strong composite
LED lighting ECU units
Cars Aerospace
High-speed Transistors RFIC, Sensor
Solar-Secondary-Fuel cells Supercap.
Flexible Display Touch Screen
Next Generation Semiconductors
3. Commercialization Projects (2011)

- Technical Feasibility
- Time to commercialize
- Revenue
<table>
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<th>Category</th>
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Budget: 200 mil USD for 6 years (Gov. 83.4 mil USD, Non-Gov. Matching 127. USD)

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<th>‘16</th>
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Planning Started

Preliminary Budget Report Submitted

MKE/OSP, Experts workshops, Retrial agreed

Demand analysis from companies and researchers

Preliminary Budget Report Submitted

5th Task Force Meeting

Final report submitted

Technological Evaluation

Technological Review Passed

2010
DEC  Mar  Oct  Oct  Nov  Dec  Dec  Dec  Feb  Mar

2011

2012

2010
DEC  Mar  Oct  Oct  Nov  Dec  Dec  Dec  Feb  Mar

2011

2012

Fail to pass the budget review
Special Thanks To Dr. Soon Hyung Hong, Managing Director of Office of Strategic R&D Planning (OSP) Ministry of Knowledge Economy (MKE) & KGRS Members

Acknowledgements

Industrial Collaborators
- Samsung Techwin, Electronics, Mobile Display, LED
- SK energy, Substrate Films
- POSCO, Composites
- LS Cable
- LG, Wire Applications, Energy Applications