

The Pioneer of CVD Graphene Commercialization

www.graphenesq.com





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.

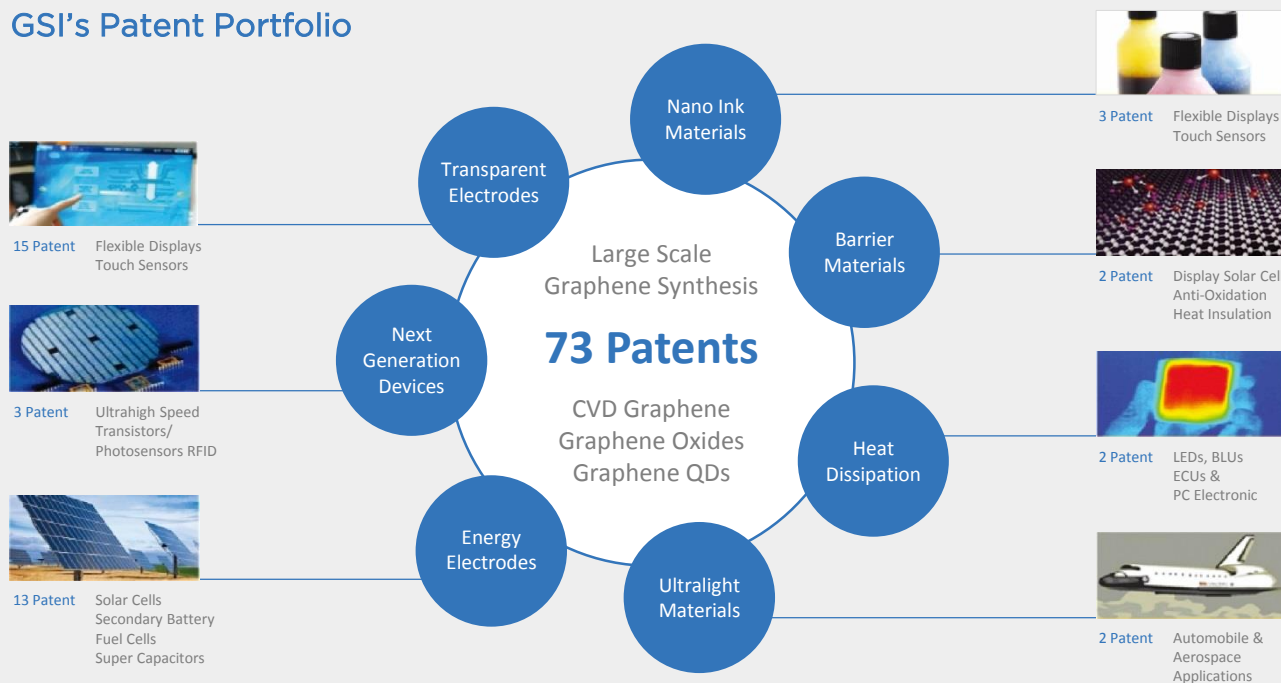
Graphene Samples & Fab. Services

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





