The Pioneer of

# CVD Graphene Commercialization

www.graphenesq.com

GRAPHENE SQUARE

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Graphene Square, Inc. is a pioneer in the commercialization of graphene material and graphene films for use as a transparent conductor and in other electronics applications. Established in 2012 as a spin-off of the research of Prof. Byung Hee Hong at Seoul National University and with headquarters in Seoul, Korea.

Our mission is to be the world's first company commercializing CVD graphene technology and No.1 cost-competitive & best-quality graphene film supplier in both rigid and flexible electronic markets.

## Business Areas

**CVD Synthesis Systems**

For researchers who want to synthesize their own graphene or 2D materials, Graphene Square markets a low-cost thermal CVD system that allows the users to easily begin synthesizing their own large-area, high-quality graphene and 2D materials samples in a lab environment. Graphene Square also provides training programs covering the current best practices for graphene growth, etching, patterning, and transfer. Other custom CVD systems are available for the synthesis of various 2D materials such as MoS2, WSe2, h-BN, etc.

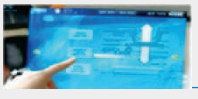
**Graphene Samples & Fab. Services**

Using state-of-the-art chemical vapor deposition (CVD) methods developed in-house, Graphene Square offers the highest quality graphene samples currently on the market. In addition to the standard samples available online, Graphene Square can provide various fab. services including the sample transfer on the customers' own substrates as well as end-equipment prototype devices. Graphene Square also supplies graphene oxides (GOs) and graphene quantum dots (GQDs) for various biological, display, and energy researches.

**IP Licensing & Consultant**

Graphene Square provides general consulting services and also licenses technology from its extensive patent portfolio, which has been recently highlighted by *Bloomberg* and *Businessweek*. Areas covered include: industrial graphene synthesis, transfer, and patterning using roll-to-roll techniques and their applications to current consumer electronic products as well as future applications including flexible and wearable electronics.

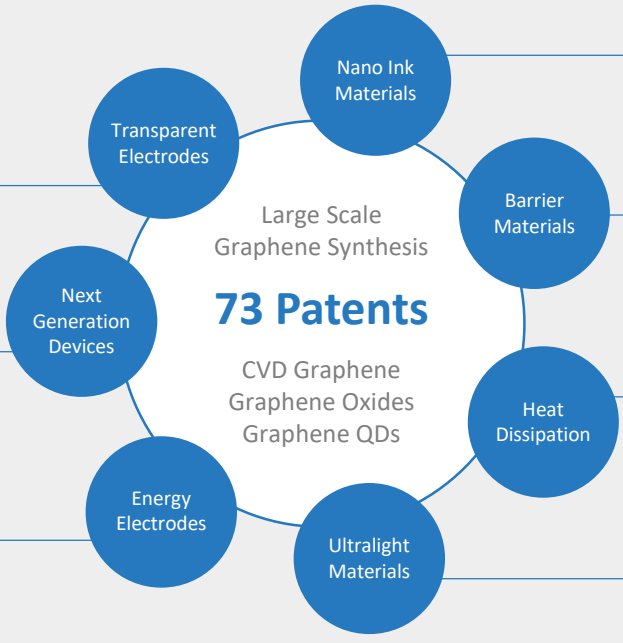
## GSI's Patent Portfolio



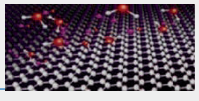
15 Patent Flexible Displays
Touch Sensors

3 Patent Ultrahigh Speed
Transistors/
Photosensors RFID

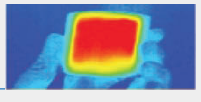
13 Patent Solar Cells
Secondary Battery
Fuel Cells
Super Capacitors




