This instruction covers the capabilities, operation, and compatibilities of the APEX SLR HDPCVD system. This workstation is located in the R bay of the cleanroom and is only to be operated by trained and authorized users.

1 SAFETY REQUIREMENTS

1.1 General Safety Information

- Safety glasses must be worn whenever in the cleanroom, except when using a microscope or when wearing protective goggles.
- Be mindful of cross-contamination of controls, equipment, and tools.

2 PROCESS MATERIALS

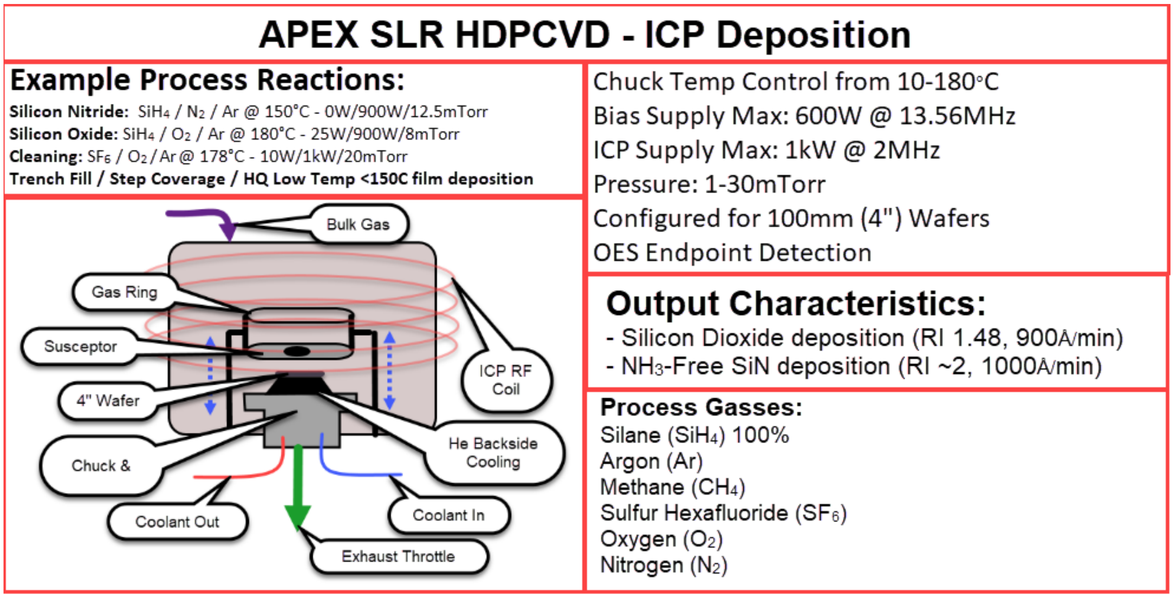
2.1 Equipment

Wafer handling tweezers

2.2 Gasses

N_2	Nitrogen
Ar	Argon
O_2	Oxygen
SF_6	Sulfur Hexafluoride
He	Helium
SiH_4	**Silane 100% (Pyrophoric)**
CH_4	**Methane (Flammable)**

3 System Overview



APEX SLR HDPCVD - ICP Deposition

Example Process Reactions:

Silicon Nitride: SiH_4 / N_2 / Ar @ 150°C - 0W/900W/12.5mTorr
Silicon Oxide: SiH_4 / O_2 / Ar @ 180°C - 25W/900W/8mTorr
Cleaning: SF_6 / O_2 / Ar @ 178°C - 10W/1kW/20mTorr
Trench Fill / Step Coverage / HQ Low Temp <150C film deposition

Chuck Temp Control from 10-180°C
Bias Supply Max: 600W @ 13.56MHz
ICP Supply Max: 1kW @ 2MHz
Pressure: 1-30mTorr
Configured for 100mm (4") Wafers
OES Endpoint Detection

Output Characteristics:

- Silicon Dioxide deposition (RI 1.48, 900Å/min)
- NH_3-Free SiN deposition (RI ~2, 1000Å/min)

Process Gasses:

Silane (SiH_4) 100%
Argon (Ar)
Methane (CH_4)
Sulfur Hexafluoride (SF_6)
Oxygen (O_2)
Nitrogen (N_2)

R. Hosler - Purdue University - Birck Nanotechnology Center - Discovery Park - 2019

Figure 1 - APEX HDPCVD Capabilities

3.1 System Capabilities

Process capabilities currently available include Silicon Dioxide (SiO_2) deposition on Si & SiC substrates, ammonia-free Silicon Nitride (SiN_x) deposition on Si substrates, Amorphous Silicon (a-Si:H) and cleaning etch. A future capability that is expected is Silicon Carbide (SiC) deposition. The system is designed for trench fill, step coverage, and high-quality low-temperature film deposition.

The APEX is capable of inductively coupled high-density plasma chemical vapor deposition on 4” wafer substrates or samples on a 4” pocket wafer. The system features a load lock chamber that is capable of loading a single 4” wafer at a time. The process chamber is temperature controlled from 50 to 60°C and the electrode can be set from 10-170°C. The substrate is secured to the electrode via backside helium cooling and a mechanical substrate clamp.

3.2 Theory of Operation (See ref. 5.2)

HD Plasma CVD processing is typically differentiated from regular PECVD by the use of two plasma sources. The ICP source controls the plasma density and ion flux, while the bias power source connected to the wafer and chuck controls the voltage between the wafer and plasma. Typical plasma densities of HD systems can be roughly 100x more dense than standard PECVD systems.

The major benefits of this configuration are that the processes can be completed at much lower temperatures (<180°C), film density is higher, Hydrogen content is lower, and there is less ion damage. Silicon Nitride recipes with HDPCVD are performed without NH_3, reducing the Hydrogen content of the film.

4 Operation

4.1 Logging In

After enabling the system in iLabs, the screens should turn on. At this point the Cortex software should be running on the lower screen and the Endpoint Works software should be running on the upper screen. The Cortex software controls the tool operation while the Endpoint Works software controls the spectroscopy-based decisions such as cleaning etch termination. The system should say ‘System Ready!’ in the main Cortex screen. Click on ‘User Login’ in the upper right-hand portion of the screen. Select the ‘Operator’ user and enter the password, which is ‘op’. Click ‘Log In’.

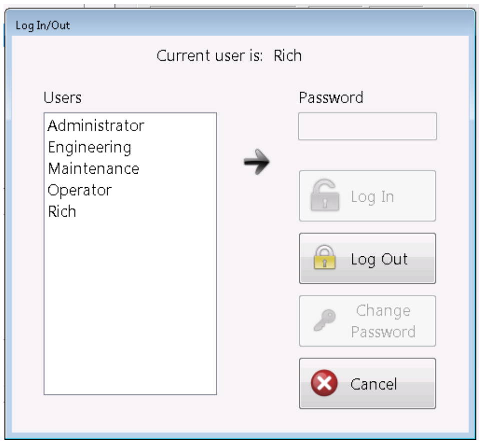
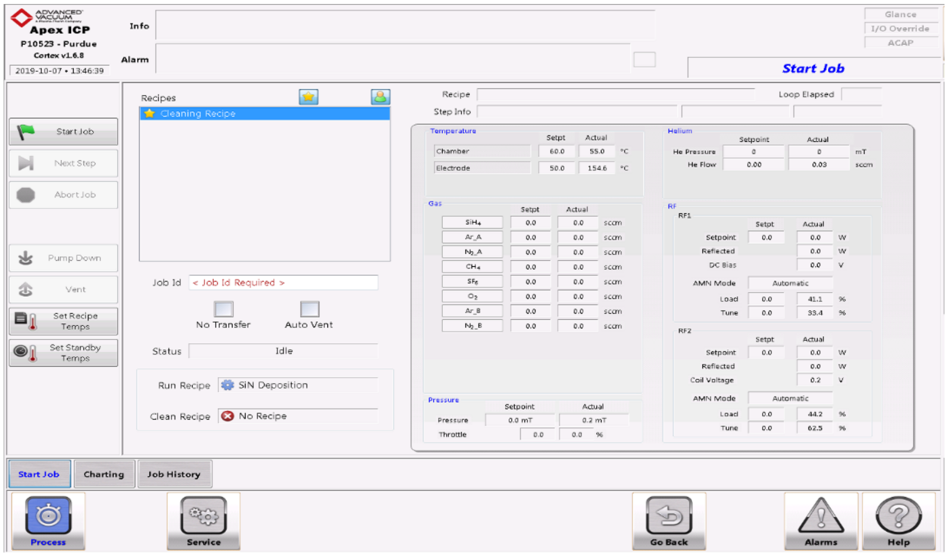