CVD Systems for Graphene & 2D Materials

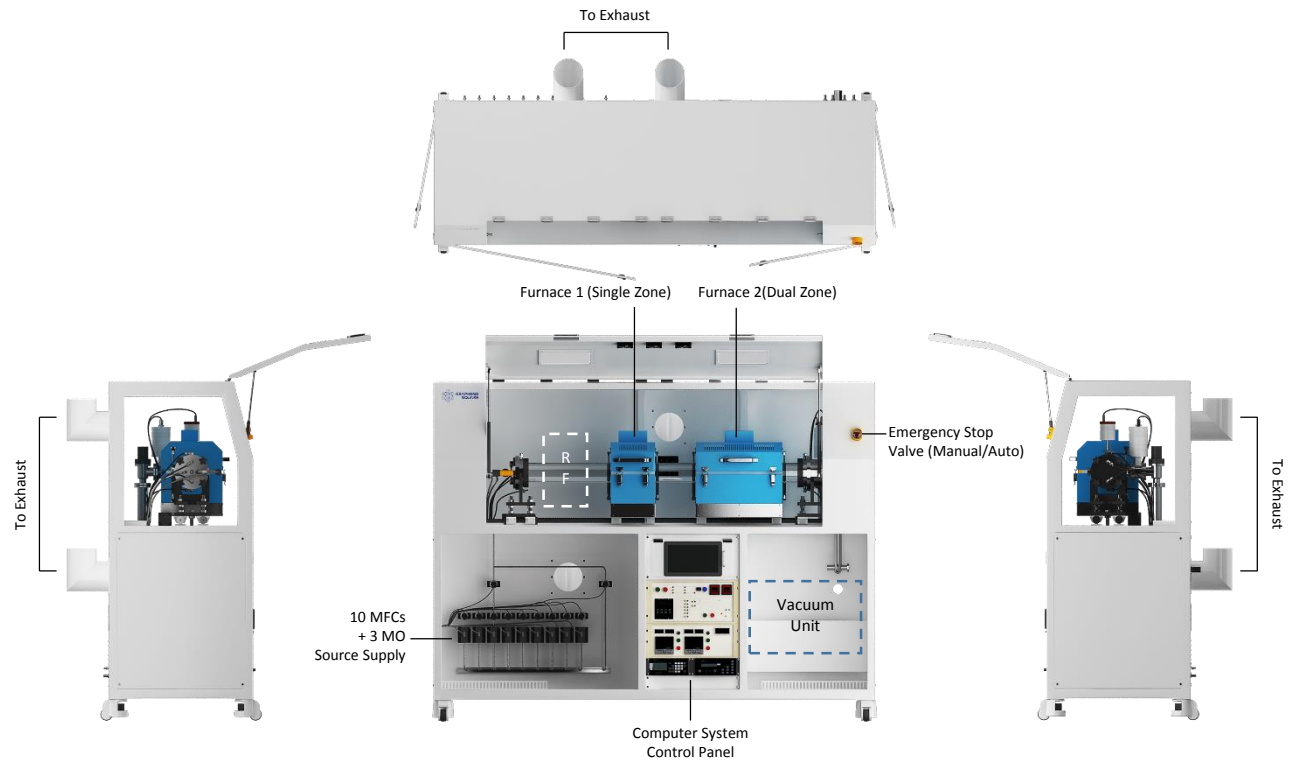
Sophisticated · Cost Effective · Reliable · Programmable Systems · for Highest Sample Quality
Fast Heating & Cooling · World's Best Training Service Available