3 Patent Flexible Displays
Touch Sensors

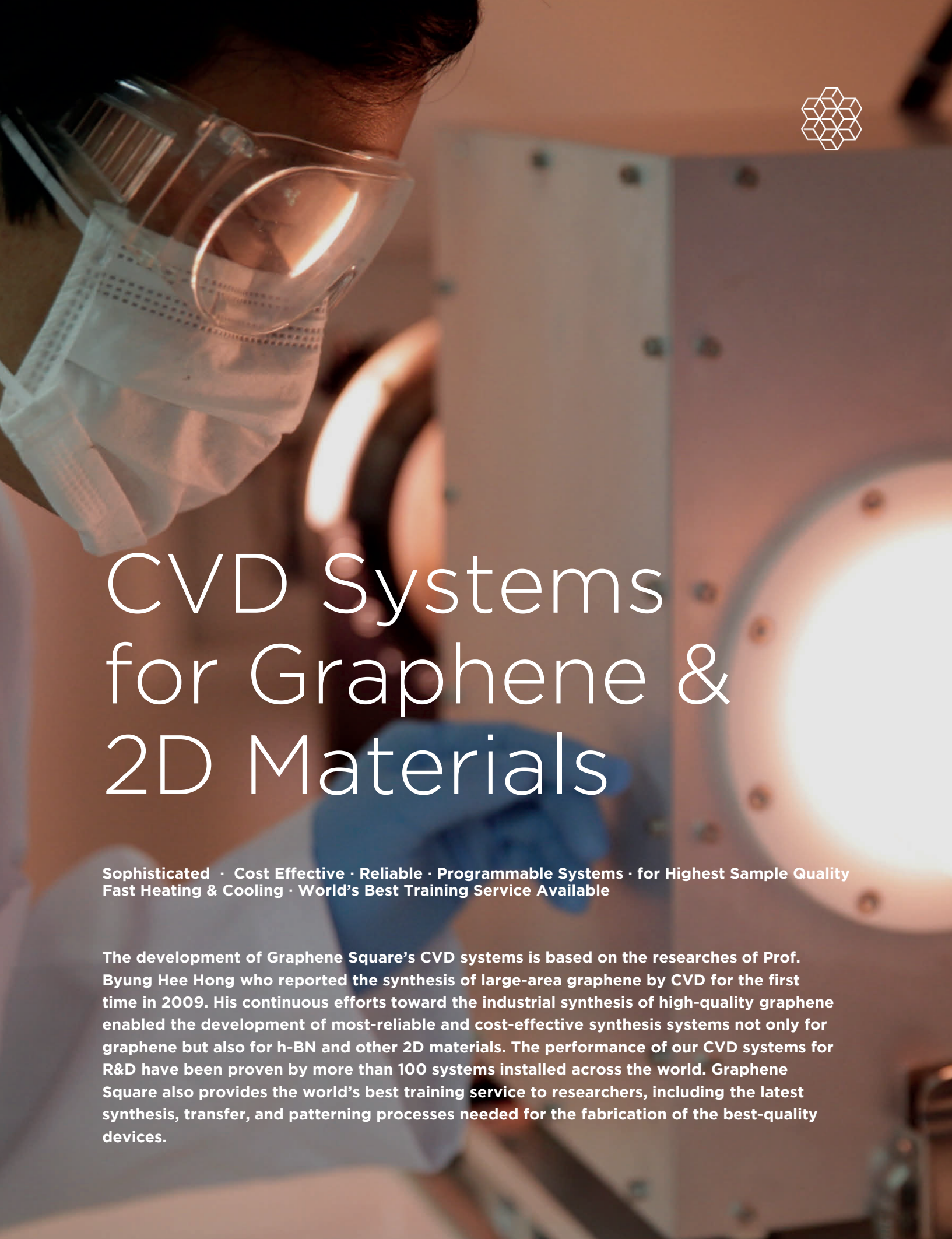


2 Patent Display Solar Cell
Anti-Oxidation
Heat Insulation



2 Patent LEDs, BLUs
ECUs &
PC Electronic

2 Patent Automobile &
Aerospace
Applications



# CVD Systems for Graphene & 2D Materials

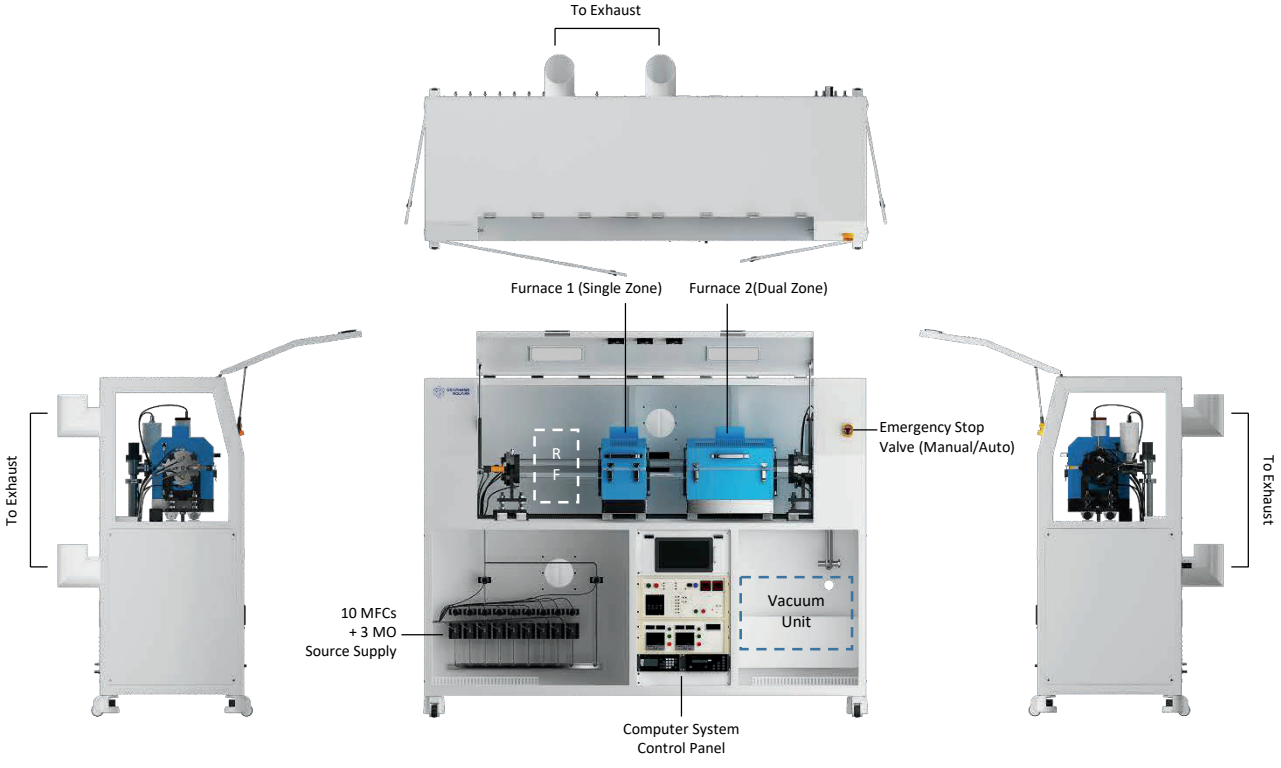
**Sophisticated · Cost Effective · Reliable · Programmable Systems · for Highest Sample Quality**
**Fast Heating & Cooling · World's Best Training Service Available**

**The development of Graphene Square's CVD systems is based on the researches of Prof. Byung Hee Hong who reported the synthesis of large-area graphene by CVD for the first time in 2009. His continuous efforts toward the industrial synthesis of high-quality graphene enabled the development of most-reliable and cost-effective synthesis systems not only for graphene but also for h-BN and other 2D materials. The performance of our CVD systems for R&D have been proven by more than 100 systems installed across the world. Graphene Square also provides the world's best training service to researchers, including the latest synthesis, transfer, and patterning processes needed for the fabrication of the best-quality devices.**

# TCVD-RF100CA

## Premium Custom-Designed System for TMDC & h-BN

Chemical vapor deposition (CVD) system for the syntheses of 2D materials at scales from a chip to a wafer, including the synthesis of **graphene, h-BN, TMDCs** on various substrates by use of gas-phase or solid precursors and metal-organic (MO) sources.




## Features

- Size (mm): 2300(W) x 1770(H) x 750(D)
- Up to 10 gases and 3 MO sources for gas-phase synthesis.
- Motor-controlled movable heater for fast heating and cooling (patented).
- Fully computer-controlled programmable recipes.
- TCVD100 platform: Proven performance for ~100 systems for more than 5 years.
- Invited training for full sample preparation processes.