Current user is: Rich

Figure 2 - Login Screen



Apex ICP
P10523 - Purdue
Cortex v1.6.8
2019-10-07 • 13:46:39

Start Job

Recipes
Cleaning Recipe

Job Id: < Job Id Required >

☐ No Transfer ☐ Auto Vent

Status: Idle

Run Recipe: SiN Deposition
Clean Recipe: No Recipe

Recipe
Loop Elapsed
Step Info

Temperature

	Setpt	Actual	
Chamber	60.0	55.0	°C
Electrode	50.0	154.6	°C

Helium

	Setpoint	Actual	
He Pressure	0	0	mT
He Flow	0.00	0.03	sccm

Gas

	Setpt	Actual	
SiH_4	0.0	0.0	sccm
Ar_A	0.0	0.0	sccm
N_2_A	0.0	0.0	sccm
CH_4	0.0	0.0	sccm
SF_6	0.0	0.0	sccm
O_2	0.0	0.0	sccm
Ar_B	0.0	0.0	sccm
N_2_B	0.0	0.0	sccm

Pressure

	Setpoint	Actual	
Pressure	0.0 mT	0.2 mT	
Throttle	0.0	0.0	%

RF

RF1

	Setpt	Actual	
Setpoint	0.0	0.0	W
Reflected		0.0	W
DC Bias		0.0	V
AMN Mode	Automatic		
Load	0.0	41.1	%
Tune	0.0	33.4	%

RF2

	Setpt	Actual	
Setpoint	0.0	0.0	W
Reflected		0.0	W
Coil Voltage		0.2	V
AMN Mode	Automatic		
Load	0.0	44.2	%
Tune	0.0	62.5	%

Figure 3 - Default Recipe Screen

4.2 Sample Preparation

All samples must be either 4” wafers or reside on a 4” pocket wafer. Samples and wafers must be cleaned using the TAI (Toluene, Acetone, IPA) process followed by either Piranha or RCA cleaning as appropriate for sample compatibility. See the wiki - Cleaning for more information on sample cleaning and preparation to avoid tool contamination.

4.3 Choosing a Recipe

At this point you should see the default screen ‘Start Job’, which is in the ‘Process’ section. Select the recipe that you wish to perform and click it so that it is highlighted. Click ‘Set Recipe Temps’ to set the electrode chiller and process heater running to the recipe setpoints. This may take 10-15 minutes typically for the electrode and could take as long as a half hour for the process chamber to reach the desired setpoints.

4.4 Loading Procedure

To load your sample into the system, either click on ‘Vent’ on the ‘Start Job’ screen in the ‘Process’ section or press the ‘Vent’ button on the load lock console. The green circle on the load lock control panel should flash, indicating that venting is in progress. After about a minute, the light should go solid and the load lock lid can be lifted. Using properly cleaned tools, load your 4” wafer sample onto the loading arm. Make sure that the flat is aligned with the to bottom pins and that at least one of the upper pins is touching the wafer.

Take care not to move the arm at this point.

