Penn State's Materials Research Institutes Nanofabrication Facility

Current Facilities and Capabilities

Available Etch Tools

- Plasma Etcher
  - Tepla America M4L
- Reactive Ion Etchers (CCP RIE's)
  - Tegal 6500 cluster tool
  - PlasmaTherm 720
  - P-5000 MERIE
- Inductively Coupled Plasma Etchers
  - Alcatel Speeder 100 for Si etching (BOSCH process)
  - Alcatel Speeder 100 for SiO2 etching
  - PlasmaTherm Versalock cluster tool
- Dry Release / Gas Etcher
  - Xactix XeF2

Plasma Etchers

Tepla America M4L

- Chamber Configuration
  - 3 large shelves
  - Wafer Sizes: Small Pieces through 8" wafers
- RF Generator
  - Frequency: 13.56 MHz
  - Power: 0 - 600 W
- Operating Pressures
  - 300mTorr - 1.3 Torr
- Gases
  - Hexafluoroethane (C_2F_6)
  - Tetrafluoromethane (CF_4)
  - Oxygen (O_2)
  - Helium (He)
- Materials Processed
  - Benzocyclobutene polymers/resist (BCB)
  - E-bean Resists:
    - PMMA, ZEP, NEB, etc
  - Graphene fluorination
  - Lift-Off Resist (LOR)
  - Parylene
  - PDMS surface modification
  - Photoresist
  - Polyimide
  - Polyprrole
  - SU-8 negative photoresist
  - KMPR negative photoresist

Reactive Ion Etchers (Capacitive Coupled Plasma Systems)

Tegal 6500 Cluster Tool

- Cassette to Cassette wafer transfer for handling small parts through 150mm (6 inch) wafers.
  - Electrostatic chuck wafer clamping
  - Helium backside cooling
  - Chiller: 0C to 80C
- RF Generators
  - Frequency (LF): 400 kHz
    - Power: 0-500W
  - Frequency (HF): 13.56 MHz
    - Power: 0-1200W
- Process Gases
  - Tetrafluoromethane (CF_4)
  - Sulfur hexafluoride (SF_6)
  - Chlorine (Cl_2)
  - Boron Trichloride (BCL_3)
  - Oxygen (O_2)
  - Argon (Ar)
- Operating Pressures
  - 1mTorr - 100mTorr
  - Ideal pressure range is 1mTorr - 20mTorr
- End point detection
- Dielectrics
  - Alumina (Al_2O_3)
  - Hafnium Oxide (HfO_2)
  - Iridium Oxide (IrO_2)
  - Lanthanum Oxide (La_2O_3)
  - Silicon Dioxide (SiO_2)
  - Silicon Nitride (Si_3N_4)
  - Yttrium Oxide (Y_2O_3)
- Piezoelectric, Pyroelectric, and Ferroelectric complex oxides
  - Lead Lanthanum Zirconate Titanate - PZT
  - Lead Magnesium Niobate-Lead Titanate - PMN-PT
  - Lead Titanate - PbTiO3
  - Lead Zirconate Titanate - PZT
  - Strontium Titanate (SrTiO3)

Tegal 6500 Cluster Tool

- Metals
  - Aluminum (Al)
  - Chromium (Cr)
  - Gadolinium
  - Gold (Au)
  - Iron (Fe)
  - Molybdenum (Mo)
  - Palladium (Pd) (under development)
  - Platinum (Pt)
  - Tantalum (Ta)
  - Titanium (Ti)
  - Titanium Tungsten (TiW)
  - Tungsten (W)
- Semiconductors
  - Aluminum Antimonide (AlSb) (under development)
  - Aluminum Gallium Arsenide (AlGaAs)
  - Bismuth Selenide (Bi_2Se_3)
  - Gallium Arsenide (GaAs)
  - Gallium Nitride (GaN)
  - Germanium (Ge)
  - Germanium Antimony (GeSb)
  - Indium Arsenide (InAs)
  - Indium Phosphide (InP)
  - Silicon (Si)
  - Silicon Carbide (SiC)
  - Silicon Germanium (SiGe)
  - Zinc Oxide (ZnO)
  - Zinc Selenite (ZnSe)
- Polymers
  - BARLi anti-reflective coating (resist)
  - Carbon Nanotubes
- Transparent Conductive Oxides
  - Indium Tin Oxide - ITO (under development)

Tegal 6500 $Pb_{0.7}(Mg_{0.33}Nb_{0.66})O_3$-$Pb_{0.3}TiO_3$ Etch

- Process Parameters
  - **Pressure**: 2 mTorr
  - **HF Power**: 800W
  - **LF Power**: 100 W
  - **Gases**:
    - **Gas 1 / Flow**: Cl2 / 10sccm
    - **Gas 2 / Flow**: CF4 / 10sccm
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 25C
  - **Etch Mask**: Ni
  - **Etch Rate:** 1.7nm/s
  - **Selectivity**: High (>4:1)

