CVD Equipment Corporation

First Nano™ Graphene

Turn-Key Equipment / Process Solutions

(Gas Delivery, Process Equipment and Gas Abatement)

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R&D Turn-Key Equipment / Process Solutions

Gas/Liquid Delivery Equipment

Process Equipment

Exhaust Abatement Equipment

- Corrosive
- Flammable
- Pyrophoric
- Toxic

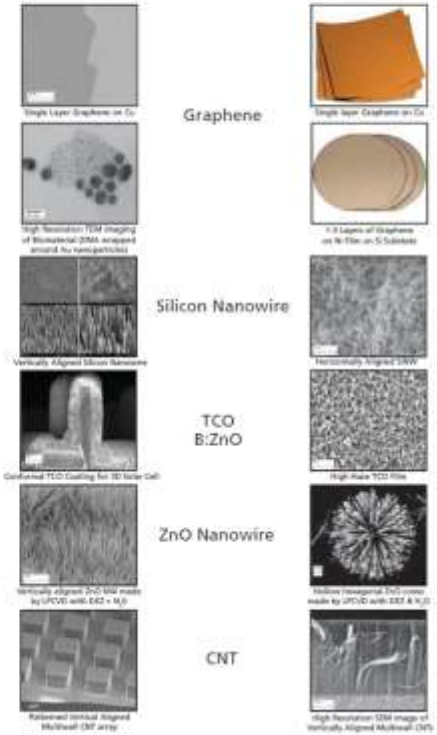
- Bulk Argon
- Inert Cylinder Gases
- Liquid Nitrogen

- ALD
- APCVD
- LPCVD
- MOCVD
- PECVD
- UHVCVD

- Atmospheric
- Low Pressure
- Ultra High Vacuum

- Pyrolizing Furnace
- Liquid Packed Tower

Accelerating Commericalization of Tomorrow's Materials



Graphene - Fundamental

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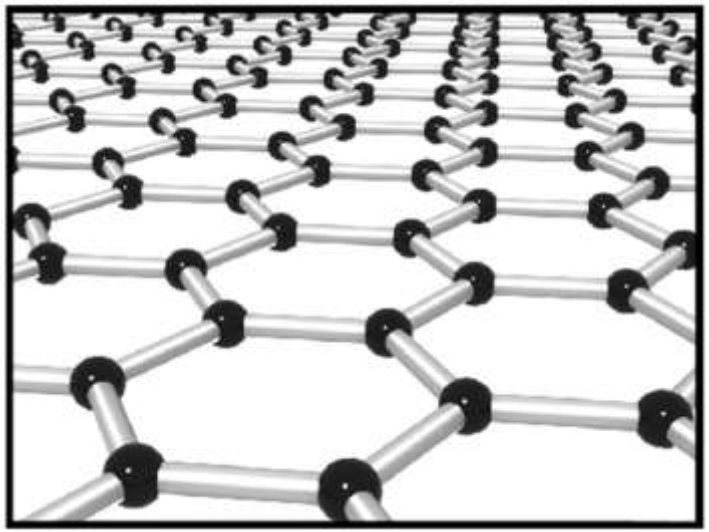
- Graphene is a monolayer of carbon atoms tightly packed into a two-dimensional (2D) honeycomb lattice.
- Graphene can be made by several methods - scotch-tape, chemical exfoliation, Chemical Vapor Deposition induced growth, graphite oxide reduction and more.
- Potential applications for Graphene include:
  - Ultra fast transistors and IC's,
  - Transparent conductive electrodes
  - High contrast TEM grids for bio/medical/material characterization
  - Sensors



Graphene made by CVD

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Among the synthesis methods, the Chemical Vapor Deposition methods is best for producing Graphene material with:

- Low defects
- Good uniformity
- Controlled number of Graphene layers
- Relatively easy to scale up production
- The Graphene films made on metal film or foil surfaces can be easily removed and transferred to other substrate surfaces.

