Deposition Tools within the Microelectronics and Nanotechnology Group at the Georgia Tech Research Institute

David W. Stollberg, Ph.D., P.E.
Research Engineer and Adjunct Faculty

Thin Film Deposition

- **Two major categories: Physical and chemical vapor deposition**
  - **Physical: movement of constituent atoms/molecules from source to a physical condensation on a substrate in an ~ line of site manner, usually in a low pressure/vacuum regime**
  - **Chemical: gas flow of chemical species which must decompose/react (thermal, plasma, light, catalysis assist) to release constituent elements**
- **PVD**
  - **Evaporation (i.e., heating) of source material: thermal, electron-beam**
  - **Ablation of source material: sputtering (high energy ions), pulsed laser**
  - **Typically solid elemental or compound source materials**
- **CVD**
  - **Mass flow controllers, pressure flow controllers**
  - **Typically metalorganic or hydride gases**

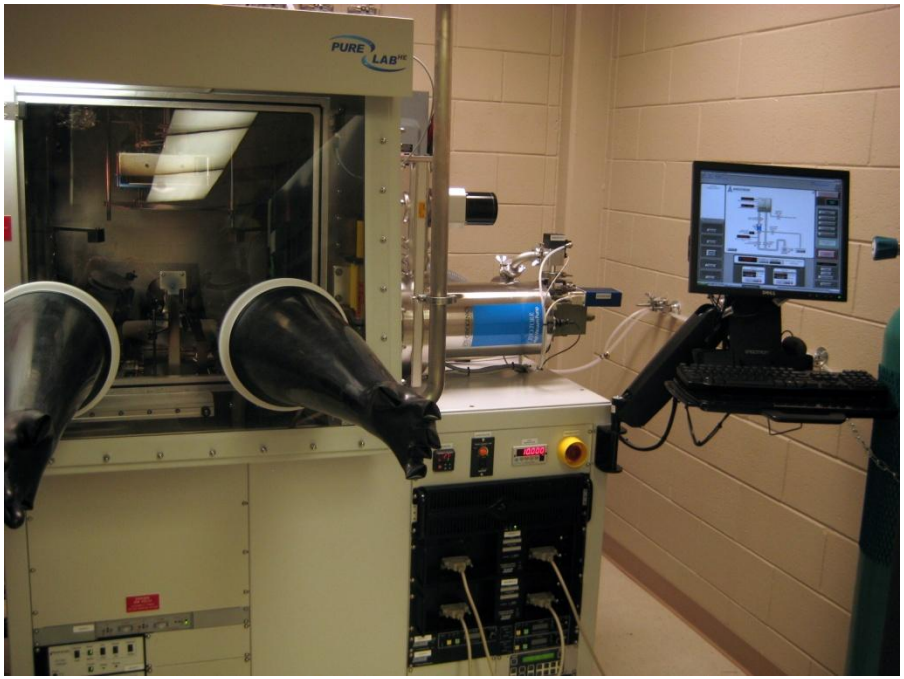
Evaporators In Baker Cleanroom

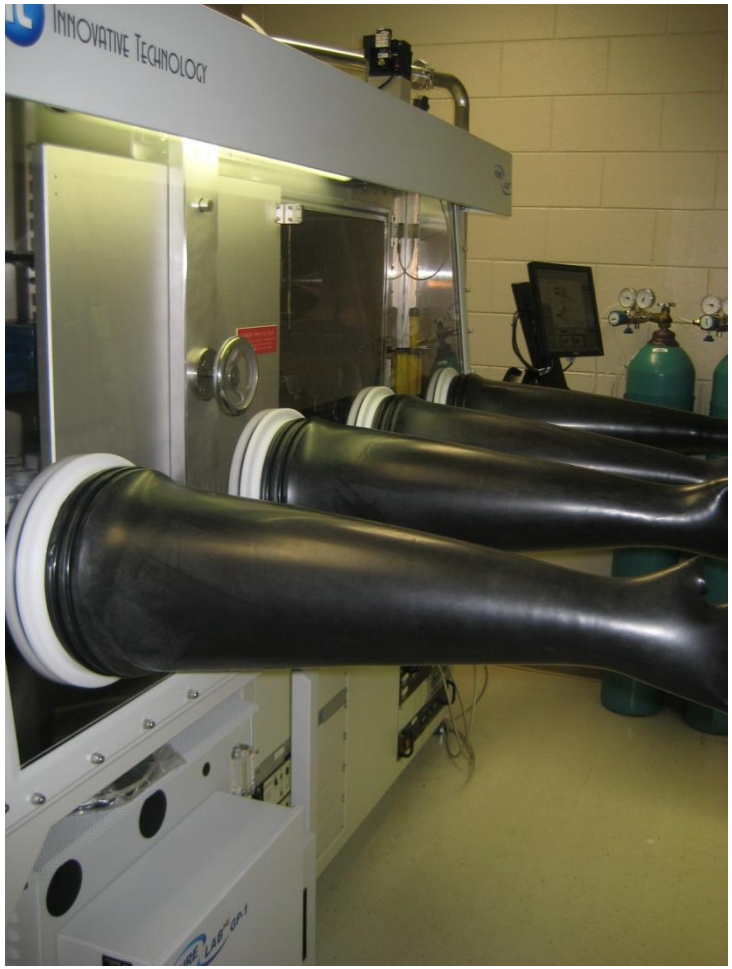
- **Veeco**
  - Manual pump down
  - Cryo-Torr 8
  - Four pocket E-beam
  - Al, Au, Ni Ti
- **Dual Chamber**
  - Auto pump down
  - Cryo-Torr 8
  - Four pocket E-beam
  - AuGe, Ni, Au, Ti

Sputtering Systems In Baker Cleanroom

- **Sputter 1**
  - Perkin-Elmer 2400
  - Auto pump down
  - Cryo-Torr 8
  - Three position plus one etch
  - RF diode with one S-gun
  - Nominal 4” dia targets
- **Sputter 2**
  - Perkin-Elmer 2400
  - Auto pump down
  - Cryo-Torr 8
  - Three position plus one etch
  - DC and RF Magnetrom
  - Nominal 8” dia targets