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



IBM Zürich Nanotech Center



Technical Specification

CVD Reactor	<ul style="list-style-type: none"> • Tube type 4 inch diameter quartz
Substrate Size	<ul style="list-style-type: none"> • Lateral insertion of 10 mm to < 4 inch wafers possible. (Loading frames for small samples) • Rolled metallic foils can be loaded to synthesize A4 sized or larger 2D materials.
Heating	<ul style="list-style-type: none"> • Dual-zone heater and controller for graphene/h-BN synthesis. Single-zone precursor heater and Dual-zone deposition heater for TMDC synthesis. • The heaters are movable along two rails and the distance can be motor-controlled, enabling 10°C/sec or faster temperature change rate.
Base Pressure	<ul style="list-style-type: none"> • 10^{-5} mbar (depending on the dryness of source)
Operating Pressure	<ul style="list-style-type: none"> • 10^{-3} mbar – 1 bar
Precursor	<ul style="list-style-type: none"> • 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. • Metal oxide sources of various transition metals placed in Heat Zone 1 for solid source growth.
Other metal organic (MO) sources	<ul style="list-style-type: none"> • Extra 3 Metal-Organic Source Injection Ports are included. (ex $\text{Mo}(\text{CO})_6$, $\text{Fe}(\text{CO})_5$) • Low-T cold trap for residual sources.
Flow control	<ul style="list-style-type: none"> • Precursor gases: 0.1 – 10 sccm • Other gases: 10 – 1000 sccm • Automatic flow control.
Vacuum	<ul style="list-style-type: none"> • Turbo pump 450 l/s (ISO160) < 10^{-6} mbar. • Dry scroll pump < 10^{-1} mbar. • Main Gate Valve Pneumatic type / Fore-line / roughing Angle Valve / Foamed bellows • By-pass pumping adaptor, clamp & centering.
T-measurement	<ul style="list-style-type: none"> • Standard Thermocouple (NIR calibrated)
Sample switching	<ul style="list-style-type: none"> • Position switching by sample loading stage.
System Control	<ul style="list-style-type: none"> • Control PC system (12" touch, dual core) • Serial Network module (4-ch) • Remote IO module (RS485) • System base programming / System recipe control module / System date file save module • Software upgrade support. • Gas valve, angle valve Open/Close / Rotary pump On/Off switch / Main power On/Off switch • 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	<ul style="list-style-type: none"> • Dual Tube type 4 inch diameter quartz. • Remote Microwave Plasma Module. • Connected to a Glove Box.
Substrate Size	<ul style="list-style-type: none"> • Lateral insertion of 10 mm to <4 inch wafers possible. (Loading frames for small samples) • Rolled metallic foils can be loaded to synthesize A4 sized or larger 2D materials.
Heating	<ul style="list-style-type: none"> • Dual-zone heater and controller for graphene/h-BN synthesis. Single-zone precursor heater and Dual-zone deposition heater for TMDC synthesis. • The heaters are movable along two rails and the distance can be motor-controlled, enabling 10°C/sec or faster temperature change rate.
Base Pressure	<ul style="list-style-type: none"> • 10^{-5} mbar (depending on the dryness of source)
Operating Pressure	<ul style="list-style-type: none"> • 10^{-3} mbar – 1 bar
Precursor	<ul style="list-style-type: none"> • 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. • Metal oxide sources of various transition metals placed in Heat Zone 1 for solid source growth.
Other metal organic (MO) sources	<ul style="list-style-type: none"> • Extra 3 Metal-Organic Source Injection Ports are included. (ex $\text{Mo}(\text{CO})_6$, $\text{Fe}(\text{CO})_5$) • Low-T cold trap for residual sources.
Flow control	<ul style="list-style-type: none"> • Precursor gases: 0.1 – 10 sccm • Other gases: 10 – 1000 sccm • Automatic flow control.
Vacuum	<ul style="list-style-type: none"> • Turbo pump 450l/s (ISO160) < 10^{-6} mbar. • Dry scroll pump < 10^{-1} mbar. • Main Gate Valve Pneumatic type / Fore-line / roughing Angle Valve / Foamed bellows • By-pass pumping adaptor, clamp & centering.
T-measurement	<ul style="list-style-type: none"> • Standard Thermocouple (NIR calibrated)
Sample switching	<ul style="list-style-type: none"> • Position switching by sample loading stage.
System Control	<ul style="list-style-type: none"> • Control PC system (12" touch, dual core) • Serial Network module (4-ch) • Remote IO module (RS485) • System base programming / System recipe control module / System data file save module • Software upgrade support. • Gas valve, angle valve Open/Close / Rotary pump On/Off switch / Main power On/Off switch • 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°C
- Protective design from heat
- Uniformity of Film Thickness: $\leq \pm 3\%$
- Testing Uniformity: $\leq \pm 3\%$
- 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°C
- Uniformity of Film Thickness: $\leq \pm 3\%$
- Testing Uniformity: $\leq \pm 3\%$
- Movable furnace method is our unique knowhow for fast heating and fast cooling of the sample
- Standard safety box

Customers



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



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

	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: $\sim 1,100^\circ\text{C}$
- Uniformity of Film Thickness: $\leq \pm 3\%$
- Testing Uniformity: $\leq \pm 3\%$
- 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