Typical CVD Growth Conditions

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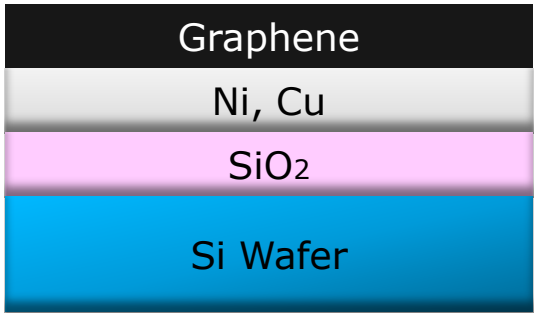
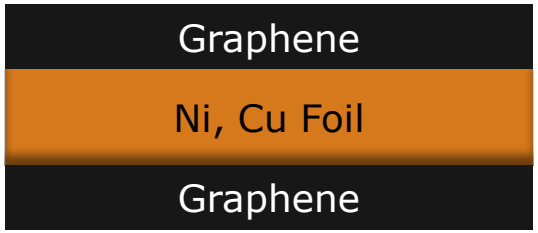
- Growth Temperature: 900°C to 1050°C
- Substrate cooling rate is important for layer thickness control
- Substrate: Ni or Cu coated Si wafer, or Ni or Cu foil
- Pressure: <1 Torr - 760 Torr
- Process gases: Nitrogen, Hydrogen & Methane
- Annealing controls the grain size for metal films
- Growth time: typical 5 - 30 minutes
- Fast cooling (>1.5°C/s) is typically required for making 1-3 layer Graphene films on Ni surfaces





Graphene Results

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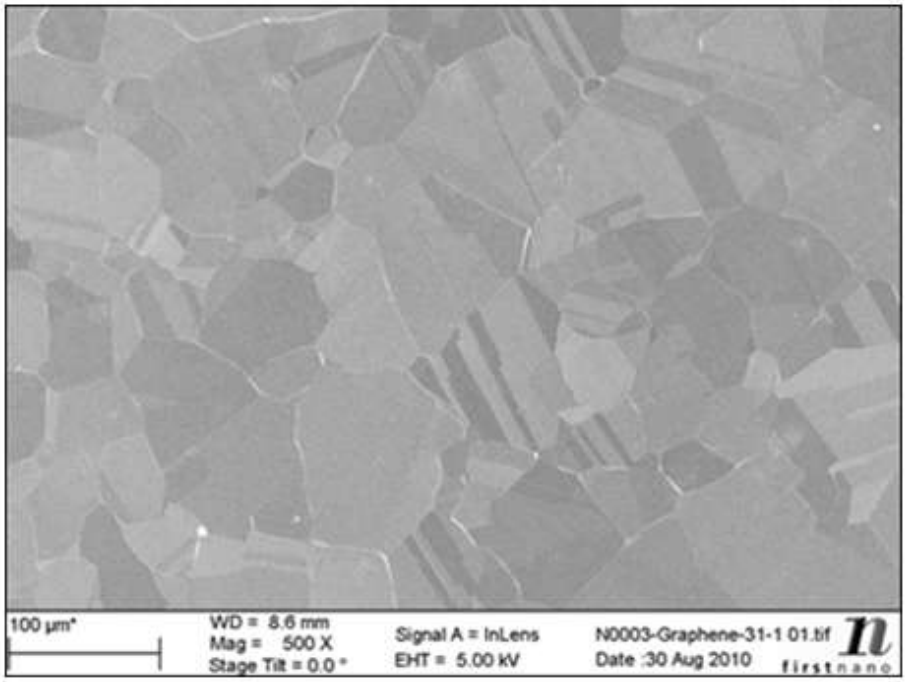
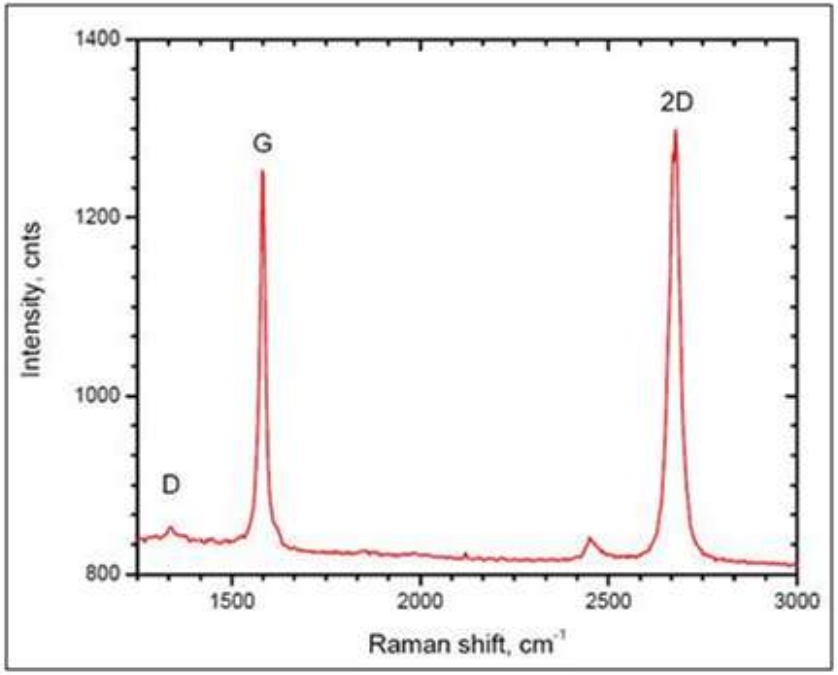


