NANO-MASTER, Inc.

HYBRID PECVD/PEALD SYTEM

NLP-4000

The NANO-MASTER NLP-4000 is a stand-alone hybrid PECVD/PEALD system for performing plasma-enhanced atomic layer deposition (PEALD) as well as plasma-enhanced chemical vapor deposition (PECVD). Both processes can be performed in a single chamber without any mechanical reconfiguration. It is also capable of depositing a stack of layers of PEALD/PECVD in the same process. It is CE and SEMI Standards-compliant and capable of processing up to 8” wafers. The system is controlled with LabVIEW software and features three-level password-controlled user authorization using a touch-screen monitor. The system is fully automated, safety-interlocked, recipe-driven, with status indicators and graphic and alphanumeric displays.

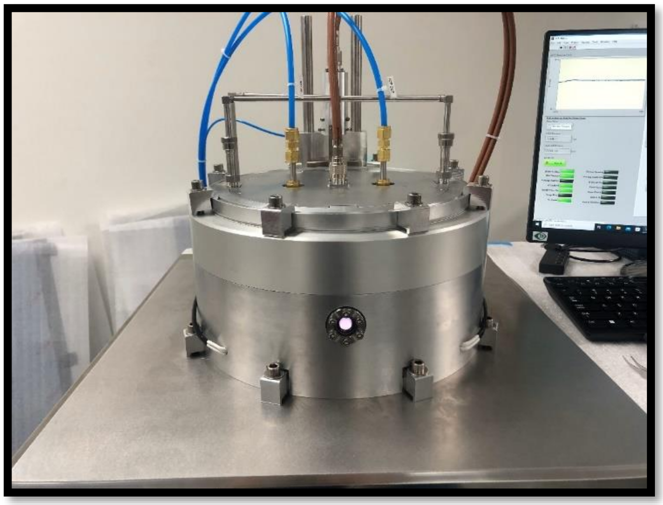


Fig 1. PEALD/PECVD Plasma ON

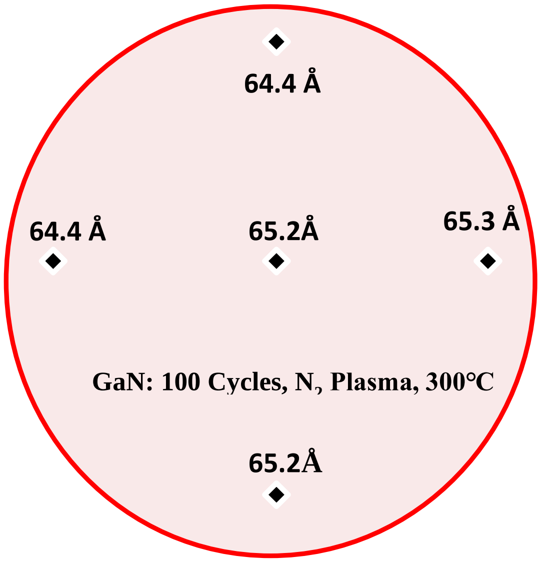


Fig 2. Deposition of GaN using PEALD

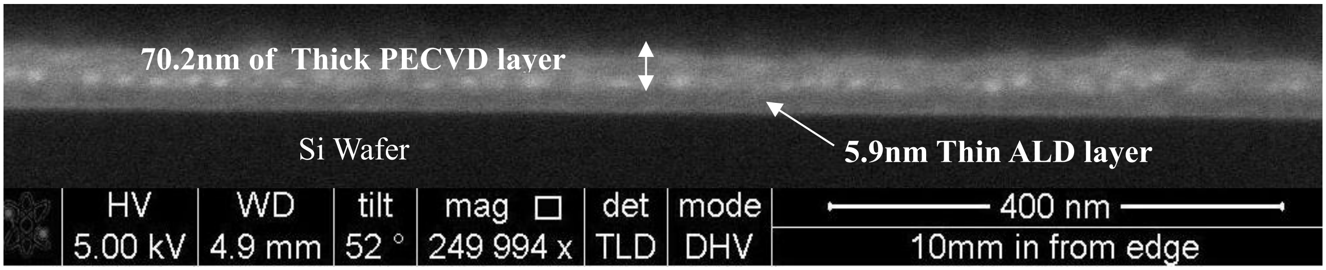
