Atomic Layer Deposition @ UCSB

UCSB Nanofabrication Facility

- **Oxford FlexAL ALD tool**

- Load locked, turbo pumped unit
  - System pressures below 240 mTorr
  - Substrate temps up to 500C
- Configured for 6 metal-organic precursors
- 8 gas lines configured for 6 reactive gases plus Ar (bubbling/purge) and water
  - Reactive gases: O_2, N_2, H_2, NH_3, and O_3
- In-situ monitoring of ALD process with Woollam Spectroscopic Ellipsometer
- ICP Remote Plasma source (up to 600W)
- Ozone Generator and Controller recently added

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Films Grown/ Precursors Used @ UCSB

<u>Standard "already developed" Processes</u>

- Al_2O_3 growth
  - Thermal: TMA + H_2O
  - Plasma: TMA + O_2
- HfO_2 growth
  - Thermal: TEMAH + H_2O
  - Plasma: TEMAH + O_2
- ZrO_2 growth
  - Plasma: ZrEMA + O_2
- SiO_2 growth
  - Plasma: 3DMAS + O_2
- SiN_x growth
  - Plasma: 3DMAS + H_2/N_2
- TiO_2 growth
  - Thermal: TTIP + H_2O
- TiN growth
  - Plasma: TDMAT + H_2/N_2

<u>New "under development" Processes</u>

- SiO_2 growth
  - Thermal: BDEAS + O_3
- TiN growth
  - Thermal: TDMAT + NH_3
- Ru metal film growth
  - Thermal: $Ru(Cp)_2$ + O_2
  - Thermal: $Ru(Cp)_2$ + O_3

Ozone for "Active" Thermal Oxidation

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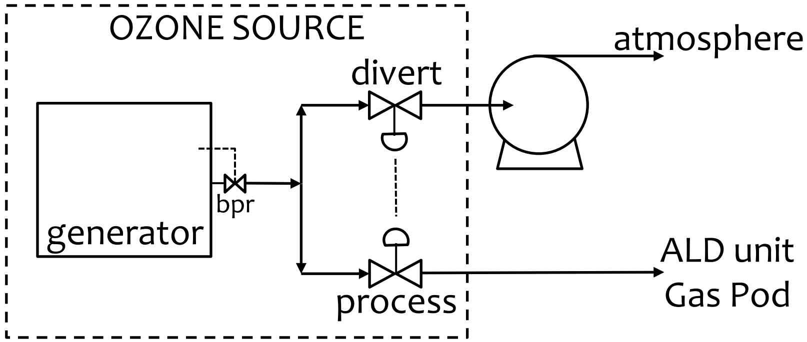
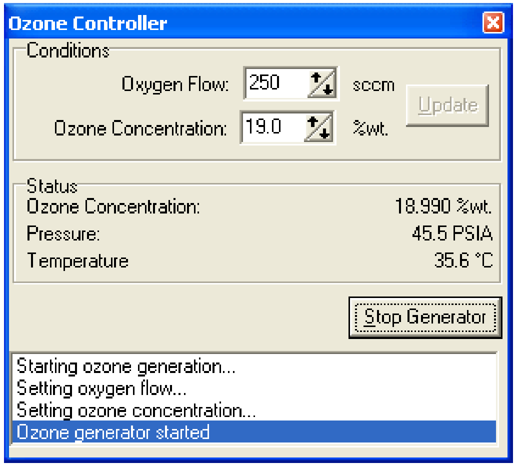
InUSA MiniODS Ozone Source + Sci-L Controller

- Closed loop feedback control of O_3 concentration using built-in O_3 monitor.
- O_2 gas flows up to 1000 sccm, O_3 concentration up to 22 wt%.
- When generator is on, O_3 is always flowing => need a divert line and a process line (built-in with source)
  - Divert line must be pumped since the generator runs @ 30 psig (maintained by BPR) and the ALD unit is low pressure.
  - Process line connects to reactive gas pod of the ALD unit => can use standard ALD valves already in place (small modification of the FlexAL control software was required)
- We use a small script to control the ozone source (gas flow, O_3 concentration, On/Off) directly from the desktop of the ALD control PC





