## *Offering a unique approach in carbon nanotube growth technology…*

**The NanoGrowth Catalyst:**

- The first commercial R&D platform available to combine in situ sputter catalyst deposition, Island formation and nanoparticle deposition and our patented, world beating, NanoGrowth® carbon nanotube and nanomaterials growth technology.
- The platform is configured in a two chamber, three bay 19" rack platform with a 36U 19" Rack ECU.
- Hardware control by NanoSoft® our award winning control solution that provides real time fully interlocked control for manual and automatic process runs. The software offers unrivalled stability and repeatability in a deposition and growth process, which is critical for any Nanomaterial growth repeatability
- **Chamber One** – Where the substrate can be conditioned for pre-clean etch*, catalyst deposition by PVD sputter (dual sources). This chamber can be optioned with a nano particle generation system.
- **Chamber Two -** After catalyst deposition the wafer is automatically transported to the, the growth chamber for island formation (if required), and subsequent nanotube growth. Post growth annealing or backfill can also be run with a suitable hardware configuration.
- The carbon nanotube growth process can be configured as a high temperature process (450°C – 1000°C) or by using our patented low temperature module for growth at a CMOS compatible substrate temperature.
- The tool is supplied with proven recipes for catalyst and Nanostructure growth, or the researcher can quickly develop their own techniques using the supplied recipes as a reference point to work from. The company also provide full technical backup to users of the technology wishing to develop new procedures and materials
- Further load lock, and NanoCluster source can be added as research and budget demands and allows

**Advantages a glance**

- Only system to offer the ability to deposit catalyst and perform CNT growth in one tool in a controlled environment
- Result – consistent reliable, repeatable CNT growth
- The only system in the world capable of CNT growth at CMOS compatible temperatures
- Load lock wafer degassing and substrate etching controlled pre-treatment of substrate prior to entering process chamber, no contamination of chamber
- Spare load lock port for additional analysis or load lock system can be added.
- Ellipsometer ports fitted as standard
- Variable target to substrate geometry capability
- High deposition uniformity on metals and dielectrics
- Hardware/Software upgradeability on site made easy by Field buss control architecture
- Intuitive software with multi level protection
- Low maintenance and high reliability by design
- Ultra low cost of ownership

**Advantages in depth**

**Chamber One** – Where the substrate can be conditioned for pre-clean etch*, catalyst deposition by PVD sputter (dual sources). This chamber can be optioned with a nano cluster nano particle generation system.

**Magnetrons – Ease of use and low cost running**

- Run in balanced and are either run directly cooled, or indirectly cooled allowing high power metal mode deposition's without subjecting the target to stress.
- Changing dark space shields, targets and magnet modules takes less than a few minutes, requires no specialized knowledge.

**Magnetrons – High quality performance by design**

- High uniformity and long life wafer heaters capable of running O2 without contaminating the system with Co2 during depositions.
- High power target switching allows RF and DC to be distributed to all magnetrons with no cross talk at the same time as RF/DC bias is running on the substrate
- Target switching is after the automatch network only one match network required per set of magnetrons

**Chamber Two -** After catalyst deposition the wafer is automatically transported to the, the growth chamber for island formation (if required), and subsequent nanotube growth. Post growth annealing or backfill can also be run with a suitable hardware configuration

**Hardware**

- Manufactured from forged aluminium, this process chamber is extremely robust, and user friendly.
- The materials used are selected high thermal conductivity, and the design of the chamber cooling system, high thermal loads can be absorbed with minimal temperature change or effect.
- Operators are not exposed to dangerous hot surfaces that you typically see on other equipment.
- The chamber is very easily disassembled with normal lab tools with no specialist knowledge required. All parts of the chamber and service collar can be removed and replaced after cleaning.

## Chamber Two – contd/-

### Gas system

- Controlled, repeatable delivery of high purity gases to the plasma chamber critical for repeatable growth results.
- Gas module is designed and built compliant to SEMI standards for ultra high purity process gas supply and delivery.
- Mass flow controllers (MFCs), Valves, fittings and tubing are Electro polished with T1 orbital welds using construction techniques designed and developed for high purity gas control and delivery within the semiconductor industry
- All MFCsMass flow controllers are digital Profibus devices, with high speed data communications to the tool computer, and each gas line can be programmed to pulse during growth to allow for precise doping or defect creation during the growth phase.

### Vacuum pumping system Quality designed in for process advantages and low maintenance

- From atmospheric pressure to 10-2 torr, the 2-stage chemical series rotary pump runs the process.
- When the chamber has been opened or a cleaning plasma been run, the turbo pump, pumps the chamber to high vacuum.
- Turbo pump isolated during processing, so no aggressive gases are pumped through it at any time.
- The rotary pump is a chemical series Fomblin filled pump, and is designed to run with aggressive gases.
- The equipment is fitted with precision vacuum gauging for display of pressure from atmospheric pressure down to 1 x 10-9 torr.
- Process pressure gauging is from an MKS High precision Baratron

### Pressure Control

- Stable process pressure control is critical for repeatable and reliable Nanomaterials growth.
- The NanoGrowth tool uses true downstream pressure control via a high speed, adaptive throttle valve system.
- Controlling process pressure with difficult to pump gases like hydrogen, demands high speed operation and on the fly auto tuning, as process gas flow rates can vary by 100’s of percent during a run.
- The NanoGrowth Series tools use field proven technology developed in real world operating conditions over many years. Our latest high-speed throttle valve system is ported for high-pressure flow regimes, which other manufacturers valves find difficult or impossible to cope with. The butterfly valve is direct driven with an open to close time of 500 milliseconds