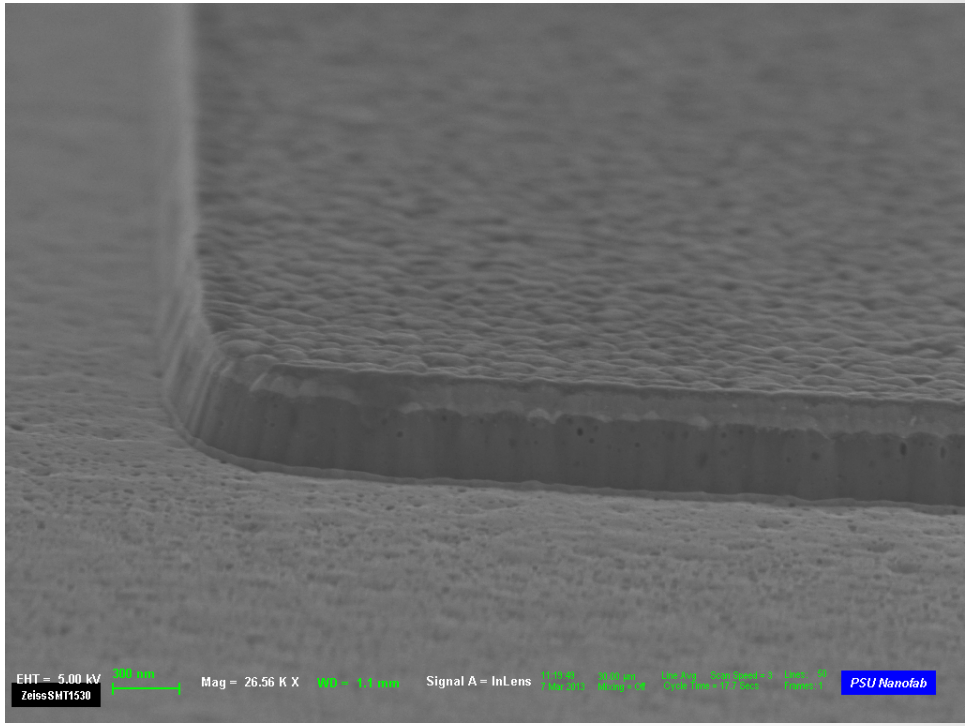


Figure 1:
$Pb_{0.7}(Mg_{0.33}Nb_{0.66})$-$Pb_{0.3}TiO_3$ thin film capacitors

PlasmaTherm 720

- Single wafer load lock system capable of processing 6" wafers through small pieces
  - No Clamp or He backside cooling
- RF Generator
  - Frequency: 13.56 MHZ
  - Power: 0-600W
- Process Gases
  - Hexafluoroethane or Halocarbon 116 (C_2F_6)
  - Tetrafluoromethane or carbon tetrafluoride (CF_4)
  - Trifluoromethane (CHF_3)
  - Sulfur hexafluoride (SF_6)
  - Chlorine (Cl_2)
  - Oxygen (O_2)
  - Argon (Ar)
  - Hydrogen (H_2)
- Operating Pressures
  - 1mTorr to 150mTorr
  - Chuck temperature range 0C to 100 C, but there is no backside helium cooling
- Dielectrics
  - Oxide (SiO_2), Nitride (Si_3N_4), OxyNitride, Si (a-Si)
- Metals
  - Gold (Au)
  - Chromium (Cr)
  - Titanium (Ti)
  - Aluminum (Al)
  - Silicon (Si)
- III-V Semiconductors
- Gallium Arsenide (GaAs)
- Indium Phosphide (InP)
- Indium Gallium Arsenide (InGaAs)
- Aluminum Gallium Arsenide (AlGaAs)
- Gallium Manganese Arsenide (GaMnAs)
- Silicon (poly and a-Si)
- Polymers
- BCB (Benzocyclobutene polymers/resist)
- LOR (Lift-off Resist)
- Photoresist
- Parylene
- PDMS (Polydimethylsiloxane)
- Polyimide
- SU-8 (epoxy photoresist)

PlasmaTherm 720 Parylene Etch

- Process Parameters
  - **Pressure**: 5 mTorr
  - **RF Power**: 50 W
  - **Gases**:
    - **Gas 1 / Flow**: O_2 / 50sccm
    - **Gas 2 / Flow**:
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 25C
  - **Etch Mask**: Al
  - **Selectivity**: High (>>20:1)