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Application: Conductive TiN Film Growth

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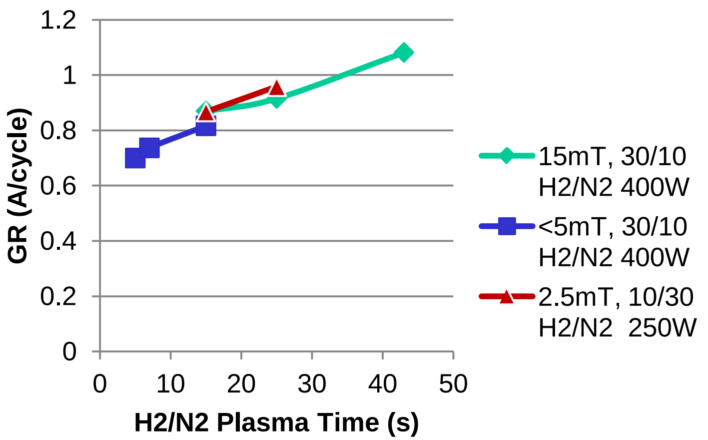
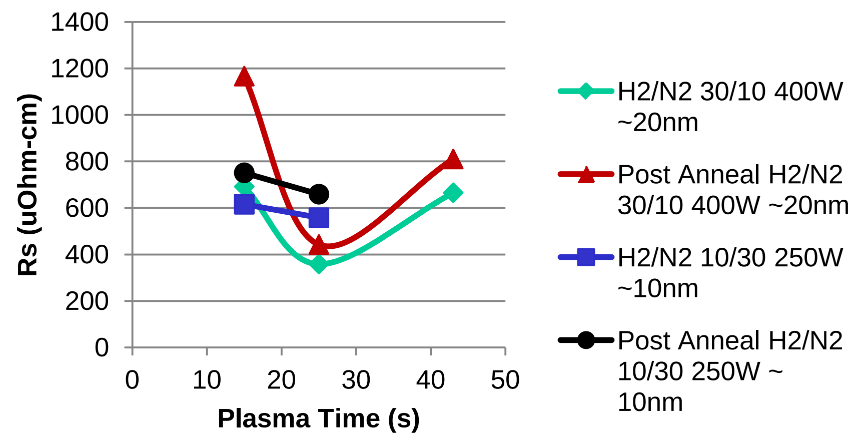
Deposition conditions

- Substrate temp = 300C,
- TDMAT cycle: 1sec @ 15mT , Ar draw @ 50sccm; Ar purge 4s @ 15mT; source @ 60C
- H2/N2 plasma dosing: flow, pressure, ICP power, time are variable

Annealing conditions (resistivity stability tests)

- 60 min @ 400C in Forming Gas





For growth conditions tested:

- GR independent of H2/N2 pressure, flow ratio
- GR independent of ICP Power
- GR does not saturate with plasma dose

For annealing conditions tested:

- Resistivity is not stable below 15s plasma time (resistivity values order of >100’sK uOhm-cm)
- Resistivity less sensitive to plasma time @ lower ICP Power and/or H2-N2 ratio