SEM:

Bilayer Graphene on Cu foil surface

Notice the different grain boundaries



Raman:

Bilayer Graphene on Cu foil surface

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Graphene Results

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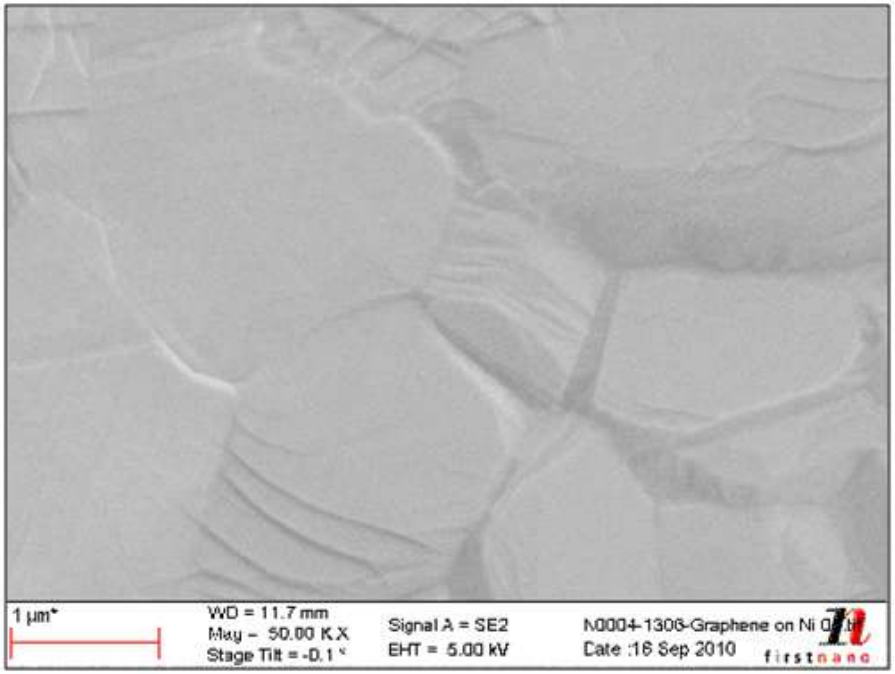
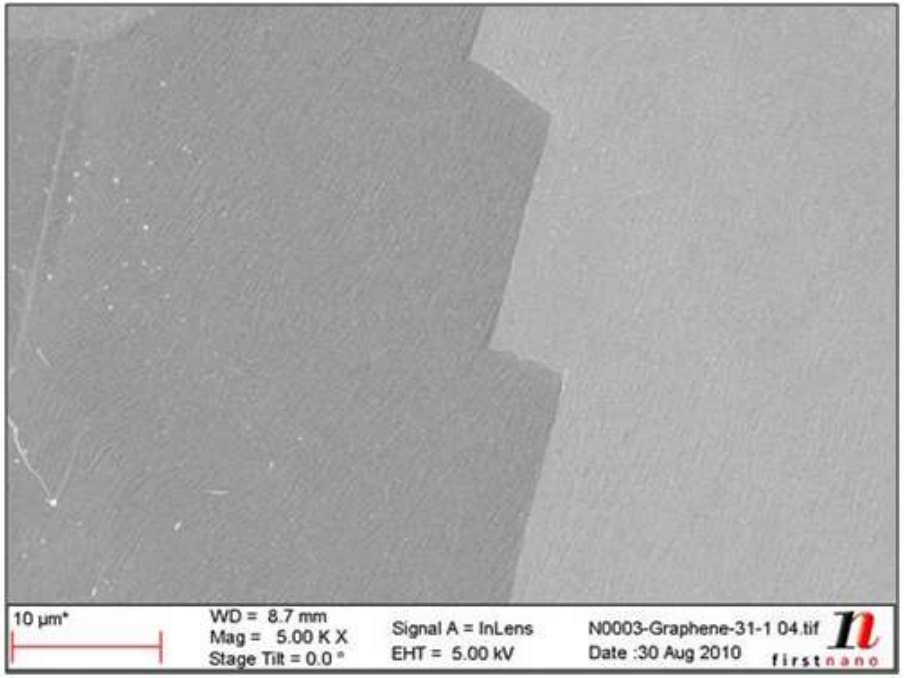