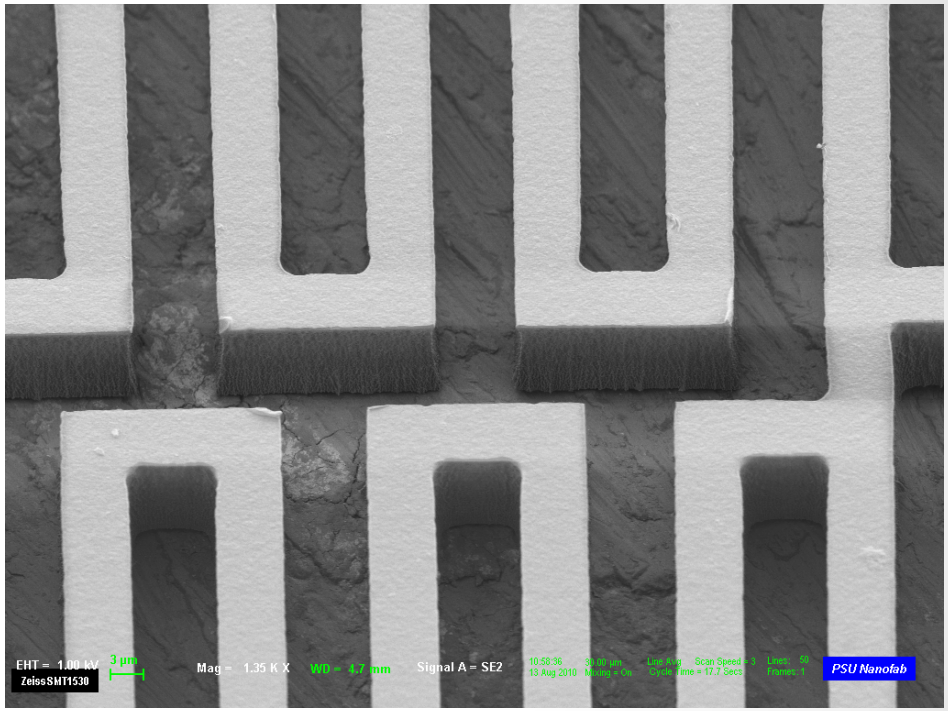


Figure 1:
Parylene springs for Medical devices

Magnetically Enhanced CCP

- Single wafer load lock system capable of processing 8" wafers through small pieces
  - Mechanically Clamped
  - He backside cooling
- RF Generator
  - Frequency: 13.56 MHZ
  - Power: 0-1200W
- Process Gases
  - Tetrafluoromethane or Carbon Tetrafluoride (CF_4)
  - Trifluoromethane (CHF_3)
  - Oxygen (O_2)
  - Argon (Ar)
  - Hydrogen (H_2)
- Operating Pressures
  - 1mTorr to 150mTorr
  - Chuck temperature range 0C to 100 C
- Dielectrics
  - Oxide (SiO_2), Nitride (Si_3N_4), OxyNitride, Si (a-Si)
- Polymers
- BCB (Benzocyclobutene polymers/resist)
- LOR (Lift-off Resist)
- Photoresist
- Parylene
- PDMS (Polydimethylsiloxane)
- Polyimide
- SU-8 (epoxy photoresist)

MERIE Polyimide Etch

- Process Parameters
  - **Pressure**: 18 mTorr
  - **Power**: 150W
  - **Gases**:
    - **Gas 1 / Flow**: O2 / 90sccm
    - **Gas 2 / Flow**:
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 3C
  - **Magnets:** 45 Gauss
  - **DC Bias:**
  - **Etch Mask**: Au
  - **Etch Rate:** 1.7nm/s
  - **Selectivity**: High (>>10:1)