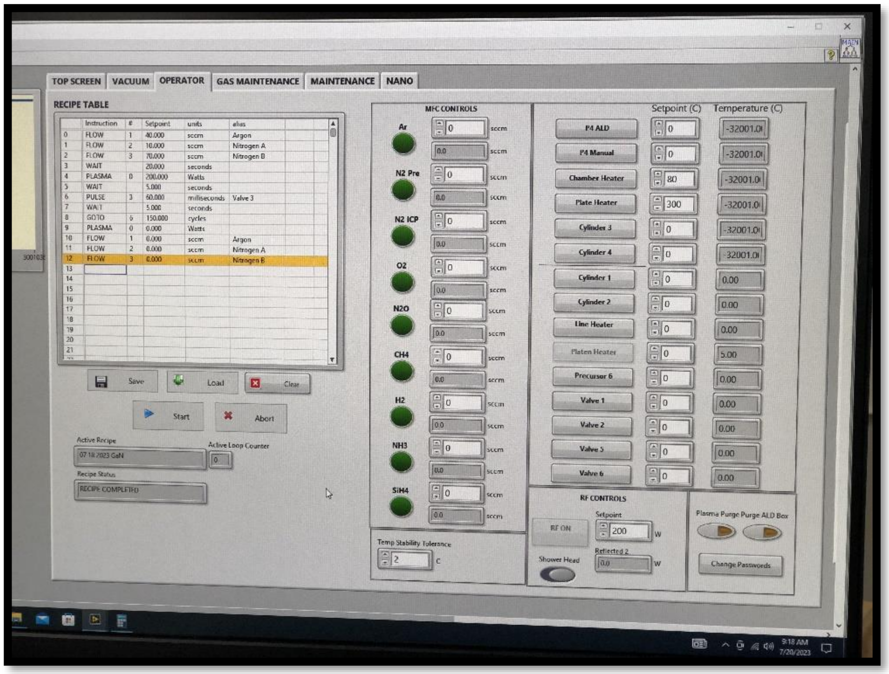


Fig 3. SEM image shows thick PECVD GaN (70.2nm) on top of thin PEALD GaN (5.9nm) deposited in a single process using NLP-4000 hybrid PECVD/PEALD system



	Instruction	#	Setpoint	units	alias
0	FLOW	1	40.000	sccm	Argon
1	FLOW	2	10.000	sccm	Nitrogen A
2	FLOW	3	70.000	sccm	Nitrogen B
3	WAIT		20.000	seconds	
4	PLASMA	0	200.000	Watts	
5	WAIT		5.000	seconds	
6	PULSE	3	60.000	milliseconds	Valve 3
7	WAIT		5.000	seconds	
8	GOTO	6	150.000	cycles	
9	PLASMA	0	0.000	Watts	
10	FLOW	1	0.000	sccm	Argon
11	FLOW	2	0.000	sccm	Nitrogen A
12	FLOW	3	0.000	sccm	Nitrogen B
13					
14					
15					
16					
17					
18					
19					
20					
21					

Active Recipe: 07 18 2023 GaN
Active Loop Counter: 0
Recipe Status: RECIPE COMPLETED

MFC CONTROLS	Setpoint	Reading
Ar	0 sccm	0.0 sccm
N2 Pre	0 sccm	0.0 sccm
N2 ICP	0 sccm	0.0 sccm
O2	0 sccm	0.0 sccm
N2O	0 sccm	0.0 sccm
CH4	0 sccm	0.0 sccm
H2	0 sccm	0.0 sccm
NH3	0 sccm	0.0 sccm
SiH4	0 sccm	0.0 sccm