Fewer layers of Graphene on Ni film made with APCVD process using fast cooling rate of 1.5°C/s



Monolayer Graphene on Cu film foil made with LPCVD process

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Graphene Results

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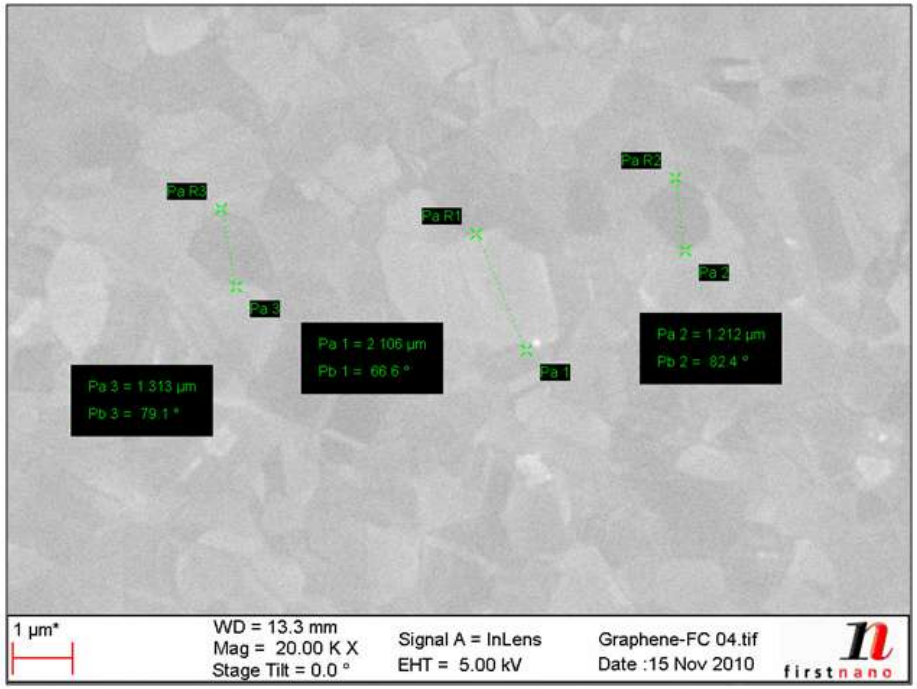
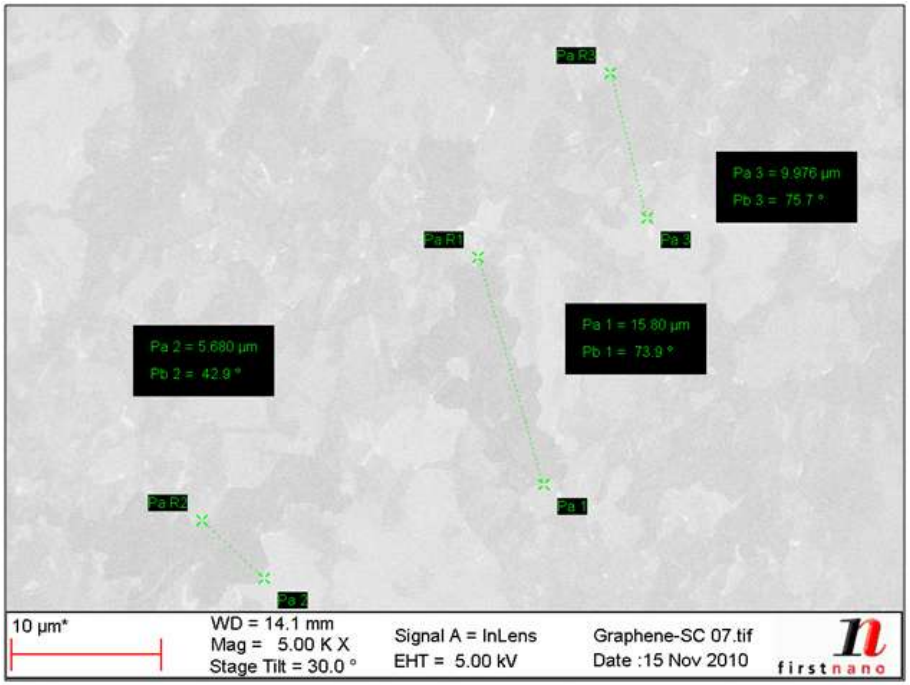