Graphene Samples

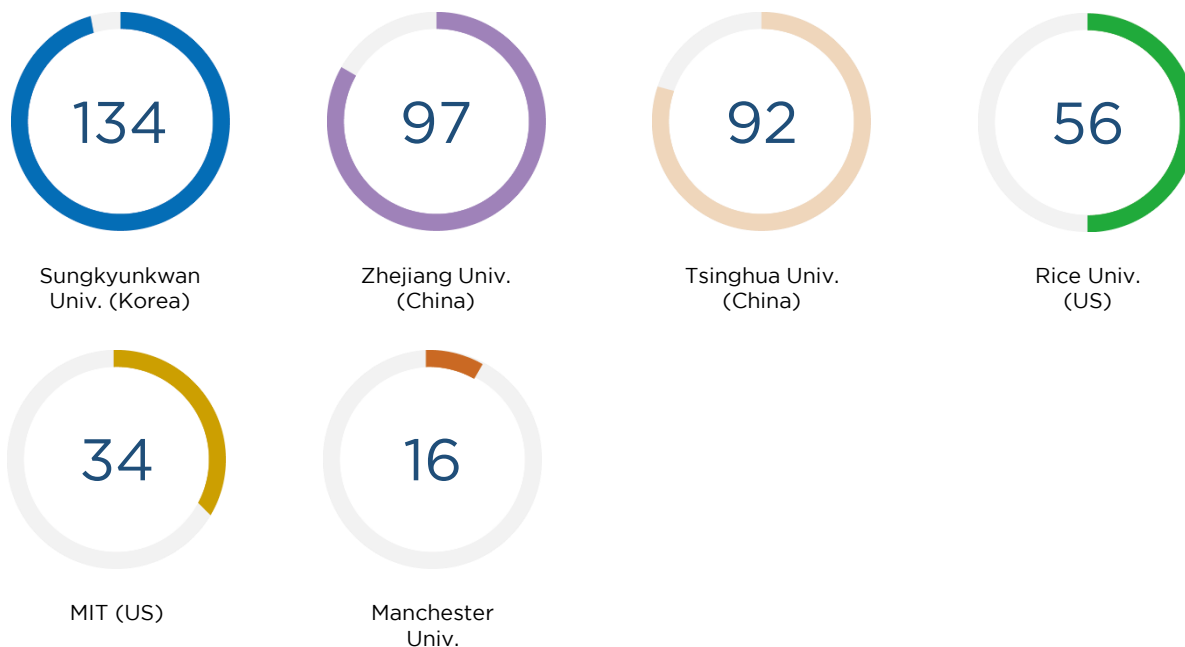
The Highest Quality CVD Graphene Films on Custom Substrates · Graphene Oxides (GOs)
Graphene Quantum Dots (GQDs) · Consumables for Graphene Researches

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.

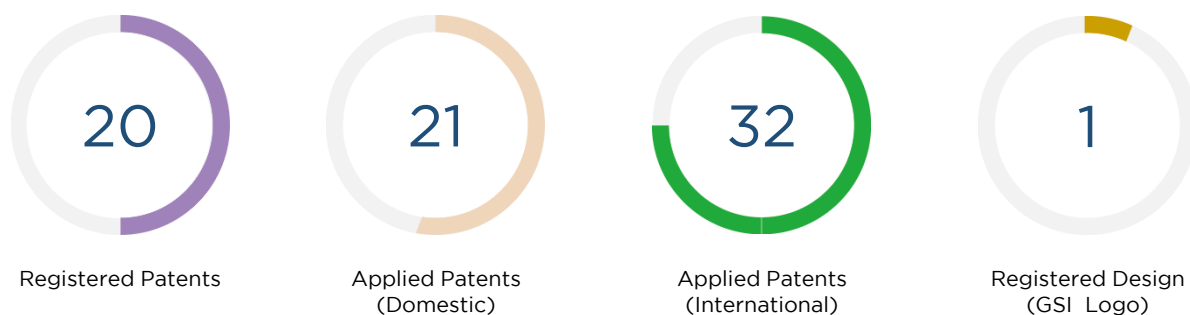
IP Development & Licensing

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.

BBC News "Graphene : patent surge reveals global race"



Graphene Square's IPs (June 20, 2014)



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)

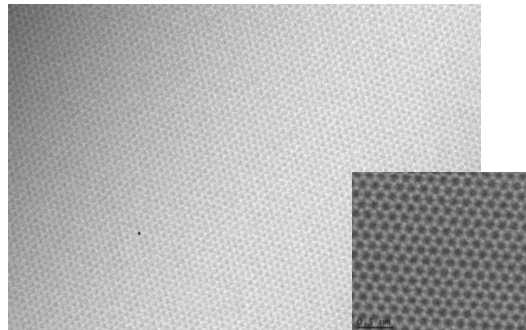


CVD Graphene on Cu foils

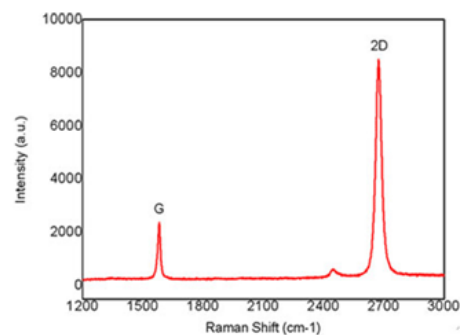


Product Size	Up to 500x600mm ²
Film Morphology	Continuous Monolayer (>95%)
Sheet Resistance	-
Mobility	>3500cm ² /Vs
Transmittance	>97%
Substrate	Cu foil (35μm thick)
Domain Size	10-20 μm