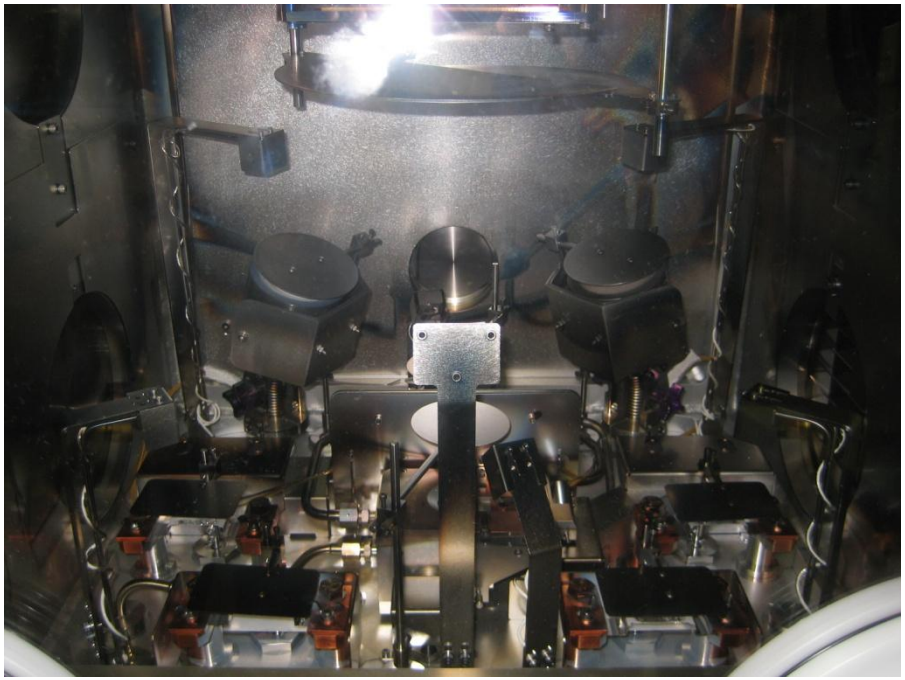
Angstrom Engineering EvoVac





Angstrom Engineering EvoVac

- Two 4 pocket E-beam crucible sources
- 4 resistive thermal evaporation sources
- 1 RF sputter source
- 1 DC sputter source
- Integrated Glove Box
- See Stephan Turano for training or help
- Users: Stephan, Jack, Graham



EvoVac Information

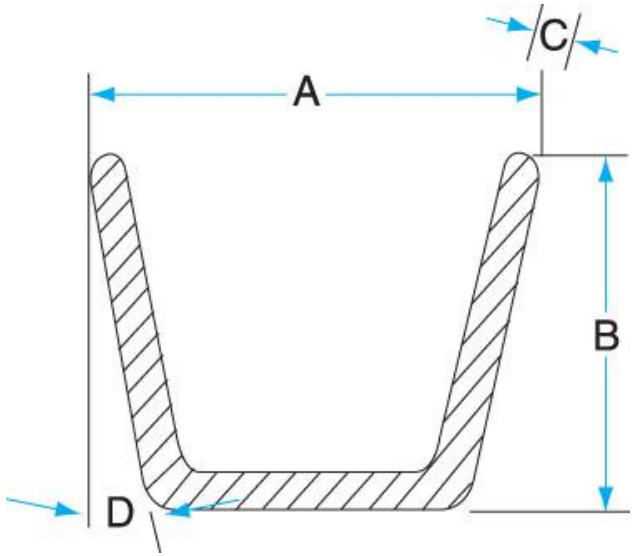
- **Pump down time: 10-12 minutes to reach $1.0x10^{-6}$ Torr**
- **$2.0x10^{-8}$ Torr possible after a few hours**
- **Rates 0.5-10Å/s possible. Recommend 4.0Å/s max for E-beam**
- **Sample size up to 6” x6” square**

- **Each new material takes a few trial runs to determine best settings.**
- **Smaller material pellets sizes (1/8” pellets) are preferred**

E-beam evaporation with the EvoVac

- **Current E-beam Materials:**
  - **Nickel**
  - **Iron**
  - **Copper**
  - **Titanium**
  - **Molybdenum**
  - **Chromium**
- **Past and Future materials**
  - **Aluminum**
  - **Cobalt**
  - **Gold**
  - **Silver**
  - **Many other metals, semi-metals and dielectrics**

- **E-beam Crucible size:**
  - **Pocket volume: 7cc**
  - **Liner volume: 4.4cc**
  - A: 1.167”
  - B: 0.563”
  - C:0.093”



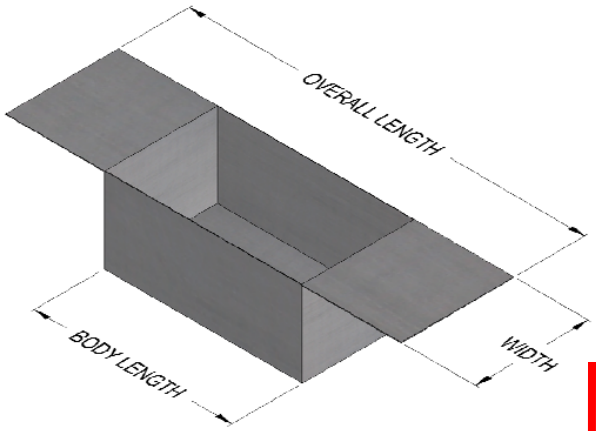
Material Deposition by Evaporation

- **Guide to material evaporation: Shared drive link**
- **General information on evaporation of 350+ materials (use as a general guideline!)**