## Customers / Demo Sites

Seoul National University
Graphene Research Center

ETH zürich IBM

IBM Zürich Nanotech Center

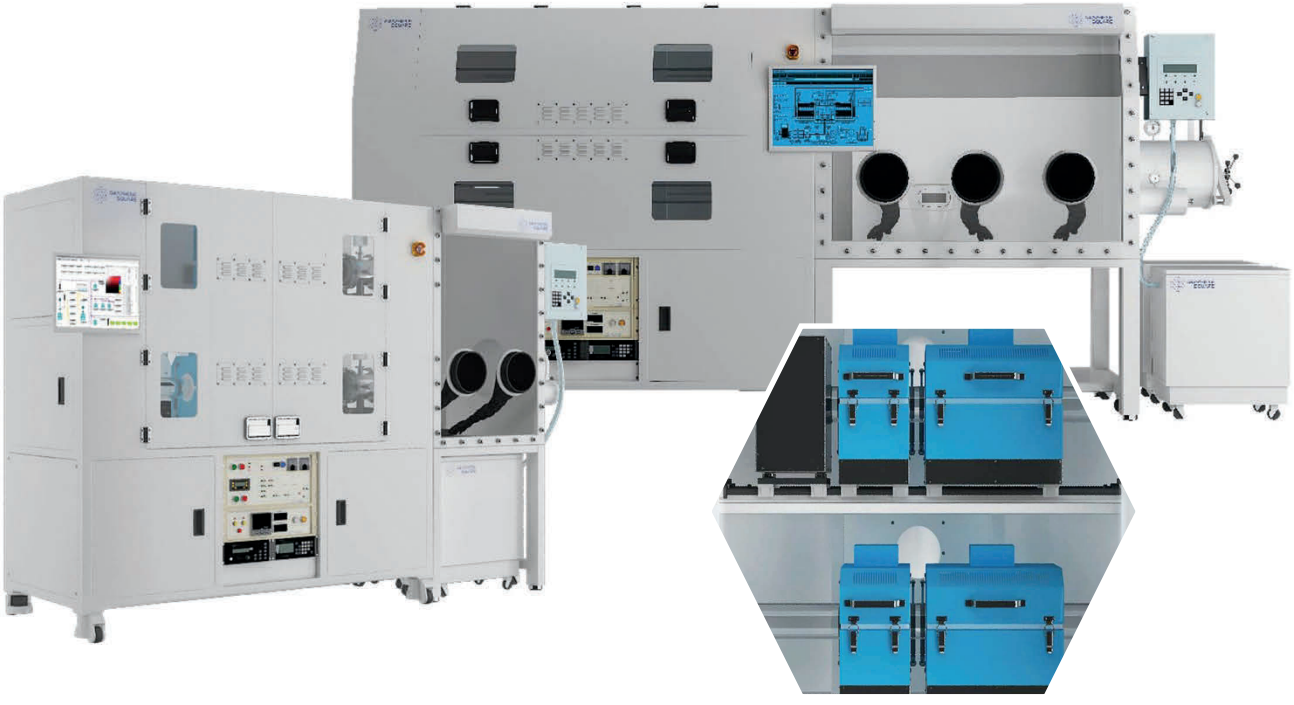
## Technical Specification

| | |
|---|---|
| CVD Reactor | • Tube type 4 inch diameter quartz |
| Substrate Size | • Lateral insertion of 10 mm to < 4 inch wafers possible. (Loading frames for small samples)<br>• Rolled metallic foils can be loaded to synthesize A4 sized or larger 2D materials. |
| Heating | • Dual-zone heater and controller for graphene/h-BN synthesis. Single-zone precursor heater and Dual-zone deposition heater for TMDC synthesis.<br>• The heaters are movable along two rails and the distance can be motor-controlled, enabling 10ºC/sec or faster temperature change rate. |
| Base Pressure | • $10^{-5}$ mbar (depending on the dryness of source) |
| Operating Pressure | • $10^{-3}$ mbar – 1 bar |
| Precursor | • Max 10 gas lines (ex. $CH_4$, $C_2H_4$, $NH_3$, $B_2H_6$, Ar, $H_2$, $H_2S$, $H_2Se$, $N_2$, $O_2$) + 2 extra ports.<br>• Metal oxide sources of various transition metals placed in Heat Zone 1 for solid source growth. |
| Other metal organic (MO) sources | • Extra 3 Metal-Organic Source Injection Ports are included. (ex Mo(CO)6, Fe(CO)5)<br>• Low-T cold trap for residual sources. |
| Flow control | • Precursor gases: 0.1 – 10 sccm<br>• Other gases: 10 – 1000 sccm<br>• Automatic flow control. |
| Vacuum | • Turbo pump 450 l/s (ISO160) < $10^{-6}$ mbar.<br>• Dry scroll pump < $10^{-1}$ mbar.<br>• Main Gate Valve Pneumatic type / Fore-line / roughing Angle Valve / Foamed bellows<br>• By-pass pumping adaptor, clamp & centering. |
| T-measurement | • Standard Thermocouple (NIR calibrated) |
| Sample switching | • Position switching by sample loading stage. |
| System Control | • Control PC system (12" touch, dual core)<br>• Serial Network module (4-ch)<br>• Remote IO module (RS485)<br>• System base programming / System recipe control module / System date file save module<br>• Software upgrade support.<br>• Gas valve, angle valve Open/Close / Rotary pump On/Off switch / Main power On/Off switch<br>• Cooling water & air pressure switch. |

# TCVD-DC100CA

## Premium Custom  Design Dual CVD System with a Glove Box

Chemical vapor deposition (CVD) system for the syntheses of 2D materials at scales from a chip to a wafer, including the synthesis of **graphene, h-BN, TMDCs** on various substrates by use of gas-phase or solid precursors and metal-organic (MO) sources. The synthesized samples can be transferred to a glove box filled with inert gases for further processes without exposure to air environment.



## Features

- Size(mm): 3000(W) x 1800(H) x 750(D)
- Up to 10 gases and 3 MO sources for gas-phase synthesis.
- Motor-controlled movable heater for fast heating and cooling (patented).
- Fully computer-controlled programmable recipes.
- TCVD100 platform: Proven performance for ~100 systems for more than 5 years.
- Invited training for full sample preparation processes from synthesis, etching, and transfer.
- Supply of high-quality source materials.
- 1 year warranty included (2 year extended warranty available)
- CVD chambers connected to a Glove Box. Free from air exposure.

## Customers / Demo Sites

Seoul National University
Graphene Research Center

University of North Texas

## Technical Specification

| | |
|---|---|
| CVD Reactor | • Tube type 4 inch diameter quartz |
| Substrate Size | • Lateral insertion of 10 mm to < 4 inch wafers possible. (Loading frames for small samples)<br>• Rolled metallic foils can be loaded to synthesize A4 sized or larger 2D materials. |
| Heating | • Dual-zone heater and controller for graphene/h-BN synthesis. Single-zone precursor heater and Dual-zone deposition heater for TMDC synthesis.<br>• The heaters are movable along two rails and the distance can be motor-controlled, enabling 10ºC/sec or faster temperature change rate. |
| Base Pressure | • $10^{-5}$ mbar (depending on the dryness of source) |
| Operating Pressure | • $10^{-3}$ mbar – 1 bar |
| Precursor | • Max 10 gas lines (ex. $CH_4$, $C_2H_4$, $NH_3$, $B_2H_6$, Ar, $H_2$, $H_2S$, $H_2Se$, $N_2$, $O_2$) + 2 extra ports.<br>• Metal oxide sources of various transition metals placed in Heat Zone 1 for solid source growth. |
| Other metal organic (MO) sources | • Extra 3 Metal-Organic Source Injection Ports are included. (ex Mo(CO)6, Fe(CO)5)<br>• Low-T cold trap for residual sources. |
| Flow control | • Precursor gases: 0.1 – 10 sccm<br>• Other gases: 10 – 1000 sccm<br>• Automatic flow control. |
| Vacuum | • Turbo pump 450 l/s (ISO160) < $10^{-6}$ mbar.<br>• Dry scroll pump < $10^{-1}$ mbar.<br>• Main Gate Valve Pneumatic type / Fore-line / roughing Angle Valve / Foamed bellows<br>• By-pass pumping adaptor, clamp & centering. |
| T-measurement | • Standard Thermocouple (NIR calibrated) |
| Sample switching | • Position switching by sample loading stage. |
| System Control | • Control PC system (12" touch, dual core)<br>• Serial Network module (4-ch)<br>• Remote IO module (RS485)<br>• System base programming / System recipe control module / System date file save module<br>• Software upgrade support.<br>• Gas valve, angle valve Open/Close / Rotary pump On/Off switch / Main power On/Off switch<br>• Cooling water & air pressure switch. |

# TCVD-50B

## 2-Inch Table-Top Manual Type Thermal CVD

This small-size equipment has been developed on customers' demand for the lower cost but higher quality synthesis of graphene and 2D materials. TCVD-50B is the most ideal system for researchers who are limited in budget. The versatile specifications from fully manual to semi-automatic systems can be adjusted to fit the customers' budget. We recommend this system for training or laboratory classes, and the detailed instructing program and materials will be provided upon purchase.

## Features

- Size(mm): 1500(W) x 893(H) x 590(D)
- Economic & space-saving model.
- Optimized for graphene, CNT, h-BN and TMDC growth.
- Water-cooled end chambers and doors.
- Process Temperature: ~1,100℃
- Protective design from heat
- Uniformity of Film Thickness: ≤+-3%
- Testing Uniformity: ≤+-3%
- Movable furnace method is our unique knowhow for fast heating and fast cooling of the sample

## Customization

**Furnace**

- Single – 2 Heating Zones (Standard)
- Dual – 3 Heating Zones
- Single + RF M/W Module

**Chamber Size**

- 2 inch (Standard)
- 4 inch

**Pumping Unit**

- Oil Type Rotary Pump (Standard)
- Dry Scroll Pump
- Additional: Mechanical Turbo Pump

**Gas Control Unit**

- 3 MFCs +1 Spare (Standard)
- Up to 5 MFCs

**Warranty**

- 1 year – Included (Standard)
- 2 years – Optional

# TCVD-100A

## Standard 4-Inch Thermal CVD System with a Safety Cabinet

TCVD-100A is a very sophisticated and cost effective CVD system that can be equipped with semi-automatic or fully programmable gas-flow and temperature control modules. It is the most ideal equipment for the synthesis of high quality graphene and h-BNs, which can be easily extended to various 2D materials synthesis. The safety cabinet that covers the whole system protects users from any hazardous event, and the emergency stop button will ensure the safety even further.

## Features

- Size(mm): 1750(W) x 1585(H) x 750(D)
- Advanced Semi-Auto System
- Optimized for graphene, CNT, h-BN and TMDC growth
- Water-cooled end chambers and doors
- Process Temperature: ~1,100℃
- Uniformity of Film Thickness: ≤+-3%
- Testing Uniformity: ≤+-3%
- Movable furnace method is our unique knowhow for fast heating and fast cooling of the sample
- Standard safety box

## Customization

**Furnace**

- Single – 2 Heating Zones (Standard)
- Dual – 3 Heating Zones
- Single + RF M/W Module

**Chamber Size**

- 2 inch
- 4 inch (Standard)
- 6 inch
- 8 inch

**Pumping Unit**

- Oil Type Rotary Pump (Standard)
- Dry Scroll Pump
- Additional: Mechanical Turbo Pump

**Gas Control Unit**

- 3 MFCs +1 Spare (Standard)
- Up to 8 MFCs

**Warranty**

- 1 year – Included (Standard)
- 2 years – Optional

## Customers

World-wide customers in US, EU, Middle East, and Asia countries.

| | Graphene | h-BN | TMDC |
|---|---|---|---|
| # sales | ~100 systems | 8 systems | 10 systems |
| Clients | | | |

Proven performance in more than 100 systems installed in Korea.