Temp Stability Tolerance: 2 C

	Setpoint (C)	Temperature (C)
P4 ALD	0	-32001.0
P4 Manual	0	-32001.0
Chamber Heater	80	-32001.0
Plate Heater	300	-32001.0
Cylinder 3	0	-32001.0
Cylinder 4	0	-32001.0
Cylinder 1	0	0.00
Cylinder 2	0	0.00
Line Heater	0	0.00
Platen Heater	0	5.00
Precursor 6	0	0.00
Valve 1	0	0.00
Valve 2	0	0.00
Valve 5	0	0.00
Valve 6	0	0.00

RF CONTROLS Setpoint: 200 W
Reflected 2: 0.0 W

Fig 4. Easy change of PEALD to PECVD mode through LabVIEW software

NLP-4000 System includes:

<u>Chamber</u>: 13" (330mm) Ni-plated Al chamber with a pneumatically lifted top, a 2" viewport, and heated chamber walls. The chamber can be pneumatically lifted to allow for cleaning of the chamber walls. In the upper portion of the chamber, plasma is terminated with a perforated grounded metal plate that is aligned with an underlying ceramic plate, effectively isolating the lower ALD chamber, which contains the substrate, from plasma species. A load lock that is mounted on the right-hand side of the chamber enables automatic loading and unloading of the substrate.

<u>NM ICP source:</u> NANO-MASTER's own ICP source with downstream plasma, Ar MFC, and 600W RF supply with an auto tuner. The ICP source contains two aligned plates: a grounded metal plate and a ceramic plate. In conjunction, these plates allow for uniform showerhead gas distribution. In addition, due to these plates, the plasma is able to be dissipated within a short distance, which prevents damage to a film during a process.

NANO-MASTER's patented continuous flow process cuts the process cycle time in half and doubles throughput. **"Techniques and systems for continuous flow plasma-enhanced atomic layer deposition," Patent No. 9,972,501 B1.** Alternatively, in PECVD mode, the grounded metal plate is directly powered by RF, which generates plasma within the lower portion of the chamber.

Precursors distribution: In a thermal ALD process, the reactants and oxidizer are let into the chamber from underneath and flow horizontally, level with the substrate. For a plasma ALD process, reactants such as O2, N2, and H2 flow in from the top of the chamber, and the precursor flows horitonally, level with the substrate. In PECVD deposition, reactive gases are distributed through a gas ring that surrounds the substrate.

Platen: The substrate platen is made from stainless steel and is capable of handling up to 8” wafers. The platen heater, capable of reaching temperatures of up to 400º C, contains no exposed wires or vacuum feedthroughs and is controlled through a PID temperature controller. In addition, platen biasing options are available to control stress in thick PECVD films.

Automaic Loading and Unloading of Wafer: The NLP-4000 incorporates a load-lock mechanism that allows the chamber to maintain vacuum while transferring a wafer into the chamber. The load-lock chamber maintains cleanliness and low vacuum through an external dry scroll pump. Magnetic sensors within the load lock are used to monitor the position of both the wafer load arm and the load lock door. Wafer loading can be done automatically through the load lock or manually by pneumatically lifting the chamber top at atmospheric pressures.

Precursor Box: The precursor box has options for up to six 150-ml cylinders: five precursors and an oxidizer, each with its own manual valve. Cylinders can easily and safely be removed by flushing the precursor line with N2 after the manual valve for the precursor is closed. The precursor box is enclosed and can be vented with N2. In addition, the precursor box has a built-in glove, which allows for safe access to the cylinders.

Filter: An ALD filter mounted at the chamber exhaust. The system uses a high surface area ALD filter that maintains a high conductance through a linear multi-cell design. The filter is heated with a cartridge and traps unused precursors.

MFCs: Options for Ar, N_2, H_2, O_2, SiH_4, CH4, and NH_3 mass flow controllers (MFC's) with SS gas lines and pneumatic shut-off valves. The MFCs provide accurate flow control and monitoring for delivering carrier or reactive gases. Pneumatic high-vacuum shut-off valves are placed on the MFC's outlets for user gas control during a process through the main system control software. All gas lines leading to the chamber are made of stainless steel with ultra-clean orbital welded VCR fittings..