Material	Symbol	MP (°C)	S/D	g/cm³	Temp.(°C) for Given Vap. Press. (Torr)			Evaporation Techniques						Comments
									Thermal Sources					
					10^-8	10^-6	10^-4	E-Beam	Boat	Coil	Basket	Crucible	Sputter	
Aluminum	Al	660		2.7	677	821	1010	Ex	TiB_2,W	W	W	TiB_2-BN, ZrB_2, BN	RF, DC	Alloys and wets. Stranded W is best.
Aluminum Antimonide	AlSb	1080		4.3	-	-	-	-	-	-	-	-	RF	-
Aluminum Arsenide	AlAs	1600		3.7	-	-	~1300	-	-	-	-	-	RF	-
Aluminum Bromide	$AlBr_3$	97		2.64	-	-	~50	-	Mo	-	-	Gr	RF	-
Aluminum Carbide	Al_4C_3	~1400	D	2.36	-	-	~800	F	-	-	-	-	RF	n = 2.7
Aluminum, 2% Copper	Al2%Cu	640		2.82	-	-	-	-	-	-	-	-	RF, DC	Wire feed and flash. Difficult from dual sources.
Aluminum Fluoride	AlF_3	1291	S	2.88	410	490	700	P	Mo, W, Ta	-	-	Gr	RF	-
Aluminum Nitride	AlN	>2200	S	3.26	-	-	~1750	F	-	-	-	-	RF, RF-R	Decomposes. Reactive evap in 10^{-3} T N2 with glow discharge.
Aluminum Oxide	Al_2O_3	2072		3.97	-	-	1550	Ex	W	-	W	-	RF-R	Sapphire excellent in E-beam; forms smooth, hard films. n = 1.66
Aluminum Phosphide	AlP	2000		2.42	-	-	-	-	-	-	-	-	RF	-
Aluminum, 2% Silicon	Al2%Si	640		2.69	-	-	1010	-	-	-	-	TiB_2-BN	RF, DC	Wire feed and flash. Difficult from dual sources.
Antimony	Sb	630	S	6.68	279	345	425	P	Mo,*** Ta***	Mo, Ta	Mo, Ta	BN, C, Al_2O_3	RF, DC	Toxic. Evaporates well.
Antimony Oxide	Sb_2O_3	656	S	5.2	-	-	~300	G	Pt	-	Pt	BN, Al_2O_3	RF-R	Toxic. Decomposes on W. n = 2.09, 2.18, 2.35
Antimony Selenide	Sb_2Se_3	611		-	-	-	-	-	Ta	-	-	C	RF	Stoichiometry variable.
Antimony Sulfide	Sb_2S_3	550		4.64	-	-	~200	G	Mo, Ta	-	Mo, Ta	Al_2O_3	-	No decomposition. n=3.19, 4.06, 4.3
Antimony Telluride	Sb_2Te_3	629		6.5	-	-	600	-	-	-	-	C	RF	Decomposes over 750°C.
Arsenic	As	817	S	5.73	107	150	210	P	C	-	-	Al_2O_3, BeO, VC	-	Toxic. Sublimes rapidly at low temperature.
Arsenic Oxide	As_2O_3	312		3.74	-	-	-	-	-	-	-	-	-	-
Arsenic Selenide	As_2Se_3	~360		4.75	-	-	-	-	-	-	-	Al_2O_3, Q	RF	-

EvoVac

- **Thermal Evaporation Sources**
  - **Filament, box, boat or rods are acceptable**
- **Useful links:**
- **http://www.lesker.com/newweb/menu_evapsources.cfm**
- **http://www.lesker.com/newweb/Evaporation_Sources/Evaporation_TempVSPower.cfm?pgid=0**



Source Sizing Guide

	Åmod	Nexdep	EvoVac	Covap
Overall length:				
without clamp extension	3.25in to 3.50in	2.89in to 3.50in	3.10in to 3.65in	3.25in to 3.50in
with clamp extension	1.75in to 2.00in	1.61in to 2.20in	1.75in to 2.40in	1.75in to 2.15in
Body Length:				
without clamp extension	2.7in or less	2.40in or less	2.50in or less	2.7in or less
with clamp extension	1.30in or less	1.15in or less	1.35in or less	1.35in or less
Width:	1.125in or less	1.00in or less	1.00in or less	1.00in or less

EvoVac

- **Sputter sources:**
  - **Aluminum**
  - **SiO2**
  - **Al2O3**
  - **TiN**
  - **Ni**
- **3 inch sputter targets. Foils accpetable**
- **Maximum thickness 3/8”**
- **http://www.lesker.com/newweb/menu_depositionmaterials.cfm?section=targets&init=skip**

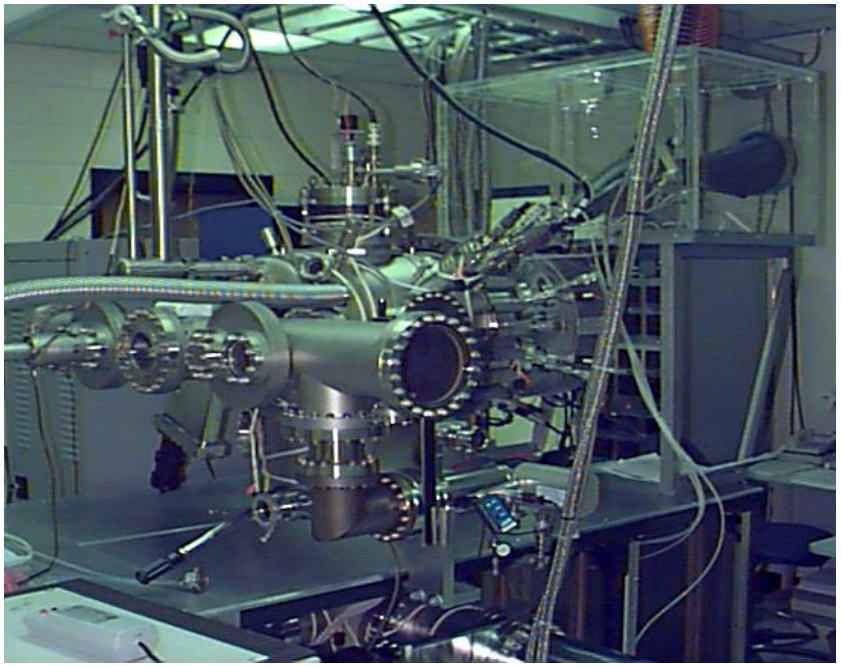
- **Sputter gases:**
  - **Ar, N**
- **Rates ~ 1-10Å/s**
- **Processing parameters not fully explored**