# TCVD-D100CA

## 4-Inch Automatic Dual-Furnace CVD System for TMDC Synthesis

TCVD-D100CA is an advanced equipment dedicated to the growth of TMDC materials such as $MoS_2$, $WSe_2$, etc. The computer-aided controlling module promises the reliable growth condition for multiple users. The movable dual furnace system enables the fast heating and fast cooling of source materials and substrates, which is important for the synthesis of higher quality TMDCs. The safety housing with emergency alarm/stop functions will ensure the safe operation by users.

## Features

- Size(mm): 2300(W) x 1770(H) x 750(D)
- Advanced Computer Controlled Automatic System
- Optimized for graphene, CNT, h-BN and TMDC growth
- Water-cooled end chambers and doors
- Process Temperature: ~1,100℃
- Uniformity of Film Thickness: ≤+-3%
- Testing Uniformity: ≤+-3%
- Movable furnace method is our unique knowhow for fast heating and fast cooling of the sample.
- Standard safety box

* Price will be determined after consultation. (Different customization from the standard parts will affect the overall price.)

## Customization

**Furnace**

- Single – 2 Heating Zones
- Dual – 3 Heating Zones (Standard)
- Triple – 4 Heating Zones
- Single or Dual + RF M/W Module

**Chamber Size**

- 2 inch
- 4 inch (Standard)
- 6 inch
- 8 inch

**Pumping Unit**

- Oil Type Rotary Pump (Standard)
- Dry Scroll Pump
- Additional: Mechanical Turbo Pump

**Gas Control Unit**

- 3 MFCs +1 Spare (Standard)
- Up to 10 MFCs

**Warranty**

- 1 year – Included (Standard)
- 2 years – Optional

## Customers

Institute for Basic Science

# Reactive Ion Etcher

RI Etcher's Dry Etching is suitable for patterning since corrosion in the vertical direction can be exceedly suppressed. By using the reactive gas plasma with gases [such as oxygen, nitrogen, CF4] carbon materials such as graphene, CNT or thin film material such as SiO2, Si3N4 can be etched or doped.

## Features

- Size(mm): 1120(W) x 1269(H) x 750 (D)
- CCP / PECVD
- Anisotropic etching characteristics
- Fine machining performance
- Accelerated by the DC BIAS
- W / F and AWLL surface DAMAGE
- Metal contamination, P / T, E / R Low
- Temperature cooling

## Customization

**Chamber Unit**

- Material : Stainless304
- Chamber size : (Optional)
- Top shower head(Switched bias)
- ¼"VCR vent port
- Window port (I.D40mm)
- Material : Hard anodizing Al with ceramic insulator
- 600watt RF power with matching box
- Water cooling
- Max sample size : 6inch
- Option : Up/down / Heating - 400℃

**Gas Control Unit**

- Material : Hard anodizing aluminum with insulator
- ¼"VCR Gas input port

**Pumping Unit**

- MKS NW40 Auto pressure control valve with
- Controller
- 600l/m Rotary pump
- Capacitance gauge (10torr NW16)
- ATM sensor
- Option : High Vacuum unit Turbo pump(magnet type/Full range
- MKS Ar/O2/SF6 Mass flow controller
- On/off Diaphram valve unit
- Option : 2channel addition Gas leak sensor

**Control Unit**

- 15-inch ouch panel control
- System recipe
- Interlock (Water/Pneumatic air)
- Data loading

# E-beam Evaporator

The system is cooled by heat absorption and liquid evaporation and introducing the liquid refrigerant that has passed through expansion valve and decompressed to low temperature and low pressure and exchanges heat with surrounding space or object to be cooled.  Unlike a thermal evaporator, it is a device that deposits an electron beam by using a crucible, so that the deposited film is homogenized compared to a thermal evaporation.

## Features

- Size(mm): 1300(W) x 1637(H) x 930(D)
- Compact, space-saving design
- Rate & thickness control
- Source & substrate shutters
- Multi-source organic evaporation
- Ergonomic to operate, easy to clean
- Compatible with most standard deposition sources
- Configured for your application

## Customization

**Chamber Unit**

- Material : Stainless304 / Aluminum
- Chamber size : 450x450x600
- Front open door with window (shutter)
- ¼”VCR vent port
- Pumping port/gauge/spare port

**Substrate Unit**

- Material : Inconel600 (High temp)
- Water cooling stage : OFHC
- Max sample size : 6inch
- Option : Up/down / Heating max temp 400℃ / Rotation by motor/Bias for cleaning

**E-beam evaporator Unit**

- E-beam power supply 6kW with Sweep controller / Remote control unit
- E-Gun Boat (1~6 multi pocket capacity : 4~7cc)
- W, Mo source evaporation boat install
- Max current 300A ( Electrical rod - cooling)
- Pneumatic shutter for source

**Pumping Unit**

- Osaka turbo pump 1100l/s ISO200
- Inlet flange
- 600l/m Rotary pump
- Ion gauge/convection gauge
- ATM sensor Option : Load-lock unit/Cryo pump

**Control Unit**

- System manual operation
- Option :  Semi-auto operation system
  - · 15-inch touch panel control
  - · System recipe
  - · Interlock  (Water/Pneumatic air)
  - · Data loading

# Thermal Evaporator

The system is cooled by heat absorption by liquid evaporation by introducing the liquid refrigerant that has passed through expansion valve and decompressed to low temperature and low pressure and exchanges heat with surrounding space or object to be cooled. Unlike the E-beam evaporator, the Thermal evaporator is heated by Joule heat by placing sample on tungsten platform. It has the advantage of depositing various materials and it is possible to deposit as much sample as necessary. However, the deposited homogeneity is lower than the E-beam evaporator.

## Features

- Size(mm): 800(W) x 1707(H) x 800 (D)
- Compact, space-saving design
- Delivers optimal performance and utilizing top quality sub-components.
- High speed deposition
- Ergonomic to operate, easy to clean
- All stainless steel construction
- Configured for your application

## Customization

**Chamber Unit**

- Material : Stainless304 / Aluminum
- Chamber size : 350x350x500
- Front open door with window (shutter)
- ¼"VCR vent port
- Pumping port/gauge/spare port

**Substrate Unit**

- Material : Inconel600 (High temp)
- Water cooling stage : OFHC
- Max sample size : 6inch
- Option : Up/down / Heating max temp 400℃ / Rotation by motor/Bias for cleaning

**Thermal evaporator Unit**

- W, Mo source evaporation boat install
- Max current 300A ( Electrical rod - cooling)
- Pneumatic shutter for source

**Pumping Unit**

- Osaka turbo pump 450l/s ISO160 inlet flange
- 400l/m Rotary pump
- Ion gauge/convection gauge
- Capacitance gauge (10torr NW16)
- ATM sensor
- Option : Load-lock unit/Cryo pump

**Control Unit**

- System manual operation
- Option : Semi-auto operation system
  - · 15-inch touch panel control
  - · System recipe
  - · Interlock (Water/Pneumatic air)
  - · Data loading

# Graphene Samples

**The Highest Quality CVD Graphene Films on Custom Substrates · Graphene Oxides (GOs) Graphene Quantum Dots (GQDs) · Consumables for Graphene Researches**

**Using state-of-the-art chemical vapor deposition (CVD) methods developed in-house, Graphene Square offers the highest quality graphene samples currently on the market. In addition to the standard samples available online, Graphene Square can provide various fab. services including the sample transfer on the customers' own substrates as well as end-equipment prototype devices. Graphene Square also supplies graphene oxides (GOs) and graphene quantum dots (GQDs) applicable to various biological, display, and energy researches.**