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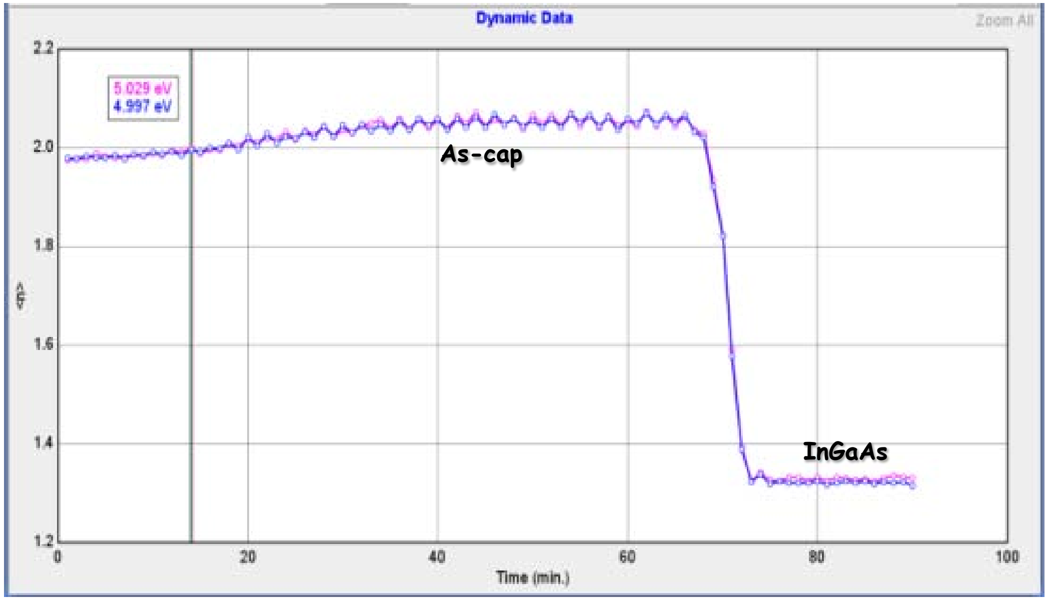
Application: MIS devices on III-V semiconductors

- In-situ As decapping in FlexAL ALD
  - Grow amorphous As-cap on InGaAs at the end of MBE growth => surface is protected from environment (ideal surface => minimal Dit?).
  - As- cap removed by exposure to low power H* plasma (2W) as AsH_3. Cycle (2W H* plasma for 5s)/(SE measurement for 4s) until interface reached.
  - Immediate oxide growth on clean InGaAs interface (interface is never exposed to air!)
  - Initial results promising



Application: SiOx ALD Growth using "SAM.24" and Ozone

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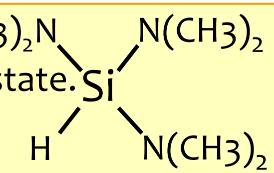
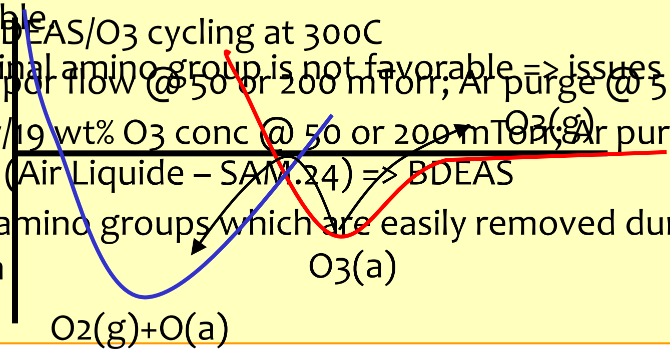
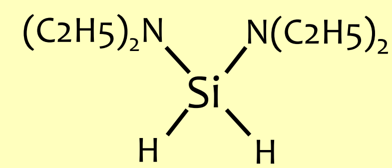
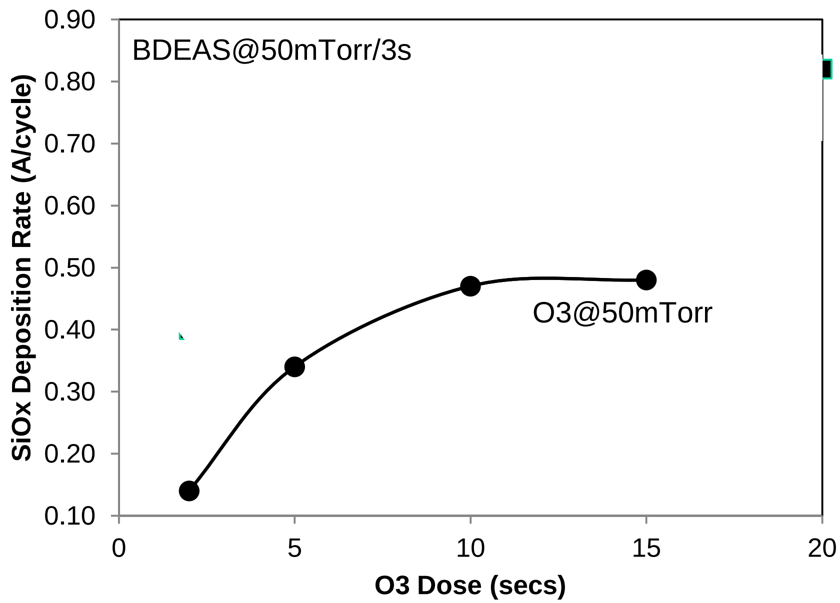
- Standard aminosilane precursor ... [illegible] (TDMAS)
  - Contains three dimethyl amino groups ... [illegible] ... desorption from molecularly adsorbed state.
  - Removal of first amino group ... [illegible] ... thermodynamically favorable.
  - Due to strain, removal of final amino group is not favorable => issues with C/N incorporation in film