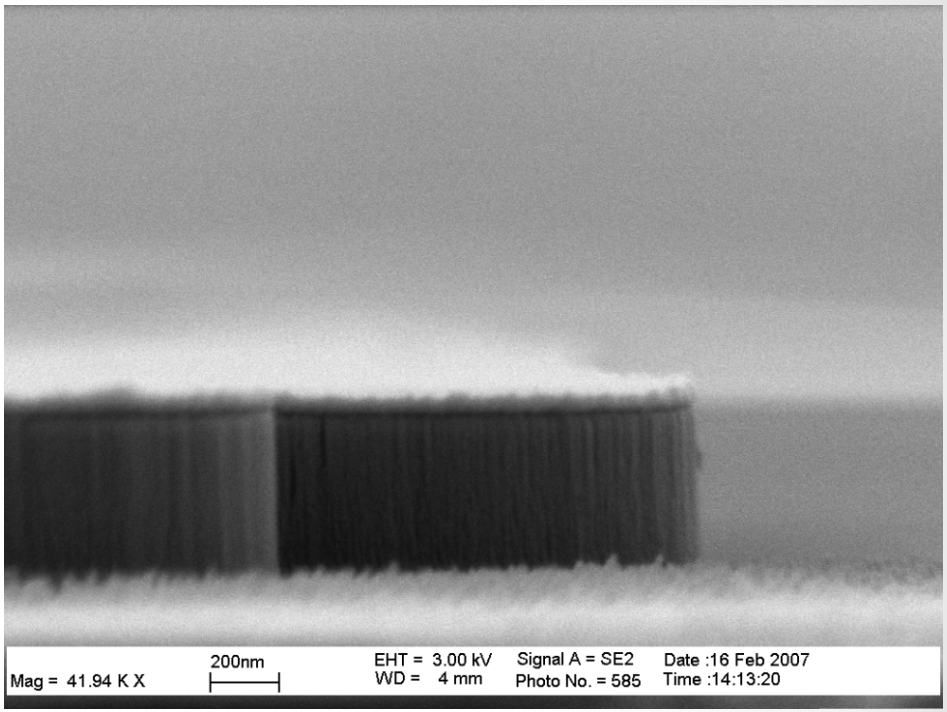


Figure 1:
Polyimide thin film

Inductively Coupled Plasma Systems

Alcatel "Speeder 100" Deep Si Etch Tool

- Single wafer load lock system capable of processing 4" wafers through small pieces
  - Mechanically Clamped
  - He backside cooling
- ICP Generator
  - Frequency: 13.56 MHZ
  - Power: 0-3000W
- RF Generator
  - Frequency: 13.56 MHz
  - Power: 0-500W
  - Pulsed Capability
- LF Generator
  - Frequency: 350kHz
  - Power: 0-500W
  - Pulsed Capability
- Process Gases
  - Octofluorocycobutane (C_4F_8)
  - Sulfur hexafluoride (SF_6)
  - Oxygen (O_2)
- Operating Pressures
  - 1mTorr to 150mTorr
  - Chuck temperature range -140C to 20 C

Alcatel Si Etch for Sub 500nm Features

- Process Parameters
  - **Process**: Morphed Bosch Process
  - **Etch Mask**: Zep520
  - **Selectivity**: 80:1
  - **Apsect Ratio**: ~38:1

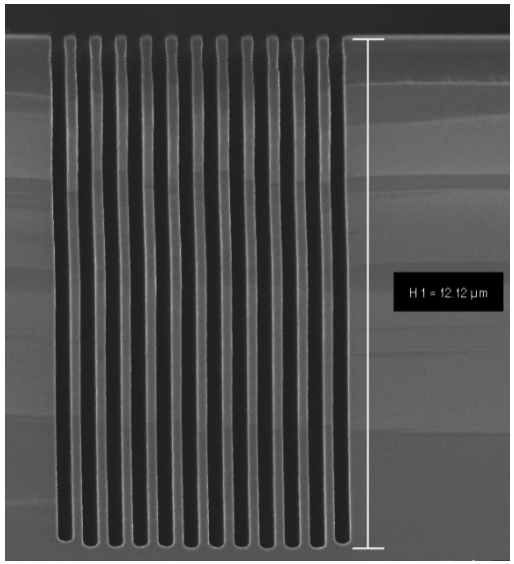
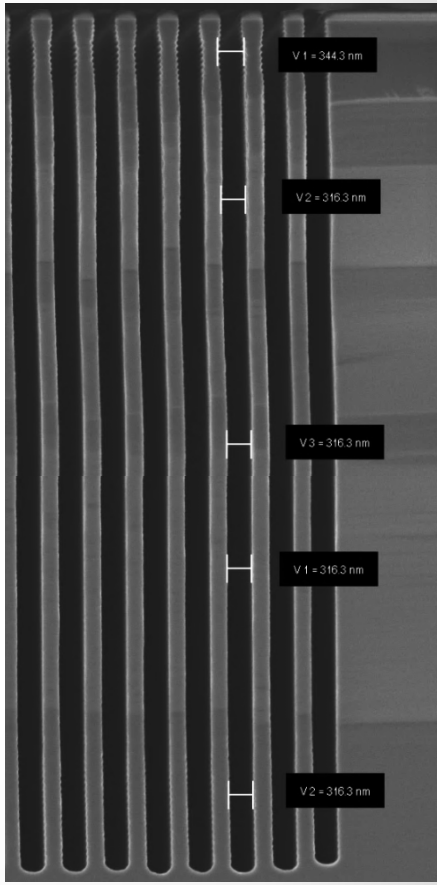