# GSI's Patents List (Selected)

## Graphene Synthesis & Doping

| No. | Reg. Date | Title (ENG) | Reg. No (Korea) | Reg. No (International) |
|---|---|---|---|---|
| 01. | 2013-08-06 | Stable graphene film and preparing method of the same | 10-1295664 | |
| 02. | 2013-08-29 | Method for transferring graphene using a hot press | 10-1303930 | US 8916013 B2 |
| 03. | 2013-09-23 | Low-temperature forming method of graphene, and direct transfer of graphene and graphene shee t using the same | 10-1312454 | JP 5705315 B2 |
| 04. | 2014-01-07 | Dual doping method of graphene, dual-doped graphene, and device including the same | 10-1351001 | |
| 05. | 2014-07-18 | Preparing method of graphene sheet, graphene laminate, preparing method of transformation-aff ordable graphene sheet, transformation-affordable graphene sheet and device using the same | 10-1423037 | |
| 06. | 2014-12-01 | N-doping method of graphene | 10-1469450 | |

## Continuous Production of Graphene

| No. | Reg. Date | Title (ENG) | Reg. No (Korea) | Reg. No (International) |
|---|---|---|---|---|
| 01. | 2013-02-12 | Roll-to-roll doping method of graphene film, and doped graphene film | 10-1234180 | US 8926854 B2 |
| 02. | 2013-05-02 | Roll-to-roll transfer method of graphene, graphene roll produced by the method, and roll-to-roll tr ansfer equipment for graphene | 10-1262327 | US 8916057 B2<br>CN 102656016 B<br>JP 5707628 B2<br>JP 5787113 B2 |
| 03. | 2014-03-03 | Graphene roll-to-roll coating apparatus and graphene roll-to-roll coating method using the same | 10-1371286 | JP 5424210 B2 |

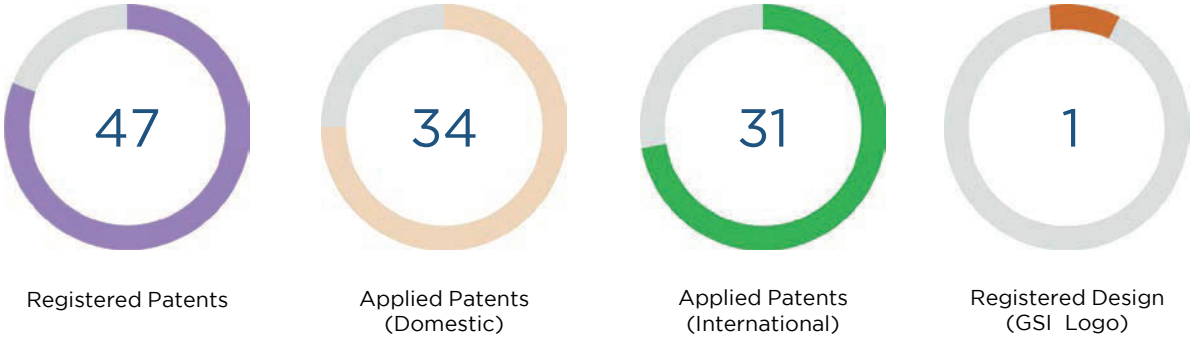
## Applications

| No. | Reg. Date | Title (ENG) | Reg. No (Korea) | Reg. No (International) |
|---|---|---|---|---|
| 01. | 2012-08-01 | Electromagnetic wave shielding method using graphene and electromagnetic wave shielding mater ial using graphene | 10-1171818 | |
| 02. | 2013-01-09 | Flexible transparent heating element using graphene and method for manufacturing the same | 10-1222639 | US 8816257 B2 |
| 03. | 2013-02-12 | Sensing method of pressure using graphene device and graphene device used therein | 10-1234181 | |
| 04. | 2013-05-02 | Method for improving electrical characteristics of graphene device and graphene device using the s ame | 10-1262331 | |
| 05. | 2013-05-02 | Transparent actuator based on graphene electrode and method of manufacturing the same | 10-1262323 | |
| 06. | 2013-05-02 | Modifying method of graphene, and device using the same | 10-1262310 | |
| 07. | 2013-05-02 | Flexible stretchable semiconductor device containing graphene electrode, method of reducing resi stance between graphene electrode and semiconductor layer, and graphene interconnector | 10-1262319 | |
| 08. | 2013-08-19 | Organic field-effect transistor, and preparing method of the same | 10-1299597 | |
| 09. | 2013-08-21 | Optical film having graphene, preparing method of the same, and back light unit and liquid crystal d isplay device having the same | 10-1300799 | |
| 10. | 2014-03-07 | Graphene transparent electode and flexible silicon thin film semiconductor device having the same | 10-1375124 | |
| 11. | 2014-06-02 | Flexible solar cell and preparing method for the same | 10-1405464 | |
| 12. | 2014-06-02 | Graphene protective film for preventing gas and water, method of forming the same and uses of th e same | 10-1405463 | |
| 13. | 2014-08-27 | Patterning method of graphene using hot embossing imprinting | 10-1436911 | |
| 14. | 2014-10-17 | Variable focus lens, and preparing method of the same | 10-1454270 | |
| 15. | 2014-11-03 | Touch sensor using graphene for simultaneously detecting a pressure and a position | 10-1459307 | US 9297831 B2 |
| 16. | 2015-11-18 | Patterning method of graphene using hot embossing imprinting | 10-1571317 | |
| 17. | 2016-02-17 | Graphene protective film for preventing gas and water, method of forming the same and uses of th e same | 10-1596859 | |

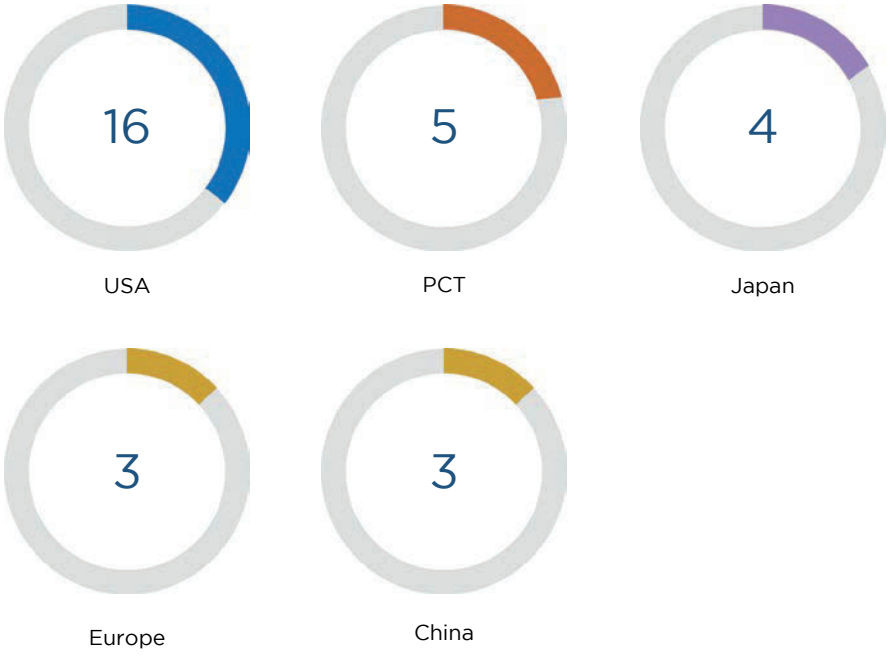
## IP Development & Licensing

Sungkyunkwan Univ. (SKKU) famous for the world's most graphene patent applications has transferred the most important graphene-related 42 patents to Graphene Square Inc. in 2012.