MBE and IAD

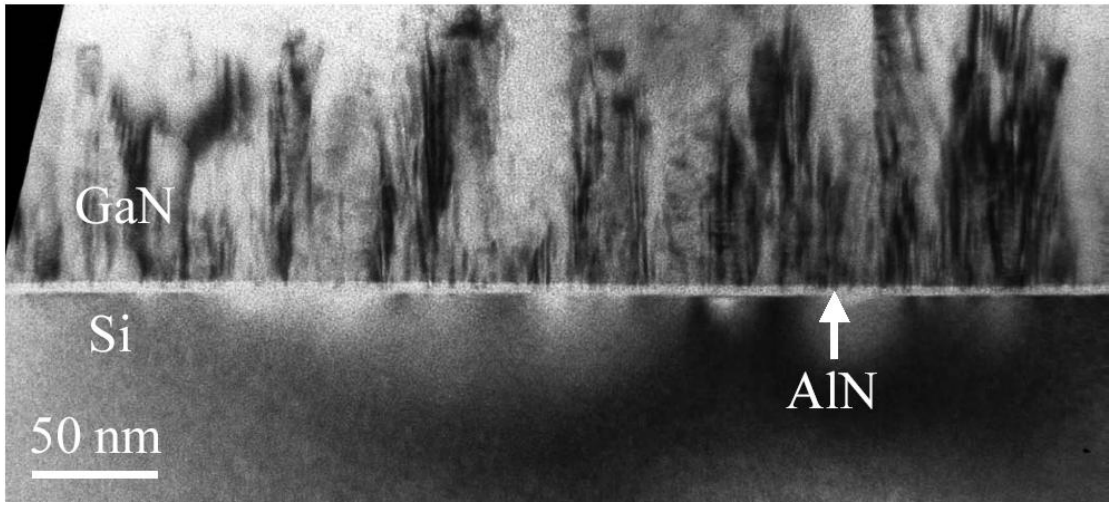
- **Molecular Beam Epitaxy (MBE)**
  - Ultra high vacuum deposition technology with single atomic layer thickness control: single crystal, polycrystalline and amorphous materials
  - Vacuum enables in-situ characterization techniques and low contamination
  - Mix of PVD and CVD (CBE) with use many sources simultaneously
  - Can deposit elemental, binary, ternary and quaternary compounds along with electrical and optical dopants over an 8 order of magnitude concentration range
- **Ion Assisted Deposition (IAD)**
  - PVD technique with the addition of an ion assist
  - Reactive evaporation possible to add extra amount of constituent or additional constituent
  - Ion assist provides energy to deposition surface to modify properties of material: stress, density , crystallinity, etc. Can replace the use of substrate temperature enabling good quality films to be deposited at low temperatures (e.g., for plastic substrates)

MBE

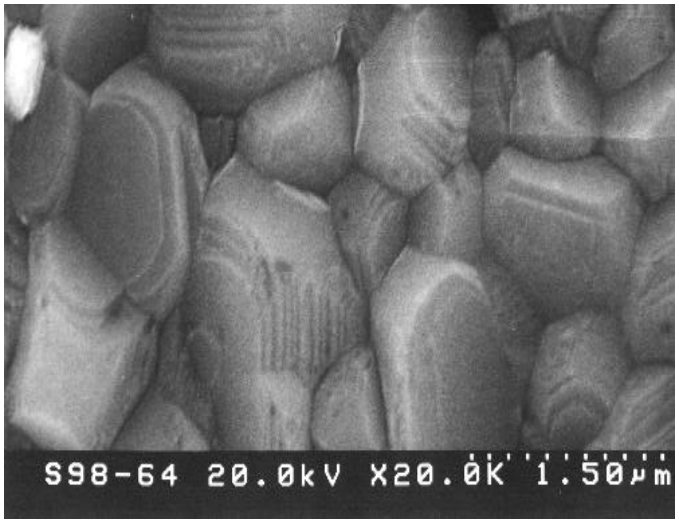
- Two MBE Systems
- Up to eight thermal evaporation or gas sources simultaneously
- Two sputtering sources
- Nitrogen plasma source for reactive deposition
- Substrates to 2” diameter, substrate temperature to ~800C
- BaAlCdZnGaHgCaSrSSeTeF; GaAlN, Si,Mn,Al,Ag,Ce,Pb,Cu,Eu