Figure 1:
300nm wide trenches etched in Silicon



Alcatel "Speeder 100" Deep SiO_2 Etch Tool

- Single wafer loadlock system capable of processing 4" wafers through small pieces
  - Mechanically Clamped
  - He backside cooling
- ICP Generator
  - Frequency: 13.56 MHZ
  - Power: 0-3000W
- RF Generator
  - Frequency: 13.56 MHz
  - Power: 0-500W
  - Pulsed Capability
- LF Generator
  - Frequency: 350kHz
  - Power: 0-500W
  - Pulsed Capability
- Process Gases
  - Octofluorocycobutane (C_4F_8)
  - Sulfur hexafluoride (SF_6)
  - Oxygen (O_2)
  - Argon (Ar)
  - Nitrogen Trifluoride (NF_3)
  - Hydrogen (H_2)
- Operating Pressures
  - 1mTorr to 150mTorr

  Chuck temperature range 5C-90C
- Materials Processed
  - SiO2
  - Quartz
  - Borofloat (Borosilicate Glass)
  - PZT

Alcatel Speeder 100 SiO_2 Etcher

- Process Parameters
  - **Pressure**: 10 mTorr
  - **ICP Power**: 2000W
  - **Bias Power**: 400 W
  - **Gases**:
    - **Gas 1 / Flow**: NF3
    - **Gas 2 / Flow**: Ar
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 25C
  - **Etch Mask**: Ni
  - **Selectivity**: High (>5:1)
  - **Etch Rate**: 0.55µm / min

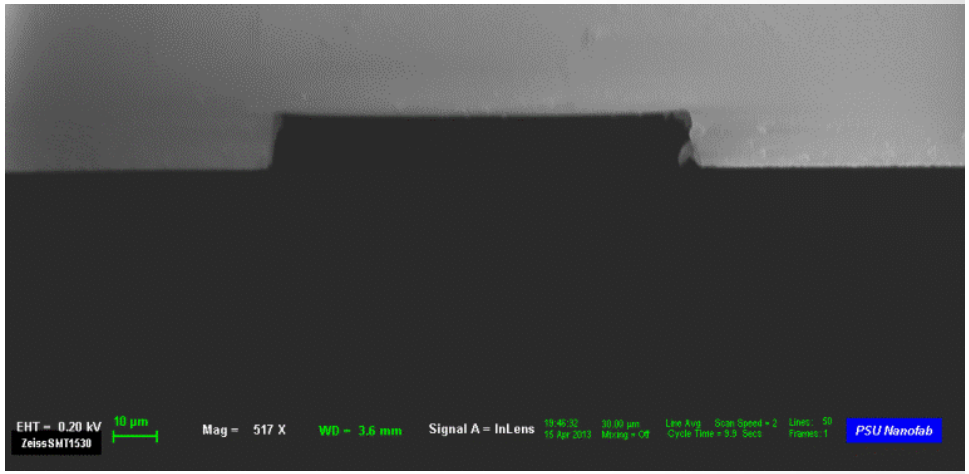


Figure 1:
Borosilicate Glass Etch using NF3 chemistries

PlasmTherm Versalock Cluster Tool

- Cassette to Cassette wafer transfer for handling small parts through 150mm (6 inch) wafers.
  - Mechanical wafer clamping
  - Helium backside cooling
  - Chiller: 5C to 80C
  - 2 Chambered System
    - Metals
    - Dielectrics
- ICP Generators
  - Frequency: 13.56 MHz
  - Power: 0-1000W
- RF Generators
  - Frequency (HF): 13.56 MHz
  - Power: 0-500W
- Process Gases
  - Tetrafluoromethane (CF_4)
  - Trifluoromethane (CHF_3)
  - Octofluorocycobutane (C_4F_8)
  - Sulfur hexafluoride (SF_6)
  - Chlorine (Cl_2)
  - Boron Trichloride (BCL_3)
  - Oxygen (O_2)
  - Argon (Ar)
- Operating Pressures
  - 1mTorr - 100mTorr
  - Ideal pressure range is 1mTorr - 20mTorr
- End point detection
  - Dielectric Chamber
    - Interferometer, OES
  - Metal Chamber
    - OES
- Dielectrics
  - Oxide (SiO2)
  - Nitride (Si3N4)
  - OxyNitride ($Si_XO_YN_Z$)
  - Alumina (Al_2O_3)
  - Hafnium Oxide (HfO_2)
  - Iridium Oxide (IrO_2)
  - Lanthanum Oxide (La_2O_3)
  - Silicon Dioxide (SiO_2)
  - Silicon Nitride (Si_3N_4)
  - Yttrium Oxide (Y_2O_3)
- Metals
  - Gold (Au)
  - Chromium (Cr)
  - Titanium (Ti)
  - Aluminum (Al)
  - Silicon (Si)
  - Molybdenum
- III-V Semiconductors
- Gallium Arsenide (GaAs)
- Indium Phosphide (InP)
- Indium Gallium Arsenide (InGaAs)
- Aluminum Gallium Arsenide (AlGaAs)
- Gallium Manganese Arsenide (GaMnAs)