### Graphene Square's IPs (March 16, 2017)




### Applied Patents by country




## GSI's Key Patents Highlighted by Bloomberg & Businessweek

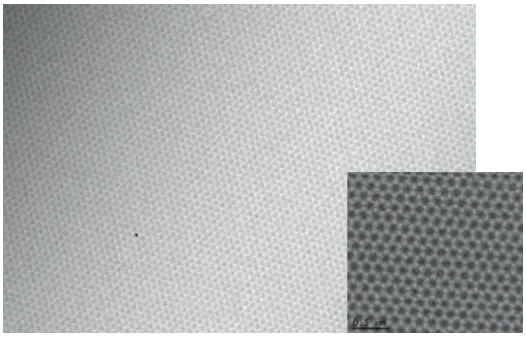
"Hong's patents are key in making cost-efficient, large-scale graphene for touchscreen panels in mass volume."

(Samsung-Apple Smartphone Battleground Is Single Atom Thick May 15, 2014, Bloomberg.com)

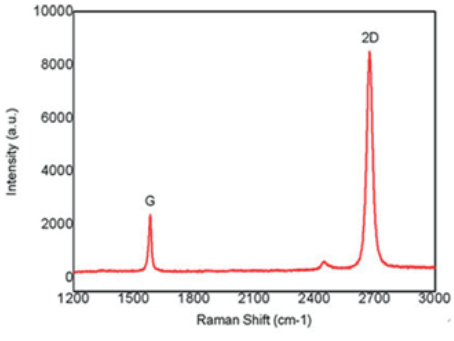
# CVD Graphene on Cu foils


| | |
|---|---|
| Product Size | Up to 500x600㎟ |
| Film Morphology | Continuous Monolayer (>95%) |
| Sheet Resistance | - |
| Mobility | >3500cm²/Vs |
| Transmittance | >97% |
| Substrate | Cu foil (35㎛ thick) |
| Domain Size | 10-20 ㎛ |

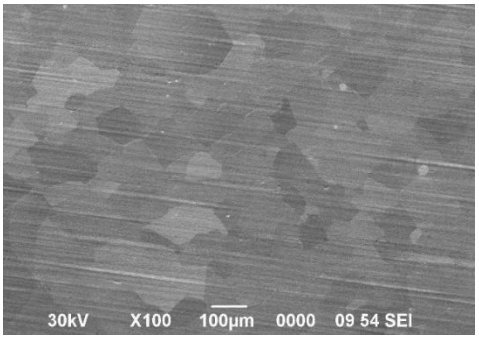
## High-Resolution TEM Images



## Raman Spectrum (after transfer)




## SEM Image of Graphene on Cu




## Reference

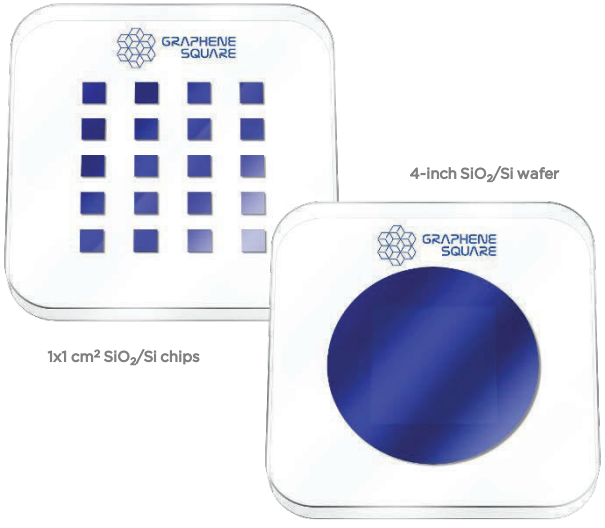
(1) S. Bae*, H. Kim* *et al*. **Roll-to-roll production of 30 inch graphene films for transparent electrodes** *Nature Nanotech*. **5**, 574 (2010).

(2) Y. Lee *et al*. **Wafer-Scale Synthesis and Transfer of Graphene Films**.*Nano Lett.* **10**, 490-493 (2010).

(3) H.-A-S. Shin *et al.* **Graphene-induced Unusual Microstructural Evolution in Ag Plated Cu Foils.** *Nanoscale* **6**, 7209-7214 (2014).

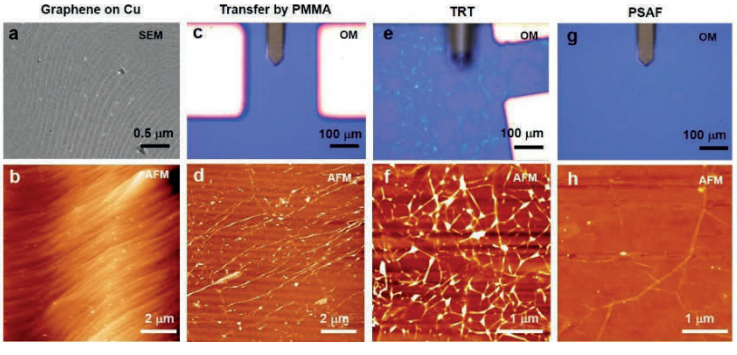
(4) Hae-A-Seul Shin*, Jaychul Ryu* *et al.* **Highly Uniform Growth of Monolayer Graphene by Chemical Vapor Deposition on Cu-Ag Alloy Catalysts.** *Phys. Chem. Chem. Phys.* **16**, 3087-3094 (2014).

# Ultra-Clean Graphene on $SiO_2$/Si Wafers

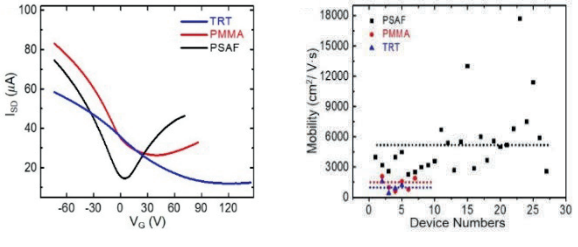



| | |
|---|---|
| Product Size | Up to 90 x 90 ㎟ (Max) |
| Film Morphology | Continuous Monolayer (>95%) |
| Sheet Resistance | Av. < 250~400 Ω/sq |
| Mobility | >3500 $cm^2/Vs$ (Max. 17,000 $cm^2/Vs$) |
| Transmittance | >97% |
| Substrate | $SiO_2$(300nm)/Si wafer (Standard) |
| Domain Size | 10-20 ㎛ |

## Ultra-Clean Transfer by Pressure Sensitive Adhesive Films




## Electrical Properties




## Reference

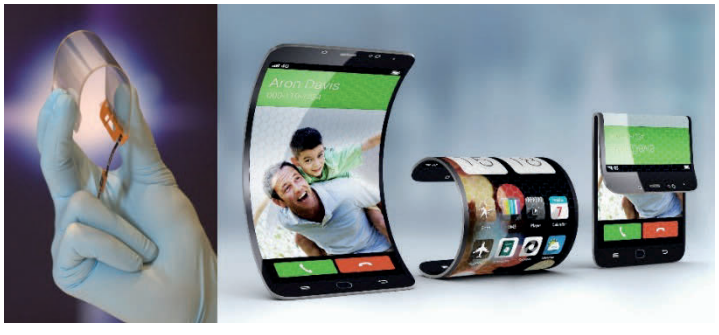
(1) S. Kim *et. al*. **Ultra-Clean Patterned Transfer of Single-Layer Graphene by Recyclable Pressure Sensitive Adhesive Films.** *Nano Lett.* **15**, 3236–3240 (2015).

(2) S. Bae*, H. Kim* *et al*. **Roll-to-roll production of 30 inch graphene films for transparent electrodes** *Nature Nanotech*. **5**, 574 (2010).