MBE



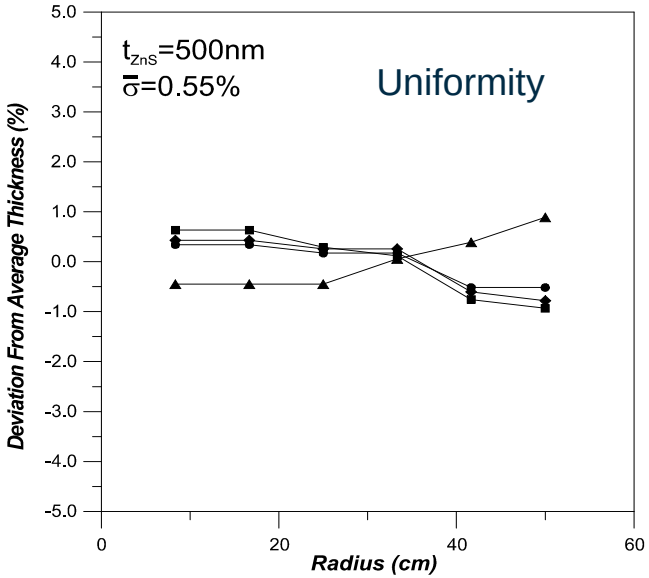
Single Crystal Material

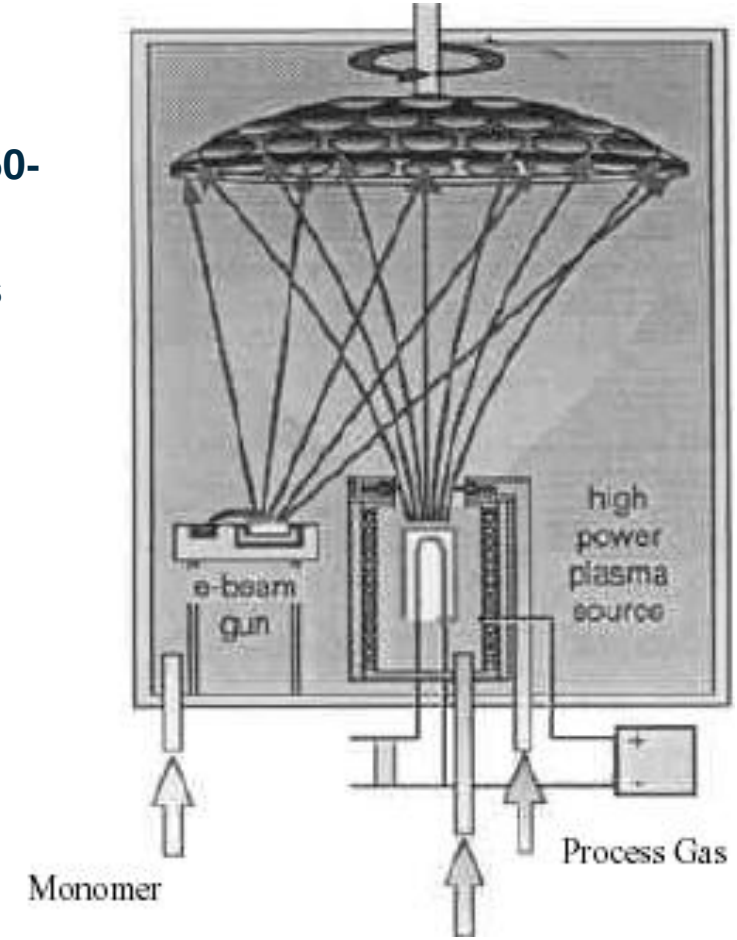


Polycrystalline Material

IAD

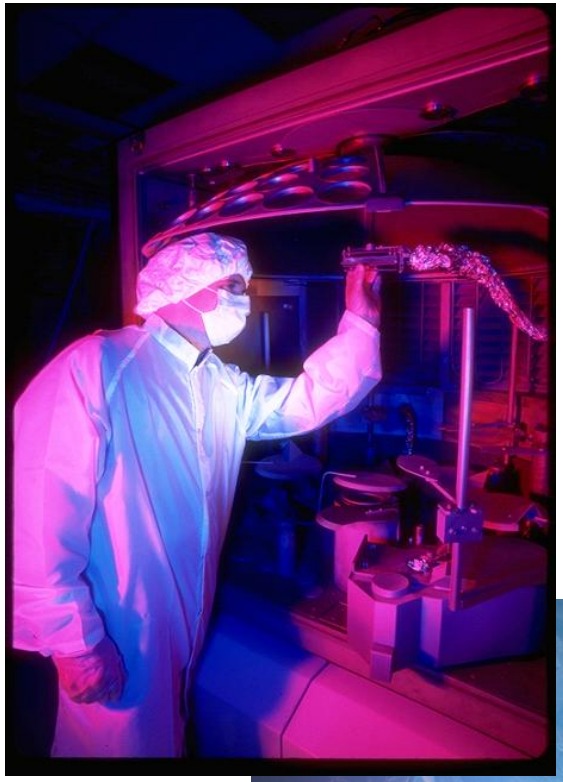
- Four thermal and one four-pocket or rotatable crucible electron beam
- Inert (Ar) and reactive (H_2S, O_2, N_2) ion assist, 50-150eV energy
- Gas scrubber on exhaust to handle toxic gases
- Deposition area 1m diameter, rates to 5nm/s
- Substrate temperature to 350C,or to 800C over 10” diagonal non-rotating area



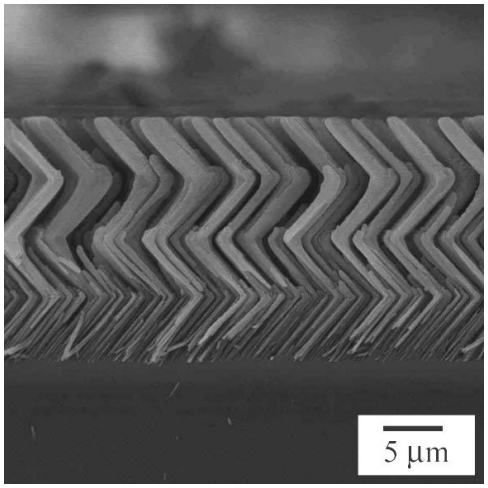


IAD

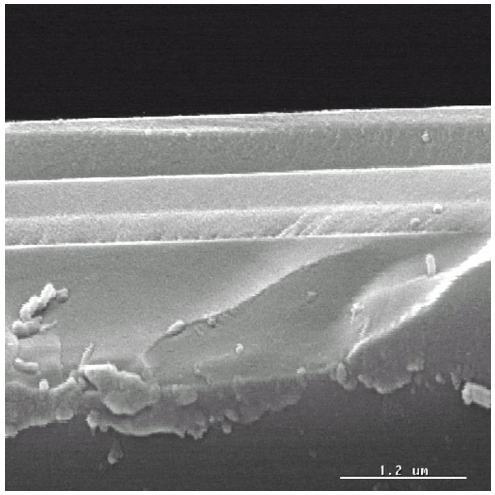
- **Materials deposited include metals, sulfides, selenides, oxides, oxysulfides, nitrides and oxynitrides covering optical regimes from the LWIR to the UVC and electrical regimes from high κ dielectrics to transparent conductors**
- **ZnSrCaGaSSe; YLaGdOS, YSiAlGeTaTiZnPbZrBaInSn:O; Pb, Cu, Ce,Ag,Tb,Eu,Pt,Pd,Mn; SiAlON; Fl,Cl**