Versalock $In_{0.7}Ga_{0.3}As/GaAs_{0.35}Sb_{0.65}$ Etch

- Process Parameters
  - **Pressure**: 5 mTorr
  - **ICP Power**: 500W
  - **Bias Power**: 50 W
  - **Gases**:
    - **Gas 1 / Flow**: BCl3 / 50sccm
    - **Gas 2 / Flow**: Ar /
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 25C
  - **Etch Mask**: Cr
  - **Selectivity**: High (>>5:1)

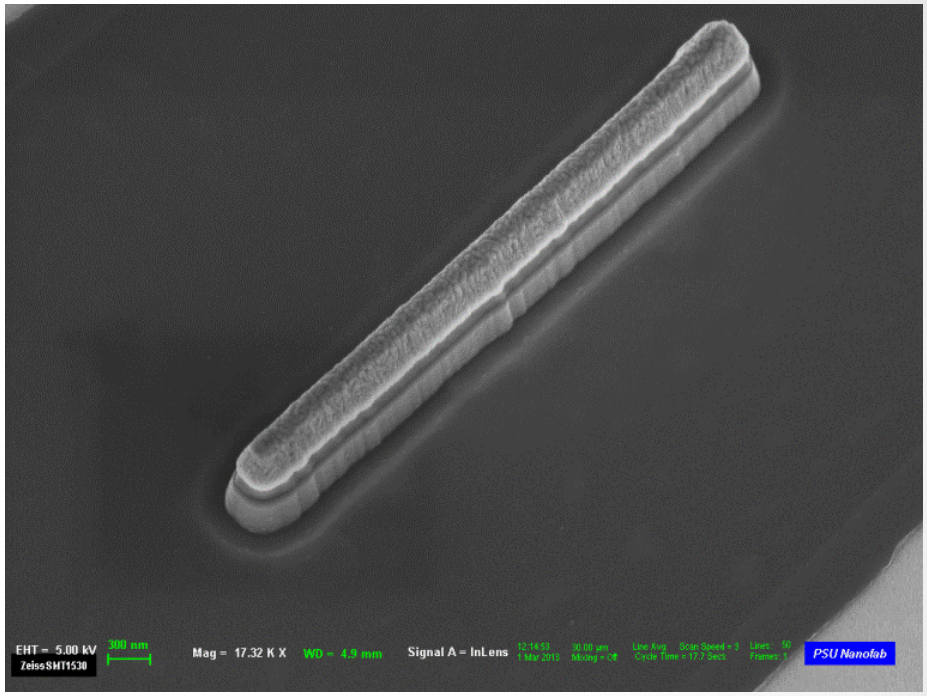


Figure 1:
$In_{0.7}Ga_{0.3}As/GaAs_{0.35}Sb_{0.65}$ Hetero-Junction TFET

- Dheeraj et. al. , *Proc. VLSI Symposium*, (2012).

Versalock $In_{0.53}Ga_{0.47}As$ Etch

- Process Parameters
  - **Pressure**: 5 mTorr
  - **ICP Power**: 75W
  - **Bias Power**: 50 W
  - **Gases**:
    - **Gas 1 / Flow**: BCl3 / ??sccm
    - **Gas 2 / Flow**: Ar / ??sccm
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 25C
  - **Etch Mask**: Zep520
  - **Selectivity**: ~1:1