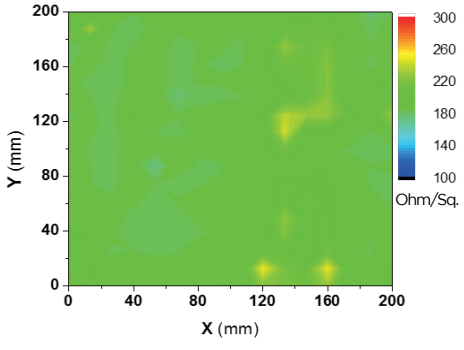
# Graphene on PET

| | |
|---|---|
| Product Size | Up to 500 x 600 ㎟ |
| Film Morphology | Continuous Monolayer (>95%) |
| Sheet Resistance | Av. < 250~400 Ω/sq |
| Mobility | >3500 $cm^2$/Vs |
| Transmittance | >97% |
| Substrate | PET (188㎛) (Standard) |
| Domain Size | 10-20 ㎛ |

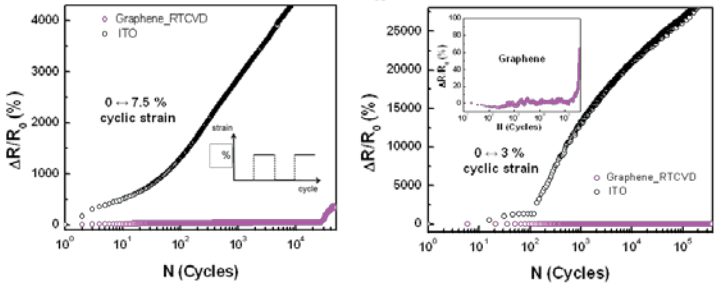
## Application of Graphene on PET for Flexible Touch Screen



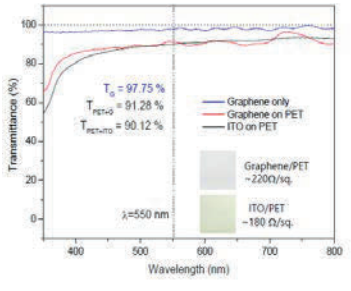
## Sheet Resistance Uniformity




## Mechanical Properties of Graphene on PET




## Optical Transmittance



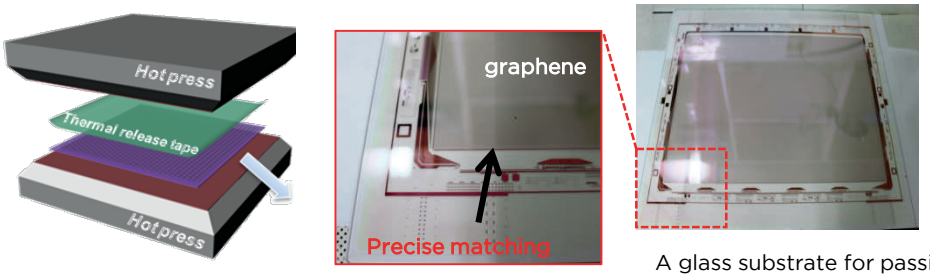

## Reference

J.-H. Ahn & B. H. Hong **Graphene for displays that bend.** *Nature Nanotech*. **9**, 737-738 (2014).

# Graphene on Glass

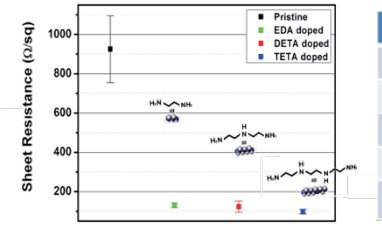

| | |
|---|---|
| Product Size | Up to 80 x 150 ㎟ |
| Film Morphology | Continuous Monolayer (>95%) |
| Sheet Resistance | Av. < 250~400 Ω/sq |
| Mobility | >3500 $cm^2$/Vs |
| Transmittance | >97% |
| Substrate | Glass (variable thickness) |
| Domain Size | 10-30 ㎛ |

## Transfer of Graphene onto Rigid Substrates by Hot Pressing




A glass substrate for passive matrix LCDs

## N-doped Graphene for Low Sheet Resistance Applications




| | Pristine | EDA doped | DETA doped | TETA doped |
|---|---|---|---|---|
| Dirac Voltage (Vg) | 1.37 ± 2.27 | -126.64 ± 6.06 | -166.37 ± 1.78 | -192.27 ± 6.49 |
| Carrier concentration($10^{13}$) | 0.01 ± 0.016 | -0.912 ± 0.043 | -1.198 ± 0.013 | -1.384 ± 0.047 |
| Mobility(h) [$cm^2$/Vs] | 6219 ± 1288 | | | |
| Mobility(e) [$cm^2$/Vs] | 3809 ± 876 | 3711 ± 913 | 3388 ± 531 | 2817 ± 475 |
| Sheet resistance (Ohm/sq) | 925 ± 170 | 130 ± 12 | 124 ± 28 | 98 ± 12 |

## Reference

(1) J. Kang *et al.* **Efficient Transfer of Large-Area Graphene Films onto Rigid Substrates by Hot Pressing**. *ACS Nano* **6,** 53060-5365 (2012)

(2) Y. Kim *et al.* **Vapor-Phase Molecular Doping of Graphene for High-Performance Transparent Electrodes**. *ACS Nano*, **8** , 868–874 (2014).

# Graphene Oxide Solution

| | |
|---|---|
| **Concentration** | 0.1g/100ml |
| Flake size | <1µm |
| Type | Dispersion in $H_2O$ / Dried powder |
| Appearance | Brown |
| Flake thickness | 1-atom layer (>60%) |
| Electrical properties | Insulator |

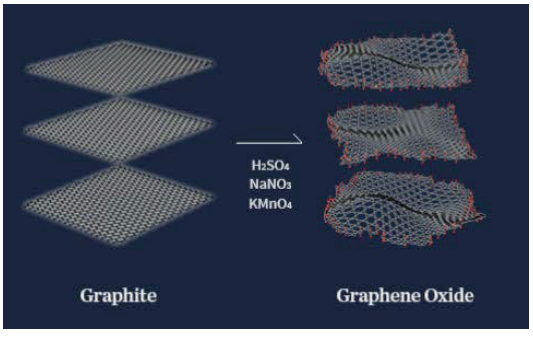
## Applications

- Functional composite materials (fabric reinforcement, hybrid scaffold for tissue engineering, barrier for electromagnetic waves)
- Biomedical & bio-imaging applications (drug delivery carrier, imaging probe, biosensor, photo-thermal therapy, enzyme activation catalyst)
- Energy conversion & storage system (battery & supercapacitor)
- Catalyst for chemical reactions
- Filter membrane for waste water treatment

## Hummer's Method

Graphene Square has the know-how in making the best and standard method of Graphene Oxide by low salt to high monolayer ratio.

Graphite powder is kept in an acidic environment for about a week to create dispersed reactions towards monolayers; then If you counter react the product from the strong acid solution, then Graphene Oxide is produced; Graphene Oxide solution can be made by mixing 1g/1L of DI water.



# Graphene Quantum Dot

| | |
|---|---|
| Solvent | DIW |
| Concentration | 0.5 g/L |
| Flake size | <10nm |
| Thickness | 1 atomic layer -at least60% |
| Color | Brown |

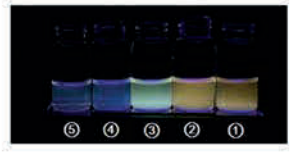
### Produc tion Method

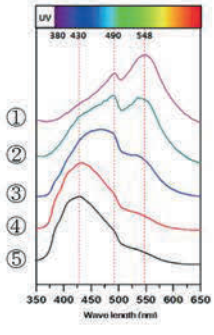
Top-down method (by Carbon fiber)

### Applications

- Nanocomposite materials
- Graphene based field effect transistor (GFET)
- Energy conversion & storage
- Chemical reaction catalyst
- Drug delivery carrier
- Tissue engineering

## Measurement data




Photoluminescence (PL) spectra

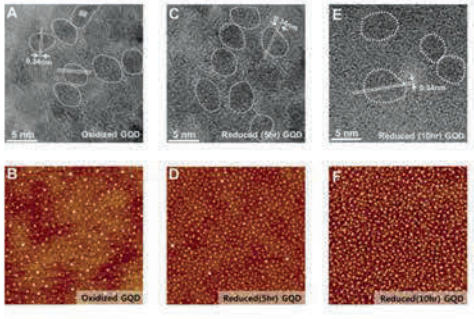
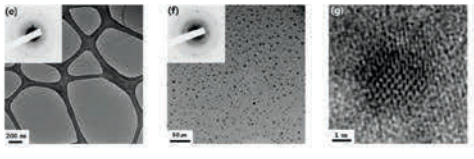



Figure 3. TEM and AFM images of GOQDs (A, B), 5 h reduced GQDs (C, D), and 10 h reduced GQDs (E, F), respectively. The AFM scan ranges are 3$\mu m$ X 3$\mu m$.