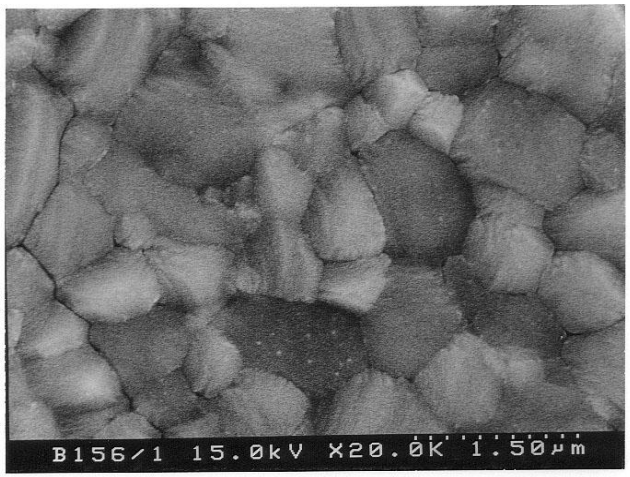
IAD



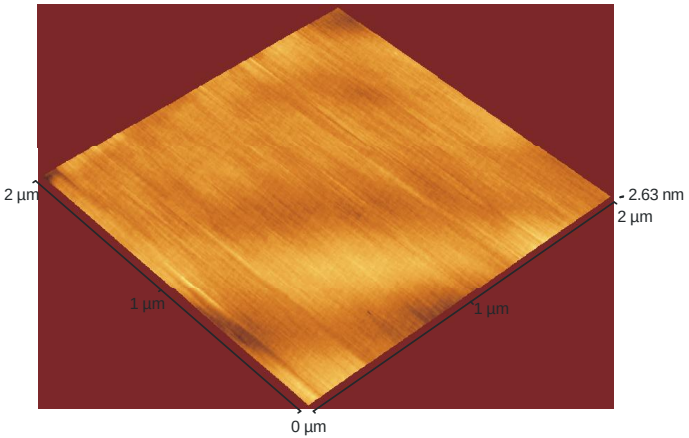
Glancing Angle Deposition



IAD $SiO_2/Ta_2O_5/SiO_2$ layers exhibiting smooth amorphous character



Crystalline Deposition



IAD SiO_2 layers exhibit very smooth surface character – Area RMS = 0.251nm

Deposition Tools at Georgia Tech Nanotechnology Research Center

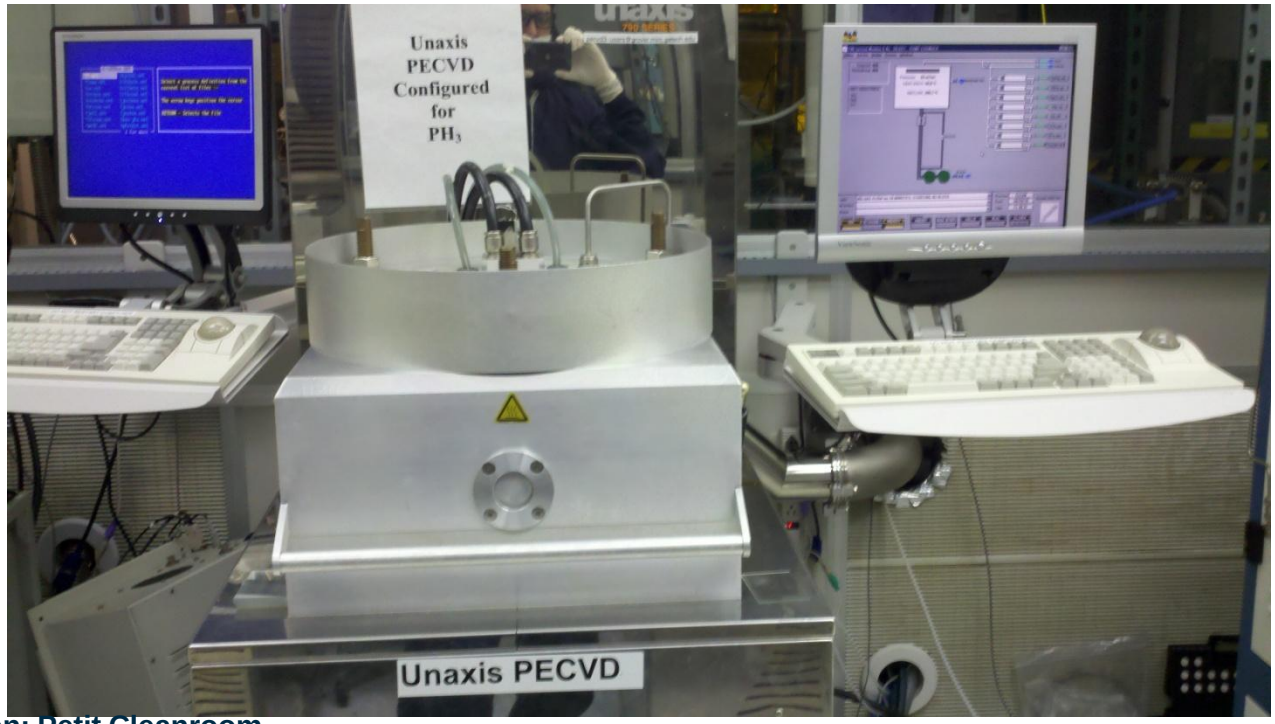
STS PECVD 2

- **Location: Petit Cleanroom**
- **Films:**
  - **SiO2**
  - **Si3N4**
  - **SiON**
- **Trained Users:**
  - **Stephan Turano**
- **Wafer Size: 4”**
- **Deposition rate varies based on conditions. Std. SiO2 rate ~420Å/min**