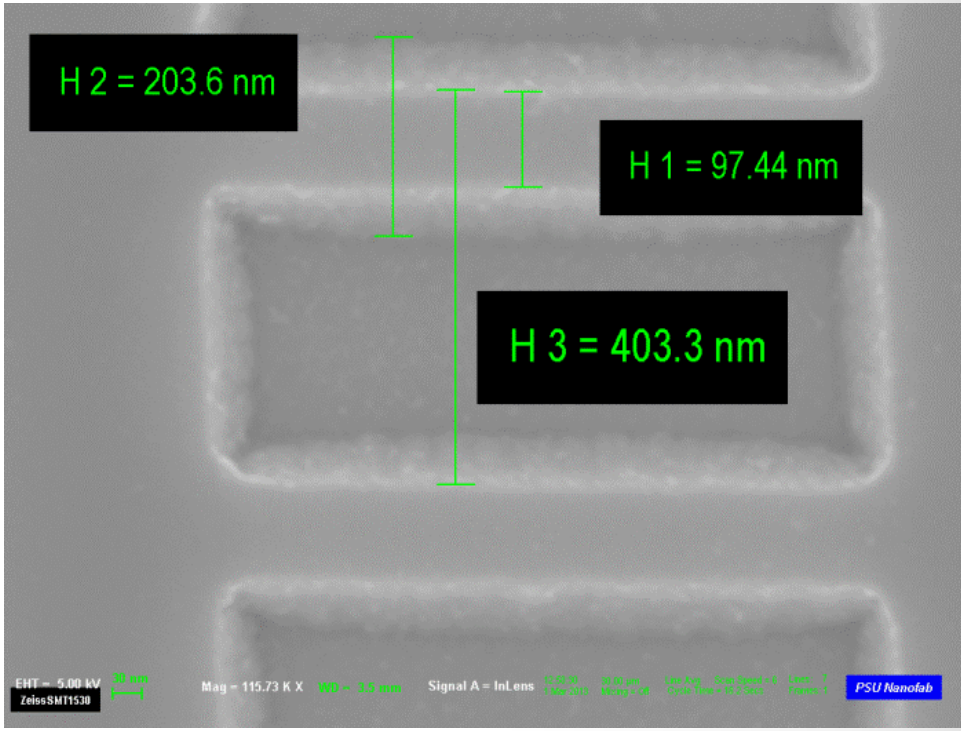


Figure 1:
50nm thick $In_{0.53}Ga_{0.47}As$ on InP

- Lu Liu et. al. , *Proc. Int. Electron Devices Meeting*, (2011).

Versalock Sub 100nm SiO2 Etch

- Process Parameters
  - **Pressure**: 3 mTorr
  - **ICP Power**: 900W
  - **Bias Power**: 50 W
  - **Gases**:
    - **Gas 1 / Flow**: CF4 / 40sccm
    - **Gas 2 / Flow**:
    - **Gas 3 / Flow**:
  - **Substrate Temp**: 10C
  - **Etch Mask**: Zep520
  - **Etch Rate:** 20A/s
  - **Selectivity**: ~1:1

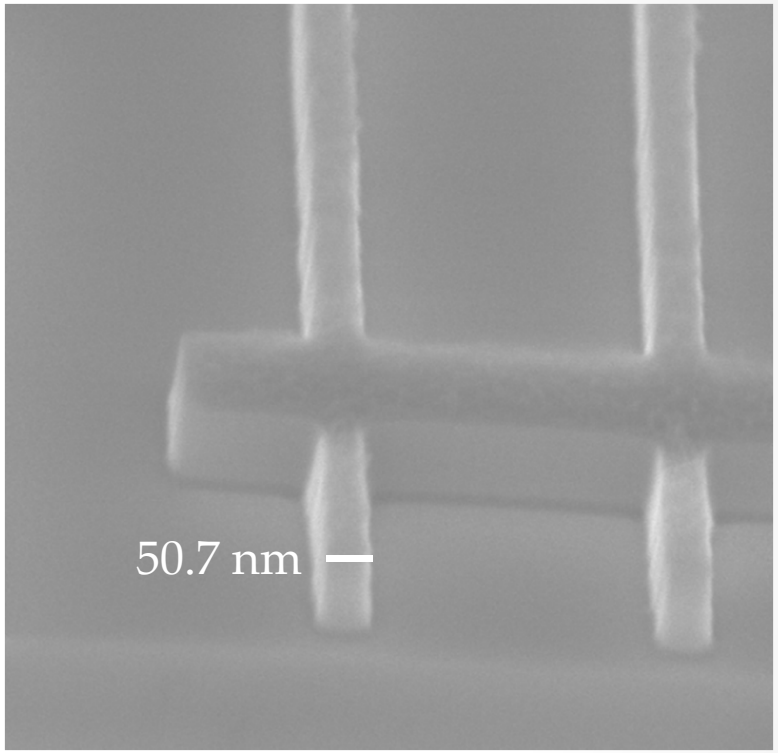


Figure 1:
100nm thick SiO2

Xactic XeF_2 Tool

- Wafer Sizes150mm (6 inch) wafers through small parts.
- Process Gases
  - Xenon Difluoride (XeF2)
- Operating Pressures
  - 1 Torr – 4 Torr

Equipment Base Lining

- All tools are base lined of a SiO2 process developed for each tool
- Process is setup optimum uniformity across a 6” wafer
- Wafers are run during initial tool trainings or when a user indicates a potential problem with their process