Gas Pod: : Separate gas pod for reactive/toxic gasses with gas leak sensors. All gas lines are flushed with N_2 at the end of a process.

Bubblers: Provision for 150cc bubblers for Silicon precursor or Gallium precursor is provided for depositing PECVD films.

Gauges: Wide Range Gauge - The system background pressure is measured using an Edwards WRG-D (wide range gauge) enabling it to cover a pressure range from atmosphere to 10^{-9} torr. The gauge is mounted underneath the base plate with a 90-degree elbow to minimize contamination and improve gauge reliability.

Pirani – Edwards APGX active linear convection gauge. To monitor process pressure during the process, a linear convection gauge is used. It is mounted onto the baseplate and can monitor the pressure during the process with less sensitivity to process conditions than wide-range gauge.

Pumps: Turbomolecular Pump - Pfeiffer ATH 500 MT, magnetically levitated, corrosive and heated. The turbo is mounted underneath the system baseplate through the ALD filter housing. The ATH 500 MT has a N_2 pumping capacity of 500 l/s and is controlled through the main system control software.

Backing Pump – Ebara EV10Sdry pump. It is used as a backing pump for the turbo and has a pumping capacity of 35cfm. The dry pump is mounted at the chamber exhaust. The vacuum system configuration provides the highest conductance and lowest base pressure for given pump and chamber by mounting the turbo directly into the chamber. In a clean system, base pressure will reach mid 10^{-7} Torr and in overnight, it will be 10^{-6} Torr range in 20 minutes of pumping.

Base Pressure: Mid 10^{-7} Torr in a clean system.

Process Control System: PC controlled with LabVIEW software featuring three levels password-controlled user authorization and touch screen monitor. The system is fully automated, safety-interlocked, recipe driven, contains status indicators, graphic and alphanumeric displays.

Facility Requirements:

a

Footprint – 660mm x 1118mm

Input Power – 208/400VAC, 30A/phase, 50/60Hz. Hardwire the line cord to a source capable of delivering the required power.

Compressed Air - Compressed air (CDA) is used in this system for operating pneumatic valves, chamber lift and other components. The system requires 90psi of CDA.