STS PECVD 1

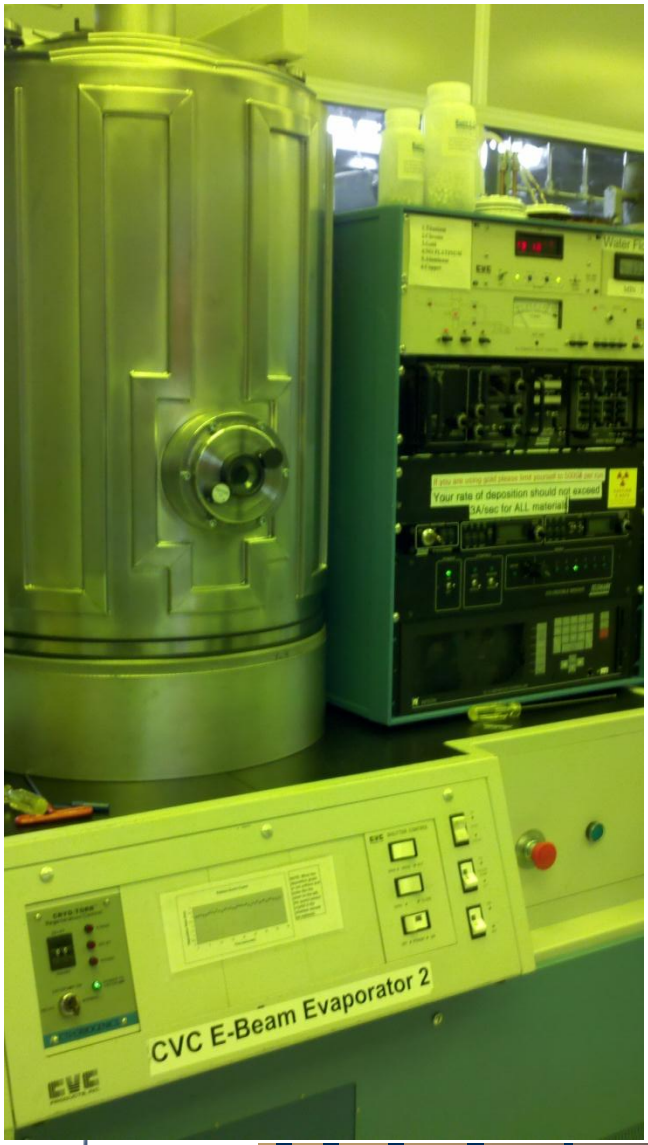
- Location: Petit Cleanroom
- Films:
  - SiO2
  - Si3N4
- Trained Users:
  - Stephan Turano
- Wafer Size: 2,3,4,5,6”
- Older system, software is less intuitive than STS 2

Unaxis PECVD



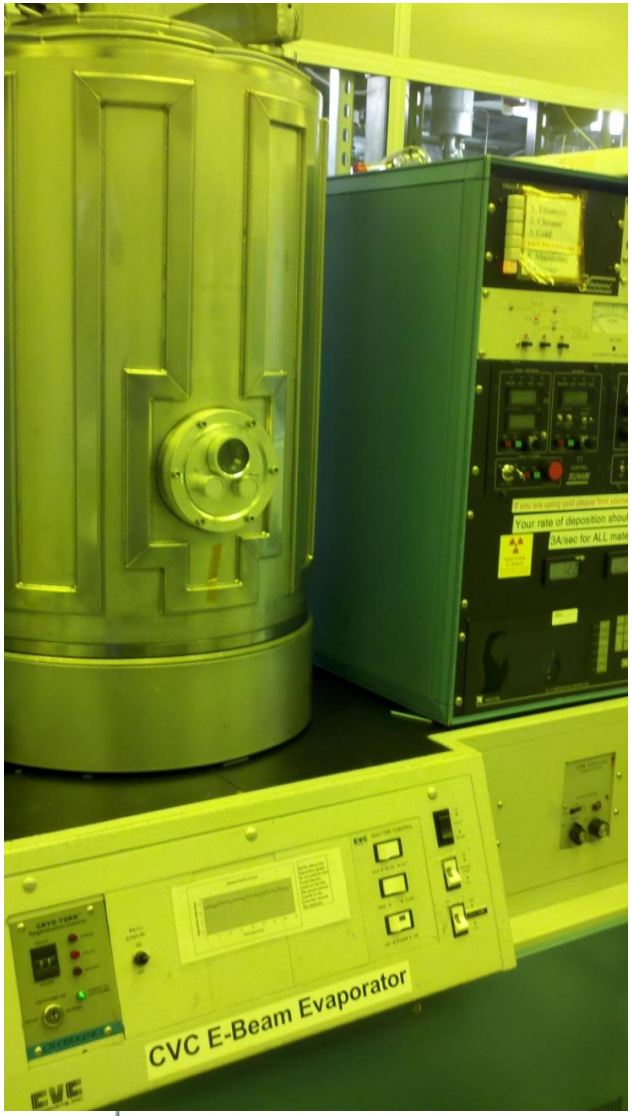
- **Location: Petit Cleanroom**
- **Films:**
  - **SiO2**
  - **Si3N4**
  - **SiOx**
- **Trained Users:**
  - **Michelle Gaines, Justin Ngyuen (?), Stephan Turano**
- **Wafer Size: Large deposition electrode: up to 5 -3", 4 - 4" wafers or a single 6" wafer**
- **Offers more ability to control film stresses than either STS tool**

CVC E-beam 2



- **Location: Petit Cleanroom**
- **Materials:**
  - **Metals and Dielectrics**
  - **MiRC has Al, Au, Ni, Ti, Cu, Cr and others**
- **Trained Users:**
  - **Stephan Turano, Graham Sanborn, Jack Flicker, Michelle Gaines (?)**
- **Wafer Size: Up to 8” samples are possible**
- **Rate is typically 1-3Å/s. Full pumpdown takes ~30-60min, can achieve $5x10^{-7}$ Torr**
- **Maximum reservation time is 3 hours peak. 3 days advance maximum**