Fewer layers of Graphene on Ni film made with APCVD process using enhanced fast cooling rate of >90°C/min

(~2 µm Ni grain size)



More layers of Graphene on Ni film made with APCVD process using standard cooling rate of >21°C/min

(~6-15 µm Ni grain size)

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Graphene Results

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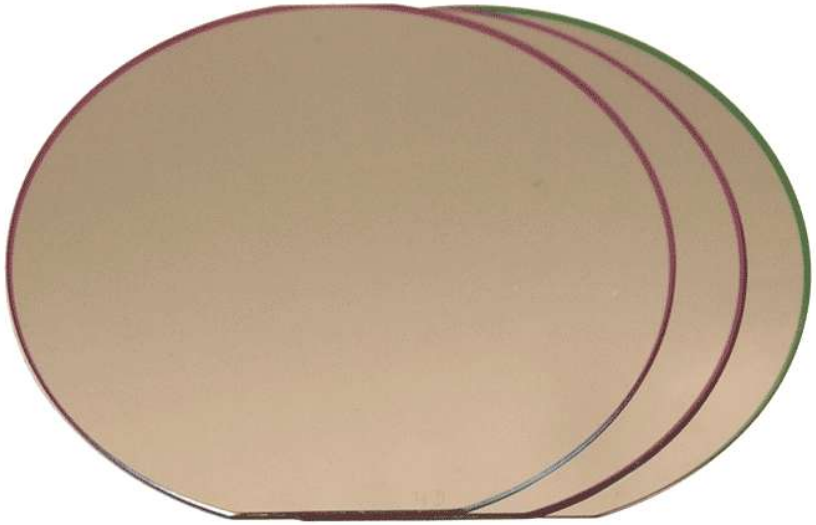
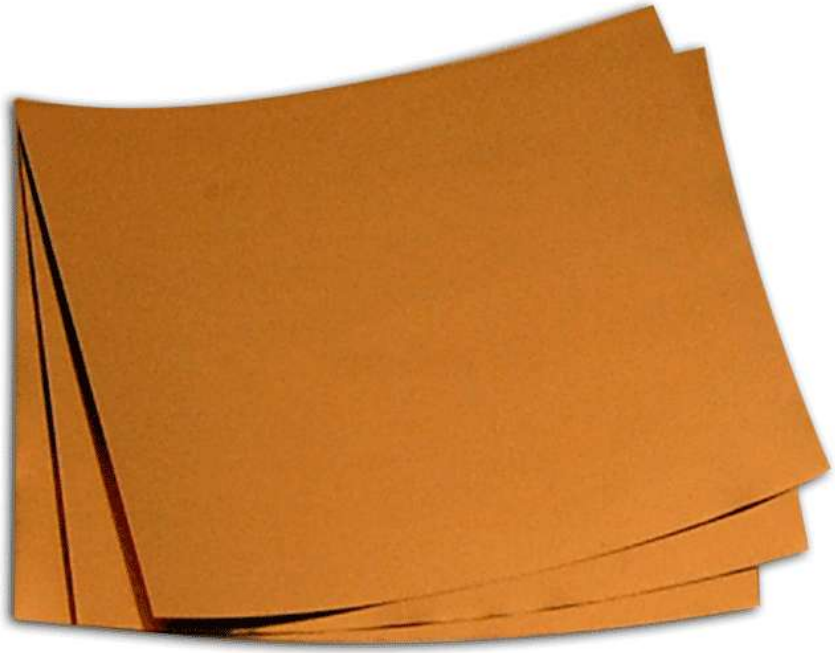