### Process Chuck/Chamber cleaning

- After many growth cycles, carbon can build up causing contamination problems.
- The tool is fitted with a fixed flow rate oxygen delivery line, which is used in combination with the pressure control system to run RF Oxygen plasma at reduced pressures. This allows rapid cleaning of build-ups of carbon and other contaminants from the chucks and surrounding areas simplifying operation maintenance and enhancing the repeatability of results

**Upgradable as research needs expand**

- Nanocluster source port designed in and can be added with minimal hardware, software changes
- Spare lock port for additional analysis or load lock system can be optioned
- A variety of analysis tool can be supported
- Upgradeability on site at later dates due to Field buss control architecture
- Software enables easy upgrades without need for new software release

**Simplicity in operation**

- Wafer transfer between load lock and chambers uses an LRP linear rack and pinion transporter system. This is a positively engage drive mechanism that gives repeatable manual or automatic wafer transport with out the potential to drop the wafer or rotate it
- LRP system gives 0.1mm repeatability with absolutely no rotation so the wafer cannot be dropped.

  (By contrast magnetic transporters which can only be manual and require a high skill to operate without dropping the wafer)

- Software 'canned cycles' are included for operators who are not skilled in the use of deposition systems
- Valves and other components are automatically put in the correct state to allow successful pumping or venting to atmosphere or high vacuum
- Control system knows, and reports on, which valves need to be open or closed

## Software

### 1 – NanoSoft - Control, Ease of use, intelligent analysis

- With Profibus control system architecture we have highly accurate and repeatable signal control to all sensors, power supplies and controllers like MFC's.
- A fully digital it avoids the shortcomings of Analogue control systems, such systems, based on lab view software and analogue pc cards, are unable to match performance and repeatability unless each analog channel is calibrated for a 'sweet spot', we avoid this issue.

### 2 – Ease of use

- Programming of recipes is intuitive and straight forward
- Our experience is that operators can be writing their own recipes with an hour of first using the software
- Automatic runs are used after developing a successful process and then wanting to repeat it over and over again, with good wafer to wafer repeatability

### 3 - Process variable trending

- Process variables are trended and capable of real time visualization in interrogation by the user
- Trends are archived and exported from the tool and can be imported to statistical data and analysis software like excel
- Each trend has a wafer identifier name so can be accurately tracked to end or developed product

### 4 – Protection and Control

- Control front end is security protected with passwords for operators, engineers and programmers, allowing usage to be tracked at any time
- Our NanoSoft software offers the user to have full manual and real time control of all process variables that are required to deposit a thin film
- Operators have full manual control – but - the NanoSoft system monitors each variable and action in real time and prevents the operator triggering a condition that is unsafe for the equipment
- This interlocking is both high and low level and operated at all times the system is running, unless commanded otherwise by engineering mode
- Touch screen control system removes the need for keyboards etc from the clean room, less real estate
- Full alarm reporting and logging for all hard and software alarms

## FAQs On CNT growth and system operation:

**1. What is the density of CNTs we can grow and how do we control it?**

A: CNT density is really a function of how the catalyst is deposited and the island formation technology. Our technology results in minimal agglomeration and results in density between 10E10 and 10E12 depending on which process we use. The catalyst tool also has an option of an Nanocluster source with mass filtered cluster size collection and can result in optimum conditions better than 10e12 nucleation sites as deposited.

**2. What is the availability of recipes ?**

A: Our nanogrowth tools are supplied with recipes for controlled growth of MWNTs in a very predictable way. SWNT recipes are also available, but these are harder to control as you will know. It does depend on the nature of the catalyst put down. On a 1000c system we do have control over the catalyst deposition, this will depend on another of your systems, see comments above. We think result are more predictable with the in-situ deposition the Catalyst tool offers

**3. What are the growth conditions of SWNT and MWCNT( temperature, gas, pressure,...) ?**

A: Process dependent and we can discuss recipes depending on what you want to achieve, please see above comments .

**4. What are the required Gases?**

A: Minimum C2H2, NH3, H2, N2, but would benefit from additional CH4, Ar +O2 for cleans and helium for LT process. We use SNS "gas doubling" we use digital MFC and compatible gases are flowed through the same MFC, providing you with a choice of 7 gases from 4 MFC's. More can be optioned

**5. Have you deposited any material on CNTs and how their compatibility to the materials is are being used in microelectronics?**

A: We have looked at TaN Copper, gold, Co and some others with no major issues yet. Perhaps we should ask if you have had compatibility issues and we would be happy to discuss at the later meeting or conference call

**6. How small are the CNTs you can deposit?**

A: This really does depend on the catalyst island size, but we don't believe our system will have a limit that restricts research. Question from us What is the feature size you want to create?

**7. How long will take to perform deposition (loading, deposition, venting,...) ?**

A: This depends on whether the system has a load lock or not, but with a load lock the time is only a few minutes.

**8. How often is the cleaning of the system**

Answer: It is highly process dependant but a typical weekly clean with O2 plasma takes 1 hr and run by software.

**9. Because system is in high temperature do we need load lock to save time and prevent hazardous gases such as NH3?**

Answer: Both systems will use NH3 and purge the chamber clean before access is granted, but a load lock is recommended if cost constraints allow