CVC E-beam 1

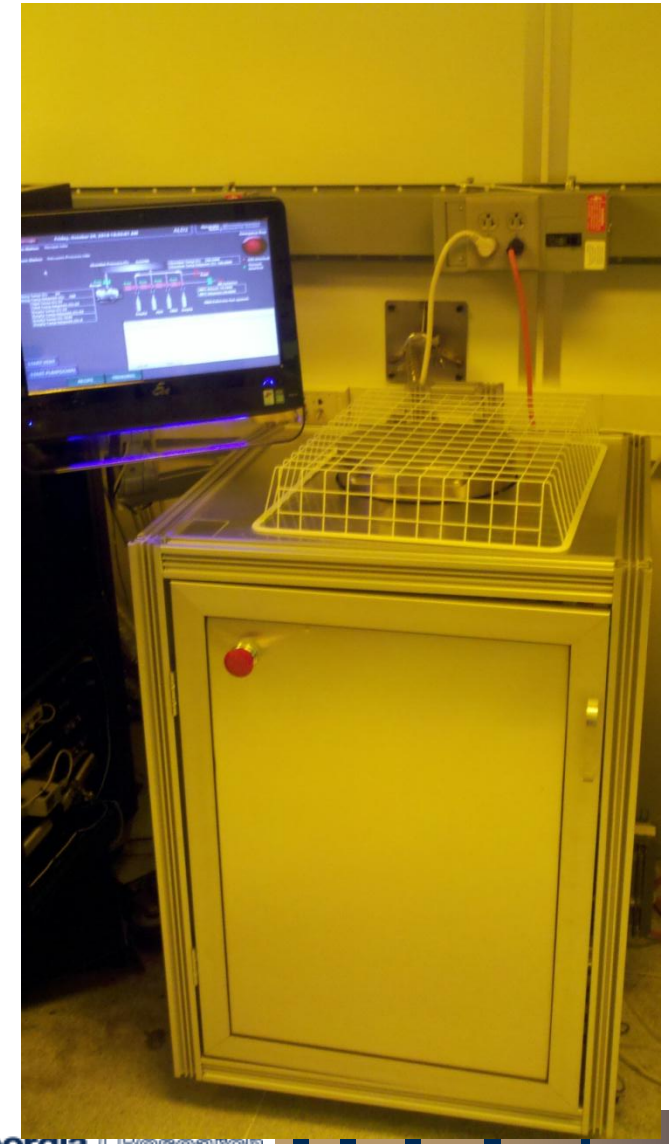


- **Location: Petit Cleanroom**
- **Materials:**
  - **Metals only**
  - **MiRC has Al, Au, Ni, Ti, Cu, Cr, SiO2, Al2O3, In, Fe, W and others**
- **Trained Users:**
  - **Stephan Turano, Graham Sanborn, Jack Flicker, Michelle Gaines (?)**
- **Wafer Size: Up to 8” samples are possible**
- **Rate is typically 1-3Å/s. Full pumpdown takes ~30-60min, can achieve $5x10^{-7}$ Torr**
- **More frequently used than CVC 2, generally quicker pumpdown times**
- **Maximum reservation time is 3 hours peak. 3 days advance maximum**

PlasmaTherm PECVD

- **Location: Petit Cleanroom**
- **Materials:**
  - **SiO2**
  - **Si3N4**
  - **SiON**
- **Trained Users:**
  - **Jack Flicker**
- **Wafer Size: Up to 6” wafers are possible**
- **Rate is typically 100-400Å/min.**

ALD 1



- Location: Petit Cleanroom
- Films:
  - Al_2O_3
- Trained Users:
  - Stephan Turano
- Wafer Size: Single wafer up to 6”.
- There was a second system which was capable or SrO_2 TiO_2 and SrTi that has been offline for several months
- Deposits single atomic layer of material in one cycle. Each cycle is roughly 30-40 s.
- 1000Å takes ~ 7 hours

CHA 2 E-beam Evaporator

- **Location: Marcus Cleanroom**
- **Films:**
  - **Metals: Ti, Al, Cr, Ni, Cu, Au, etc**
- **Trained Users:**
  - **Stephan Turano, Graham Sanborn, Jack Flicker(?), Michelle Gaines**
- **Wafer Size: Three 4” wafers can be simultaneously processed. Capable of Several 3” wafers as well .**
- **Rate is typically 1-3Å/s. Full pumpdown takes ~15-20min, can achieve $2x10^{-7}$ Torr**
- **Maximum reservation time is 3 hours peak. 3 days advance maximum**
- **Used much less frequently than CVC E-beams**

CHA 1 E-beam Evaporator

- Location: Marcus Cleanroom
- Films:
  - Dielectrics: TiO2, Al2O3, ZnO, SiO2,
  - Trained Users: Stephan Turano,
- Wafer Size: Three 4” wafers can be simultaneously processed. Capable of Several 3” wafers as well .
- Rate is typically 1-3Å/s. Full pumpdown takes several hours, can achieve $2x10^{-6}$ Torr
- Maximum reservation time is 24 hours peak. 3 days advance maximum
- Used much less frequently than CVC E-beams
- Have not done much work on this tool; film quality is very poor

Cambridge Nanotech Fiji Plasma ALD

- Location: Marcus Cleanroom
- Films:
  - Dielectrics: TiO2, Al2O3, ZnO, HfO2, ZrO
  - Metals: Platinum, more planned for future
- Trained Users: Stephan Turano
- Wafer Size: Up to three 4” wafers can be simultaneously processed. Stage size is capable of 8 inch wafer
- Can run at 250°C or lower. Plasma pulsing available for unusual films. Significant number of exotic materials can be deposited, but will require lots of process tuning.
- Maximum reservation time is several days.
- 1000Å Al2O3 takes ~5h30m

Denton Explorer and Denton Discovery

Denton Explorer – E-beam evaporator – metal deposition

- Location: Marcus Cleanroom
- Films: unsure
- Trained Users: None
- Used much less frequently than CVC E-beams and Petit Sputterers
- Training sessions infrequent

Denton Discovery – RF/DC sputterer – metal, dielectric deposition

Other clean room deposition tools

Oxford ICP PECVD (Marcus) - Marcus Inorganic Cleanroom

Etch Tools within MNG and GT

STS Pegasus DRIE (Bosch Process for Si)

STS ICP RIE for III-V Semiconductors

Plasma-Therm ICP - Pettit Cleanroom

Plasma-Therm RIE - Pettit Cleanroom

Plasma-Therm SLR RIE - Pettit Cleanroom

STS AOE - Pettit Cleanroom (advanced oxide etcher)

STS ICP - Pettit Cleanroom

STS SOE - Pettit Cleanroom (standard oxide etcher)

STS Pegasus - Pettit Cleanroom (not pictured)

Trion ICP - Pettit Cleanroom

Vision RIE2 - Pettit Cleanroom

Vision RIE1 - Pettit Cleanroom

Oxford RIE 1 - Marcus Inorganic Cleanroom