1-3 Layer Graphene
on Ni film (fast cooling)



Monolayer or Bilayer Graphene Cu foil

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EasyTube™ CVD System for Graphene Deposition

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First Nano™ offers several EasyTube™ products for Graphene deposition to accommodate different sample sizes and throughput demands.

Standard system configuration:

- 3-zone tube furnace up to 1100°C
- Standard Fast cooling Furnace (>20°C/min)
- Three Gas lines: Ar, H_2, CH_4
- Integrated vacuum control system
- Fully automatic operation
- Sample can be a flat Si wafer or Cu foil roll
  - ET101: 1" x 4"
  - ET2000: 2" x 6"
  - ET3000: 4" x 8"
  - ET6000: 4 stack furnace

EasyTube™ 101

EasyTube™ 2000

EasyTube™ 3000

EasyTube™ 6000

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Optional Configuration for Fast Cooling

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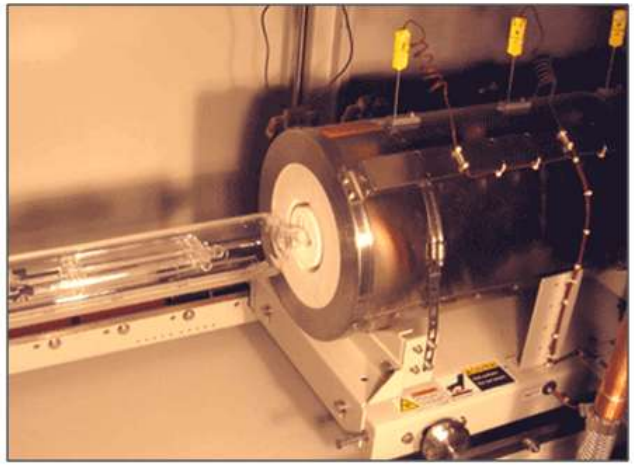
In addition to standard configurations, we also provide several options to further improve cooling rates and throughput for Graphene growth on Ni films such as:

- HotLoader™: enables loading or unloading of a sample from the hot furnace. This feature allows for faster cooling rate. It also improves throughput by eliminating the need to wait for the furnace to cool down. Available on ET2000/ET3000/ET6000.

- Rolling Furnace: Moves the hot furnace away from process zone for faster cooling rates. Requires additional floor space. Available on ET3000/ET6000.

HotLoader™ with FastCool™



Rolling Furnace

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EasyTube™ System Advantages

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- Proven Processes: Our research scientists have developed CVD Graphene growth recipes on both Ni and Cu surfaces in our Application Laboratory and we continue to make further advances.
- Precise control of temperatures and gas flows, pressure and heating / cooling rates.
- Fully automatic control, recipe driven repeatable processes with industrial strength safety systems.
- CVD*WinPRC*™ software running on PC and communicating with PLC for optimum safety and process documentation/repeatability and control
- The hot wall tube furnace provides for a uniform temperature over large areas and can grow Graphene not only on flat substrates, but also on a roll of Cu foil for increased surface area.
- Comprehensive safety interlocks, Semi-S2, S8 and CE compliant
- Fully compatible for CNT growth.
- Supporting equipment - Gas Cylinder Cabinet (gas delivery) and an Exhaust Gas Conditioning System can be provided as a turn key package.

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