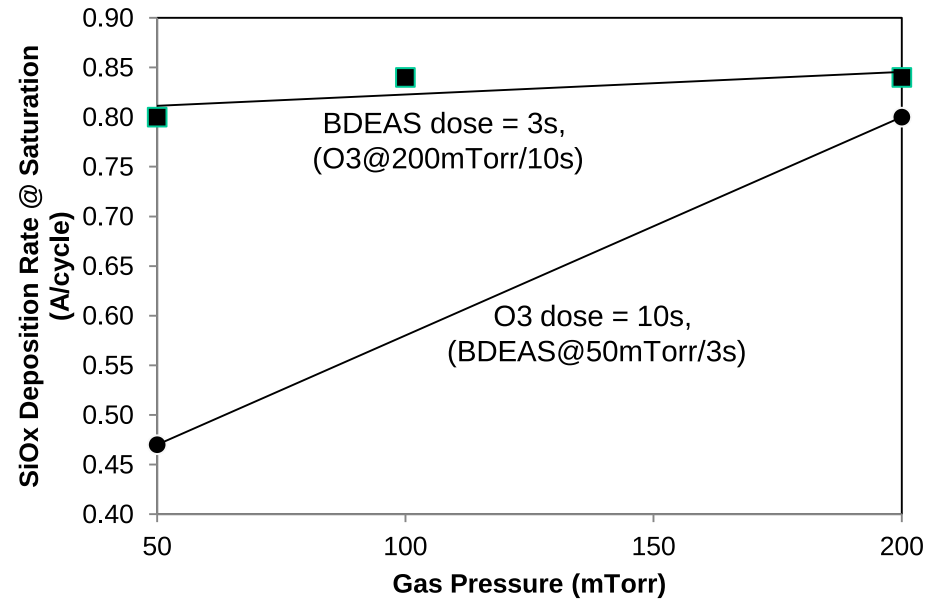


- Deposition Conditions using BDEAS/O3 cycling at 300C
  - BDEAS(50C) cycle: 100% vapor flow @ 50 or 200 mTorr; Ar purge @ 50sccm/2s; pump 3s
  - O3 cycle: 250sccm O2 flow/19 wt% O3 conc @ 50 or 200 mTorr; Ar purge @ 50sccm/2s; pump 3s
- "New" aminosilane precursor (Air Liquide – SAM.24) => BDEAS
  - Contains only two diethyl amino groups which are easily removed during dissociative chemisorption
  - Cleaner SiOx films?