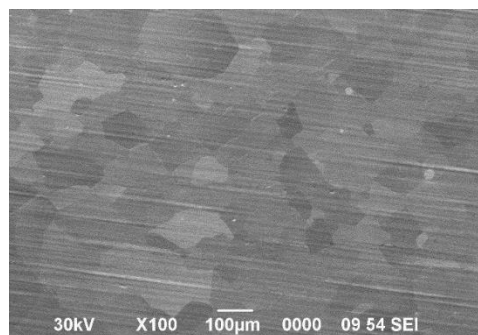
High-Resolution TEM Images



Raman Spectrum (after transfer)



SEM Image of Graphene on Cu



Reference

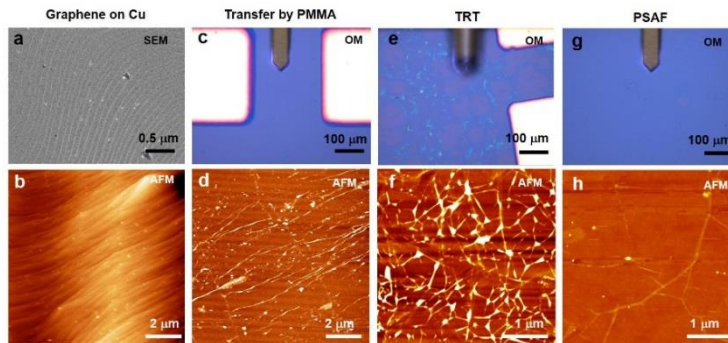
- (1) S. Bae*, H. Kim* *et al.* Roll-to-roll production of 30 inch graphene films for transparent electrodes *Nature Nanotech.* **5**, 574 (2010).
- (2) Y. Lee *et al.* Wafer-Scale Synthesis and Transfer of Graphene Films. *Nano Lett.* **10**, 490-493 (2010).
- (3) H.-A.-S. Shin *et al.* Graphene-induced 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 SiO₂/Si Wafers

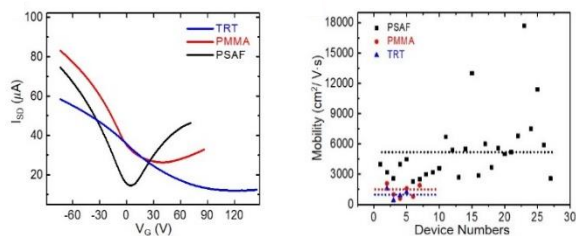


Product Size	Up to 90 x 90 mm ² (Max)
Film Morphology	Continuous Monolayer (>95%)
Sheet Resistance	Av. < 250~400 Ω/sq
Mobility	>3500 cm ² /Vs (Max. 17,000 cm ² /Vs)
Transmittance	>97%
Substrate	SiO ₂ (300nm)/Si wafer (Standard)
Domain Size	10-20 μm

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.* (accepted).
- (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

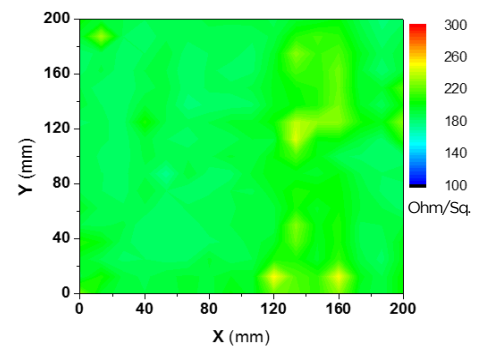


Product Size	Up to 500 x 600 mm ²
Film Morphology	Continuous Monolayer (>95%)
Sheet Resistance	Av. < 250~400 Ω/sq
Mobility	>3500 cm ² /Vs
Transmittance	>97%
Substrate	PET (188μm) (Standard)
Domain Size	10-20 μm

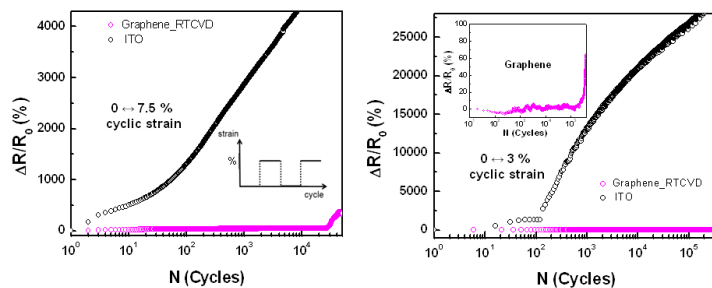
Application of Graphene on PET for Flexible Touch Screen



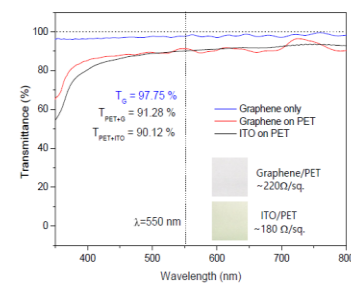
Sheet Resistance Uniformity



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).