If the arm is moved out of position, stop immediately and contact an engineer to assess the situation.

Damage to the equipment and sample may result from proceeding.

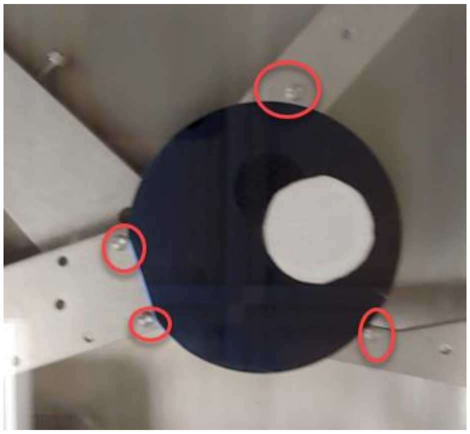


Figure 4 - Wafer Loading

DO NOT LOOK DIRECTLY AT PLASMA VIA VIEWPORTS DURING PROCESSING!
UV LIGHT IS EMITTED WHICH CAN BE HAZARDOUS TO YOUR EYES

4.5 Process Execution

Close the load lock lid and either click on the ‘Pump Down’ button in the Cortex software left side or press the ‘Vent’ button on the load lock console. Wait for the load lock to depressurize, as indicated by the blinking light on the control panel changing to solid.

Note: *If you are using SiC or any other type of red-laser transparent material, the system won’t detect the wafer and it needs to be manually loaded. Ask for assistance from the research engineer before doing this.*

When the sample is loaded and the process temperatures are ready, fill out an informative name into the ‘Job ID’ field. Ensure that ‘No Transfer’ and ‘Auto Vent’ boxes are unchecked. Click on the green flag button ‘Start Job’ in the upper left corner to begin the process. If the recipe is such that a variable amount of time is specified, you will be asked to set the steady state time value at this point.

From this point the system takes over and begins pumping down the load lock. The slit valve between the load lock and process chamber opens, and the mechanical arm linkage delivers the wafer to the chuck. Pins rise up from the chuck to lift the wafer off of the arm. The arm is then retracted and the slit valve closed. The pins lower the wafer onto the chuck and a ceramic plate is lowered onto the chuck, framing the surface of the sample around the main plasma target. The wafer is drawn to the electrode chuck with Helium at a specific vacuum set point.

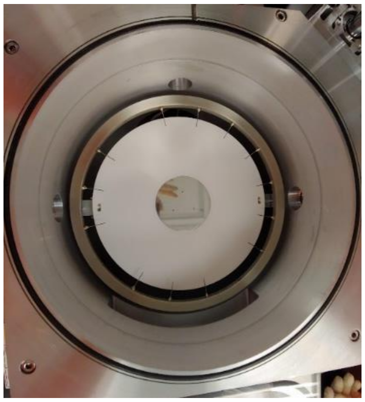


Figure 5 – Process Chamber

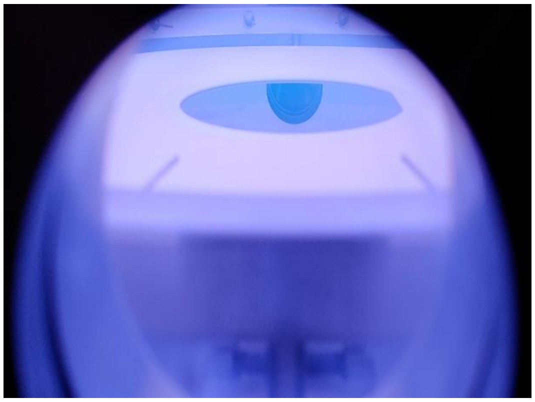


Figure 6 – Plasma Process

The progress of the recipe can be followed in the status area of the right-hand side of the screen. If a variable is waiting to settle before proceeding, it will be shaded yellow. Gasses are pumped into the process chamber both in bulk and via a gas ring which is lowered over the sample with the ceramic plate. Pressure is maintained at a specific target via a throttle valve on the exhaust. A ‘plasma strike’ power configuration is applied which ignites the first stage, which is then followed by a gas adjustment and power adjustment to initiate the steady state plasma conditions. An automated RF tuning network on the power supplies keeps the reflected power to manageable levels during this time.