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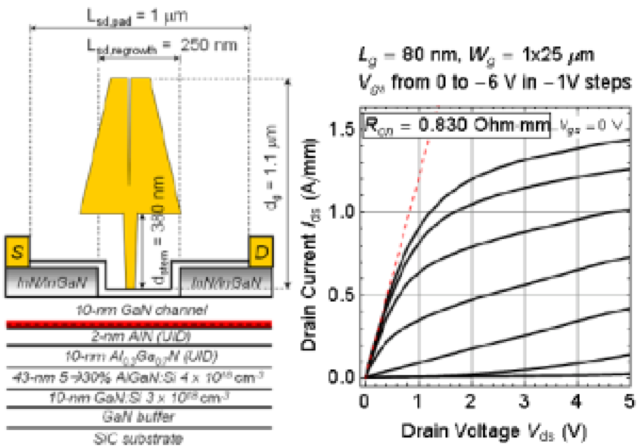
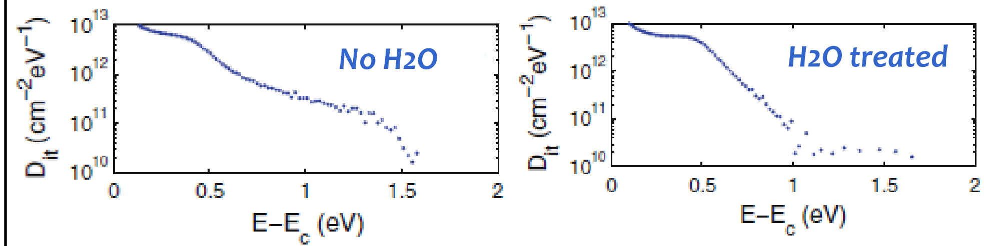
A few more applications…

High performance N-Polar GaN-HEMTs using 5nm Al_2O_3 Gate Oxide– Denninghoff et. al.



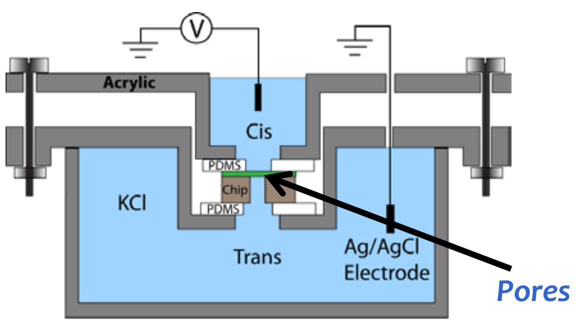
1.4 A/mm, Good Turn-off, 270GHz fmax.

Dit reduction of ALD-Al_2O_3 on Ga-faced GaN using water pre-saturation of surface – X Liu et. al.

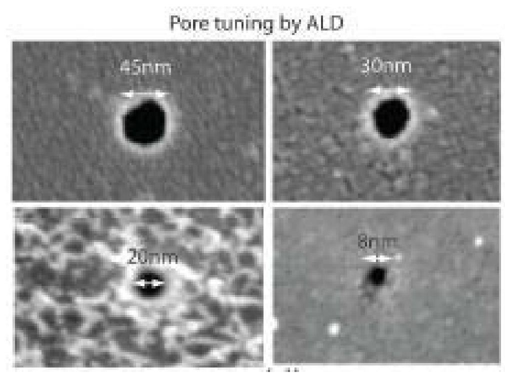


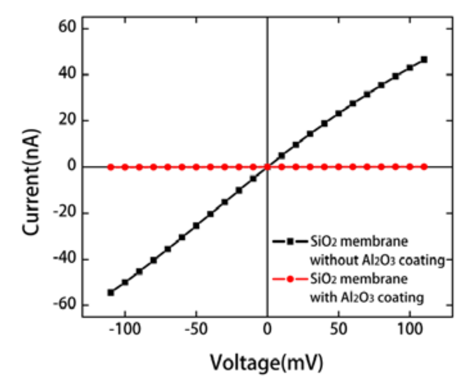
Near Midgap Dit States dropped by an order of magnitude ($5e11 cm^{-2}eV^{-1}$ to $4e10\ cm^{-2}eV^{-1}$) when pre-treating surface with H_2O before ALD growth

ALD-Al_2O_3 for SiO_2 membrane pore size shrinking and ion-current leakage suppression for CMOS-compatible Biosensing devices – A. Uddin, etl al.



EXPERIMENTAL SETUP





I-V Characteristics of blank SiOx membrane before and after ALD coating.