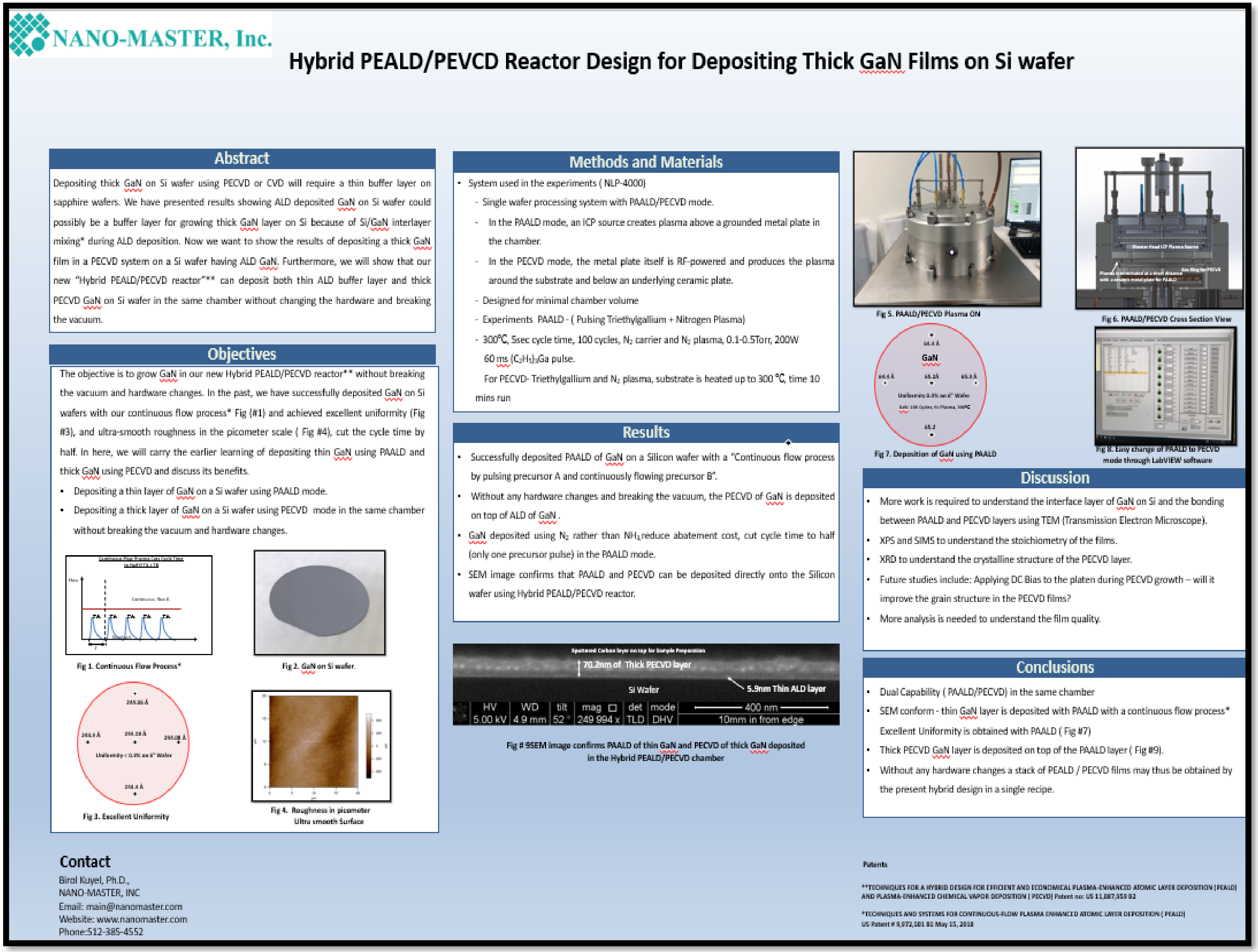
Nitrogen - Nitrogen tank is used for venting of chamber, precursor pod, gas pod, and turbo bearing. The system requires 10-15psi of Nitrogen.

Process Gases - The process gas input connections are ¼” Swagelok fittings. Process gas pressure must be no more than 20psi. For this system, the required gases are of research grade purity.

Exhaust - The output/exhaust of the backing pumps must be connected to an exhaust line for the building. The connection fittings for the backing pump exhausts are KF25 (or NW25). The building exhaust line must be able to handle the effluent produced by the process.

Poster presented at AVS ALD/ALE 2023 - Hybrid PEALD/PEVCD Reactor Design for Depositing Thick/Thin GaN Films on Si wafer.

NANO-MASTER, Inc.



NANO-MASTER, Inc.

Hybrid PEALD/PEVCD Reactor Design for Depositing Thick GaN Films on Si wafer

Abstract

Depositing thick GaN on Si wafer using PECVD or CVD will require a thin buffer layer on sapphire wafers. We have presented results showing ALD deposited GaN on Si wafer could possibly be a buffer layer for growing thick GaN layer on Si because of Si/GaN interlayer mixing* during ALD deposition. Now we want to show the results of depositing a thick GaN film in a PECVD system on a Si wafer having ALD GaN. Furthermore, we will show that our new "Hybrid PEALD/PECVD reactor"** can deposit both thin ALD buffer layer and thick PECVD GaN on Si wafer in the same chamber without changing the hardware and breaking the vacuum.