Once the target time has elapsed, the power supplies are turned off and gasses are purged from the chamber. The extraction is the reverse of the insertion procedure. You’ll have to ‘vent’ the load lock to retrieve your sample at this point. When you have taken your sample, be sure to close the load lock and click ‘pump down’ again to leave the lock in a vacuum state.

4.6 Chamber Cleaning

After finishing the deposition process and removing your sample, a cleaning run (with the provided cleaning wafer) must be performed on the system. This recipe is located in the same place as the prior recipes and must be run for a minimum of 5 minutes. If cleaning SiO_2, clean for the same amount of time as your deposition. If using SiN or Amorphous Silicon, clean for 2x the deposition time. This recipe removes deposited material from the chamber walls and helps keep the system from requiring more extensive maintenance and downtime. If you are finished using the machine and nobody is waiting after you, click ‘Set Standby Temps’ on the screen to return the heat exchanger temperatures back to idle.

If the cleaning routine fails due to low power on RF2, this is usually due to the chamber chemistry being sub-optimal at the 1000W level. Use one of the 750W cleaning recipes and increase the cleaning time by 25%.

5 Standard Processes

5.1 Availability of other processes

Currently processes that are available on the recipe menu are the only approved items. If you have questions about modifying a process or developing a new one, contact the engineer in charge. Plasma-Therm maintains a process library and engineering support we can ask as a resource.

The following deposition processes advertised by Plasma-Therm as available for this system:

Validated:

- SiO_2 (SiH_4 + O_2)
- SiN_x (SiH_4 + N_2)
- A-Si:H (SiH_4 + Ar) (yet to be characterized)

In Development:

- SiC (SiH_4 + CH_4)

Plasma-Therm Technical Support (ask for process support)

E-mail: techsupport@plasmatherm.com

Phone: (800) 246-2592

5.2 Silicon Dioxide (SiO_2) on Silicon or Silicon Carbide Substrates

Deposit SiO_2 on substrate at a rate of approximately 100nm/min (1.6nm/sec) for a variable amount of time.

- Process Chamber Temperature: 60°C
- Electrode Temperature: 170°C

Table 1 - SiO_2 Deposition Recipe

Process Step	Time (s)	Pressure (mTorr)	RF Bias/RF ICP (W)	SiH_4 (SCCM)	Ar (SCCM)	N_2 (SCCM)	O_2 (SCCM)
Chuck	-	2	0/0	0	0	0	0
Argon Purge	20	5	0/0	0	25/25	0	0
Argon Stabilization	10	8	0/0	0	50	0	0
Argon Ignition	15	8	130/900	0	50	0	0
Argon Plasma	90	8	130/900	0	50	0	0
SiO_2 Stabilization	10	8	0/0	17	41	0	22
SiO_2 Ignition	5	8	130/900	17	41	0	22
SiO_2 Deposition	variable	8	25/900	17	41	0	22
Argon Purge	120	5	0/0	0	25/25	0	0
Nitrogen Purge	30	2	0/0	0	0	100	0
Dechuck	-	50	0/0	0	0	0	0

5.3 Silicon Nitride (SiN_x) on Silicon Substrates

Deposit SiN_x on substrate at a rate of approximately 144nm/min (2.4nm/sec) for a variable amount of time.