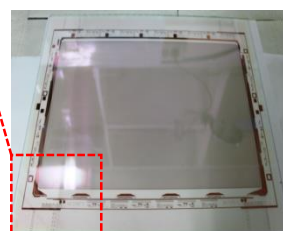
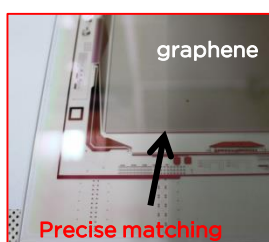
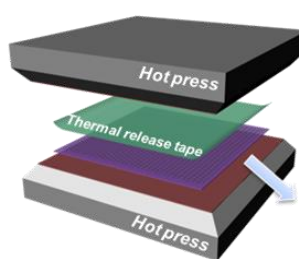


Graphene on Glass



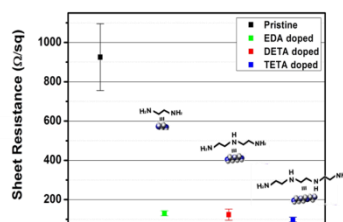
Product Size	Up to 80 x 150 mm ²
Film Morphology	Continuous Monolayer (>95%)
Sheet Resistance	Av. < 250~400 Ω/sq
Mobility	>3500 cm ² /Vs
Transmittance	>97%
Substrate	Glass (variable thickness)
Domain Size	10-30 μm

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 Square in Global Market, As the Leader of Graphene Commercialization

Customers

USA	Columbia University	UK	University of Cambridge
	University of North Texas		Nokia Research Centre
	Massachusetts Institute of Technology		University of Oxford
	HRL Laboratories		University of Leeds
	California Institute of Technology		University of Exeter
	Carnegie Mellon University	Netherland	Delft University of Technology
	University of Minnesota		University of Groningen
	Utah State University		Philips Research Lab
	University of Wisconsin-Madison		ASML
	North Carolina State University	Finland	Nokia
	Millennium Laboratories		Aalto University
	Stanford University	Greece	Institute of Material Science NCSR Demokritos
Deutschland	IHP GmbH	Switzerland	ABB Switzerland Ltd.
	University of Regensburg		ETH Zurich
Spain	ICFO		IBM Zurich Nanotech Center



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

Austria	University of Vienna	Japan	JX Oil & energy
Italy	University of Bari		NTT-AT
Poland	University of Lodz	Hong Kong	Hong Kong Baptist University
Estonia	University of Tartu		A&P Instrument
South Africa	University of South Africa	India	Institute of Inorganic
Republic of Korea	Samsung		Methodologies and Plasmas
	LG Display		Tata Institute of fundamental Research
	Seoul National University		BHAI BHAI ENTERPRISE
	SungKyunkwan University		GE corporation
	Korea University		VIT university
	KAIST	Thailand	King Mongkut's University of Technology Thonburi
	GIST	Saudi Arabia	King Abdullah University of Science and Technology
Singapore	National University of Singapore	Australia	CSIRO - Commonwealth Scientific and Industrial Research Organisation
	S&L Innovations and Technology Pte. Ltd		
China	University of Nanjing		



Lodz University of Technology

UNISA



LG Display



KAIST



광주과학기술원
Gwangju Institute of Science and Technology



香港浸會大學
HONG KONG BAPTIST UNIVERSITY





KOREA HEAD OFFICE

Rm 216-1, Bldg. 104
Inter-University Semiconductor Research Center
Seoul National University, 1 Gwanak-ro
Seoul 151-742, South Korea

US BRANCH OFFICE

1938 Washington Street #403, Newton, MA 02466, USA

Tel +82-2-880-6569 (KOR) +1-201-815-1460 (US)

E-mail info@graphenesquare.com

Website www.graphenesq.com