(e) TEM image of monolayer graphene supported by holely carbon grids.

(f, g) Low and high-resolution TEM images of N-GQSs on a graphene-supported grid.

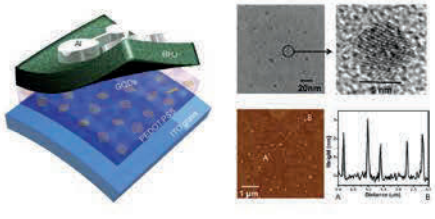


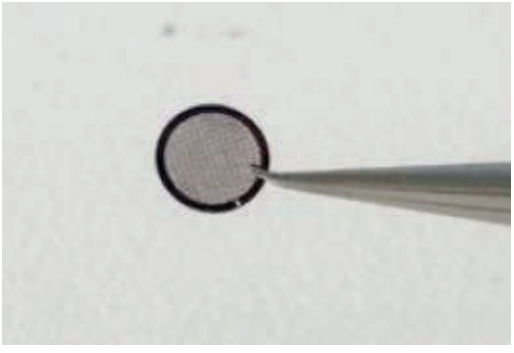
Figure 1. Schematic of device, and TEM and AFM images of GQDs. Schematic of OPV device with a GQD-incorporated PEDOT:PSS layer, and TEM images of the GQDs. The scale bar is 20nm on the TEM image, and 5nm on the inset image. AFM image of GQDs (5$\mu m$ by 5$\mu m$) and height distribution from A to B.

## Reference


(1) J.Moon *et al.* **One-Step Synthesis of N-Doped Graphene Quantum Sheets from Monolayer Graphene by Nitrogen Plasma**. *Adv. Mater*. **26**, 3501–3505 (2014).

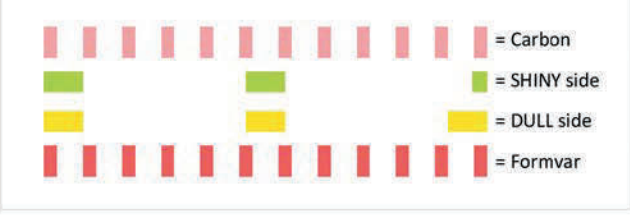
(2) Jung Kyu Kim*, Sangjin Kim* *et al*. **Graphene Quantum Dots Incorporated Hole Extraction Layer for Efficient Organic Photovoltaics**. *Sci Rep*, **5** , 14276

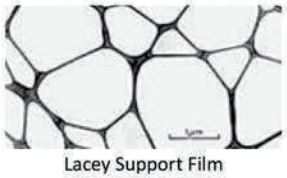
# CVD Graphene on TEM Grid

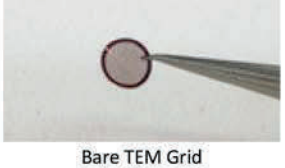


| TEM Grid | Graphene |
|---|---|
| Grid Hole Size : 63μm | Sheet Resistance : Av. < 250~400 Ω/sq |
| Lacey Carbon Type-A | Mobility : >3500cm2/Vs (Max. 17,000 cm2/Vs) |
| 300 mesh | Transmittance : >97% |
| Copper frame | Coverage : <30% (PMMA-free), <60% (2-layers) |

## Grid Cross Section

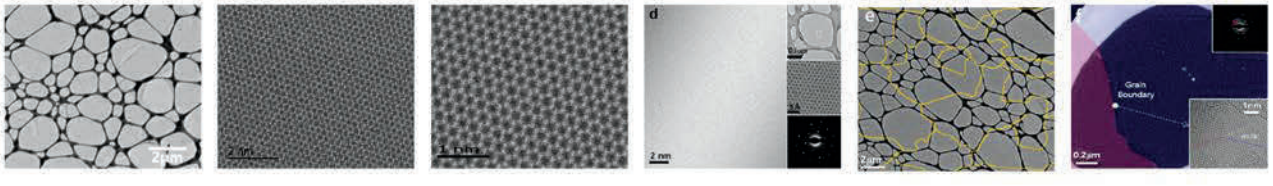




Lacey Support Film


Bare TEM Grid

**Lacey carbon Type A**: The Lacey formvar film is applied to the dull side of the grid and carbon depositied onto the shiny side. When the formvar is removed in solvent the carbon film is left on the shiny side.

## Measurement data




(d) HR-TEM results showing the atomic lattice structures of RT-CVD graphene. The graphene samples were prepared with holey carbon grid (upper inset). The aberration-corrected scanning TEM image provides an atom-by-atom analysis of graphene (mid inset). The diffraction pattern indicates the corresponding graphene is a highly crystalline monolayer (lower inset). (e) Graphene domain distribution investigated by selected area diffraction patterns (SADP) and TEM imaging. (f) Graphene boundaries of RT-CVD graphene characterized by dark-field TEM and aberration-corrected HR-TEM images . The left and right parts of the grain boundary are imaged with an aperture at the red and blue circled spots of the diffraction pattern (upper inset). The atomic image shows that two graphene domains are smoothly connected with an angle of 36° (lower inset). See also Supporting Figure S2 for more dark-field TEM analyses.

## Reference

(1) Kim, Sang Jin, *et al.* "Simultaneous etching and doping by Cu-sta-bilizing agent for high-performance graphene-based transparent electrodes." *Chem. Mater.* **26** 2332 (2014)

(2) Ryu, Jaechul, *et al.* "Fast synthesis of high-performance graphene films by hydrogen-free rapid thermal chemical vapor deposition." *ACS*, nano **8**, 950 (2014).

# Graphene Square in Global Market, As the Leader of Graphene Commercialization

## Customers

| | |
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| | California Institute of Technology |
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| | Stanford University |
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| | Ohio University |
| | GM |
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| | IBM Zurich Nanotech Center |
| France | Logitrade(Campus polytech) |
| Germany | IHP GmbH |
| Malaysia | Avante Systems |

## All about Graphene

Graphene Square, Inc. is a pioneer in the commercialization of graphene material and graphene films for use as a transparent conductor and in other electronics applications. Established as a spin-off of the research of Prof. Byung Hee Hong at Seoul National University and with headquarters in Seoul, Korea. Graphene Square will continue to stay as the world leader of the graphene commercialization research, also will continue to provide the best quality graphene and equipment to all over the world for the continuous development of carbon and 2D materials for the bright future of the science & technology for mankind.

## Customers

| | |
|---|---|
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| | VIT university |
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| Australia | CSIRO - Commonwealth Scientific and Industrial Research Organisation |
| | Curtin University Australia |
| | School of Photovoltaic |
| Taiwan | Taiwan University |
| Spain | ICFO |

# Graphene Samples for R&D

CVD Graphene on
Cu Foil

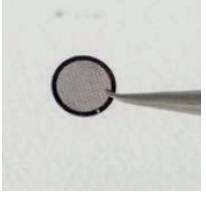
Graphene on
Sio2/Si wafer

Graphene on
PET/Quartz glass

Graphene Oxide
Solution

Transfer Kit(CVD Graphene
on Cu foil & TRT)

Graphene
Quantum Dot



CVD Graphene
on TEM Grid

# Graphene &
# 2D Materials Growth Equipment

**TCVD 50B**

**TCVD-100A**

**TCVD-RF100CA**

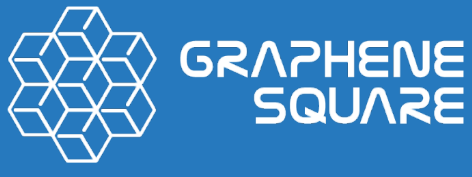
**TCVD-DRF100CA**

**TCVD 50B**

**Reactive Ion Etcher**

**Reactive Ion Etcher**

**Thermal Evaporator**

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