Objectives

The objective is to grow GaN in our new Hybrid PEALD/PECVD reactor** without breaking the vacuum and hardware changes. In the past, we have successfully deposited GaN on Si wafers with our continuous flow process* Fig (#1) and achieved excellent uniformity (Fig #3), and ultra-smooth roughness in the picometer scale (Fig #4), cut the cycle time by half. In here, we will carry the earlier learning of depositing thin GaN using PAALD and thick GaN using PECVD and discuss its benefits.

- Depositing a thin layer of GaN on a Si wafer using PAALD mode.
- Depositing a thick layer of GaN on a Si wafer using PECVD mode in the same chamber without breaking the vacuum and hardware changes.

Fig 1. Continuous Flow Process*

Fig 2. GaN on Si wafer.

Fig 3. Excellent Uniformity

Fig 4. Roughness in picometer
Ultra smooth Surface

Methods and Materials

- System used in the experiments (NLP-4000)
  - Single wafer processing system with PAALD/PECVD mode.
  - In the PAALD mode, an ICP source creates plasma above a grounded metal plate in the chamber.
  - In the PECVD mode, the metal plate itself is RF-powered and produces the plasma around the substrate and below an underlying ceramic plate.
  - Designed for minimal chamber volume
  - Experiments PAALD - (Pulsing Triethylgallium + Nitrogen Plasma)
  - 300°C, 5sec cycle time, 100 cycles, N_2 carrier and N_2 plasma, 0.1-0.5Torr, 200W 60 ms $(C_2H_5)_3Ga$ pulse.

    For PECVD- Triethylgallium and N_2 plasma, substrate is heated up to 300 °C, time 10 mins run

Results

- Successfully deposited PAALD of GaN on a Silicon wafer with a "Continuous flow process by pulsing precursor A and continuously flowing precursor B".
- Without any hardware changes and breaking the vacuum, the PECVD of GaN is deposited on top of ALD of GaN .
- GaN deposited using N_2 rather than NH_3 reduce abatement cost, cut cycle time to half (only one precursor pulse) in the PAALD mode.
- SEM image confirms that PAALD and PECVD can be deposited directly onto the Silicon wafer using Hybrid PEALD/PECVD reactor.

Fig # 9SEM image confirms PAALD of thin GaN and PECVD of thick GaN deposited in the Hybrid PEALD/PECVD chamber

Fig 5. PAALD/PECVD Plasma ON

Fig 6. PAALD/PECVD Cross Section View

Fig 7. Deposition of GaN using PAALD

Fig 8. Easy change of PAALD to PECVD mode through LabVIEW software

Discussion

- More work is required to understand the interface layer of GaN on Si and the bonding between PAALD and PECVD layers using TEM (Transmission Electron Microscope).
- XPS and SIMS to understand the stoichiometry of the films.
- XRD to understand the crystalline structure of the PECVD layer.
- Future studies include: Applying DC Bias to the platen during PECVD growth – will it improve the grain structure in the PECVD films?
- More analysis is needed to understand the film quality.

Conclusions

- Dual Capability (PAALD/PECVD) in the same chamber
- SEM conform - thin GaN layer is deposited with PAALD with a continuous flow process* Excellent Uniformity is obtained with PAALD (Fig #7)
- Thick PECVD GaN layer is deposited on top of the PAALD layer (Fig #9).
- Without any hardware changes a stack of PEALD / PECVD films may thus be obtained by the present hybrid design in a single recipe.

Contact

Birol Kuyel, Ph.D.,
NANO-MASTER, INC
Email: main@nanomaster.com
Website: www.nanomaster.com
Phone:512-385-4552

Patents

**TECHNIQUES FOR A HYBRID DESIGN FOR EFFICIENT AND ECONOMICAL PLASMA-ENHANCED ATOMIC LAYER DEPOSITION [PEALD] AND PLASMA-ENHANCED CHEMICAL VAPOR DEPOSITION [PECVD] Patent no: US 11,087,959 B2

*TECHNIQUES AND SYSTEMS FOR CONTINUOUS-FLOW PLASMA ENHANCED ATOMIC LAYER DEPOSITION (PEALD]
US Patent # 9,972,501 B1 May 15, 2018