- Process Chamber Temperature: 60°C
- Electrode Temperature: 150°C

Table 2 - SiN_x Deposition

Process Step	Time (s)	Pressure (mTorr)	RF Bias/RF ICP (W)	SiH_4 (SCCM)	Ar (SCCM)	N_2 (SCCM)
Chuck	-	2	0/0	0	0	0
Argon Purge	20	5	0/0	0	50	0
SiN Stabilization	10	12.5	0/0	27	50	27/20
SiN Ignition	10	12.5	0/900	27	50	27/20
SiN Deposition	variable	12.5	0/900	27	50	47
Argon Purge	240	5	0/0	0	50	0
Nitrogen Purge	30	2	0/0	0	0	100
Dechuck	-	50	0/0	0	0	0

5.4 a-Si:H Amorphous Silicon on Silicon Substrates

Deposit amorphous silicon on substrate at a rate TBD/min (~60 nm/sec) for a variable amount of time.

- Process Chamber Temperature: 60°C
- Electrode Temperature: 150°C

Table 3 – a-Si:H Deposition

Process Step	Time (s)	Pressure (mTorr)	RF Bias/RF ICP (W)	SiH_4 (SCCM)	Ar (SCCM)	N_2 (SCCM)
Chuck	-	2	0/0	0	0	0
Argon Purge	20	5	0/0	0	25/25	0
A-Si Stabilization	10	5	0/0	20	20	0
A-Si Ignition	5	5	80/600	20	20	0
A-Si Deposition	variable	5	80/600	20	20	0
Argon Purge	120	2	0/0	0	25/25	0
Nitrogen Purge	30	2	0/0	0	0	100
Dechuck	-	50	0/0	0	0	0

5.5 Cleaning Etch

Etch chamber walls and substrate for a variable amount of time.

- Process Chamber Temperature: 60°C
- Electrode Temperature: 170°C

Table 4 – Chamber Clean Etch

Process Step	Time (s)	Pressure (mTorr)	RF Bias/RF ICP (W)	SF_6 (SCCM)	Ar (SCCM)	O_2 (SCCM)
Chuck	-	50	0/0	0	0	0
Argon Purge	20	5	0/0	0	0/50	0
Clean Stabilization	20	40	0/0	70	0/35	20
Clean Ignition	10	40	200/1000 (750)	70	0/35	20
Plasma Clean	variable	40	10/1000 (750)	70	35	20
Argon Purge	10	5	0/0	0	50/50	0
Dechuck	-	50	0/0	0	0	0

6 Troubleshooting

6.1 Problem: I received an error message regarding the Heat Exchanger.

- Solution 1: The setpoint may need some time to stabilize, especially at high temperature. Give the system 10 minutes to stabilize and check the electrode temperature again.
- Solution 2: The heat exchanger is off or disconnected. Contact the engineer in charge.

6.2 Problem: The process won't begin, saying that a sample is not present.

- Solution: Some substrates do not reflect the light of the red laser used to detect the presence of a wafer. Contact the engineer in charge to see if a new procedure is required. SiC is a good example of this.

6.3 Problem: The sample has broken in the chamber or otherwise loaded incorrectly.

- Solution: STOP! The system can severely damage itself in this event, including breakage of the loading arm, pins, ceramic plate and more. Contact the engineer in charge or any staff member immediately.

Do not attempt to fix this issue yourself!

6.4 Problem: The loading arm has become stuck or moved out of position.

- Solution: STOP! The system can severely damage itself in this event, including breakage of the loading arm, pins, ceramic plate and more. Contact the engineer in charge or any staff member immediately.

Do not attempt to fix this issue yourself!

7 References

7.1 ***Inductively-Coupled Plasma Deposition of Low Temperature Silicon Dioxide and Silicon Nitride films for III-V Applications***

7.2 **Stanford Nanofab HDPCVD Information and Operating Instructions**

7.3 **Birck Nanotech Wiki – Cleaning Page**

8 REVISION RECORD

Reason for Revision	Date of Revision	Person Responsible
Initial Release		Rich Hosler
Cleaning Changes, a-Si:H	9/22/2020	Rich Hosler
Wafer requirement revisions – Clarifications	8/3/2022	Rich Hosler

Location: Cleanroom / R-Bay