Materials Etched in the Facility

Material Processing Chart						
Material	**Abbr.**	**M4L**	**PT720**	**AMAT MERIE**	**PT Versalock**	**Tegal 6540**
Alumina	Al2O3 / AlOx		yes		yes	yes
Aluminum	Al		no		yes	yes
Aluminum Antimonide	AlSb		no		yes	exp.
Aluminum Gallium Arsenide	AlGaAs		exp.		yes	yes
Aluminum Indium Arsenide	AlInAr				yes	
Aluminum/Titanium	AlTi		no		probable	ask
Antimony	Sb		no		yes	
Barium Titanate	BaTiO3		no			ask
BARLi anti-reflective coating (resist)	BARLi	yes	yes	yes	yes	yes
Benzocyclobutene polymers/resist	BCB	probable	yes	no		
Bismuth	Bi		no			-
Bismuth Selenide	Bi2Se3		no		no	yes
Carbon Nanotubes	CNT		yes		yes	yes
Chromium	Cr	slow	yes		yes	yes
Cobalt	Co		no		No	No
Copper	Cu		no		no	no
Gadolinium	Gd		no		yes	yes
Gadolinium Nitride	GdN		no		yes	ask
Gallium Arsenide	GaAs		yes		yes	yes
Gallium Nitride	GaN		slow		yes	yes
Germanium	Ge		yes		yes	yes
Germanium Antimony	GeSb		probable		probable	yes
Gold	Au		yes		yes	yes

Key:
Yes = at least one recipe is working for a researcher
No = Cannot be etched in equipment
Probably = based on published papers the material can be etched on the equipment, but the process needs to be developed
Exp. = the etch is experimental and under development

Materials Etched in the Facility

Material Processing Chart						
Material	Abbr.	M4L	PT720	AMAT MERIE	PT Versalock	Tegal 6530
Gorilla Glass	-		no	probable	yes	
Graphene fluorination	-	probable	yes		yes	
Graphene.	-	yes	yes	yes	yes	
Hafnium Oxide	HfO2		probable		yes	yes
Indium	In	no	no		no	no
Indium Arsenide	InAs		no		yes	yes
Indium Gallium Arsenide	InGaAs		yes		yes	
Indium Phosphide	InP		yes		yes	yes
Indium tin oxide	ITO		no		exp	exp.
Iridium	Ir		no		ask	ask
Iridium Oxide	IrO2		no		yes	yes
Iron	Fe		no		exp.	exp.
Iron-Manganese	Fe-Mn		no		ask	ask
KMPR photoresist	KMPR	yes	yes	probable		
Lanthanum Calcium Manganese Oxide	LCMO		0		yes	
Lanthanum Oxide	La2O3		0		yes	yes
Lanthanum Strontium Manganese Oxide	LSMO		0		yes	
Lead Lanthanum Zirconate Titanate	PLZT		no	No	no	yes
Lead Magnesium Niobate-Lead Titanate	PMN-PT		No	No	no	yes
Lead Nickel Niobate-Lead Zirconate Titanate	PNN-PZT		No	No	no	
Lead Titanate	PbTiO3		no	no	no	yes
Lead Zirconate Titanate	PZT		no	No	no	yes

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Materials Etched in the Facility

Material Processing Chart						
Material	Abbr.	M4L	PT720	AMAT MERIE	PT Versalock	Tegal 6530
Lithium Cobalt Oxide	LCO / LiCoO2		no		ask	ask
Lithium Niobate	LiNbO3		no		yes	
Magnesium	Mg		no		ask	ask
Magnesium oxide	MgO		no		probable	probable
Manganese Arsenide	Mg3As2		exp.		yes	
Molybdenum	Mo		yes		yes	yes
Nickel	Ni		no		hard mask	no, hard mask
Nickel Iron	NiFe		no		no	no.
Nickel/Chromium	NiCr		no		ask	ask
Niobium	Nb		no		probable	probable
Niobium/Iron	NbFe		no		ask	ask
Palladium	Pd		probable		exp.	exp.
Parylene / poly(p-xylylene) polymer		probable	yes	probable	no	no
PDMS surface modification		yes	yes			
Platinum	Pt		no		yes	yes
poly(dioctyl-bithiophene)	PDOT	probable	yes	yes	yes	
Poly(methyl methacrylate)	PMMA		yes	excellent		
Polydimethylsiloxane	PDMS	no	yes	no		
Polyimide		probable	yes	yes		
Quartz			yes	yes	yes	
Sapphire			no	no	yes	
Silicon	Si		yes		yes	yes

Key:
Yes = at least one recipe is working for a researcher
No = Cannot be etched in equipment
Probably = based on published papers the material can be etched on the equipment, but the process needs to be developed
Exp. = the etch is experimental and under development

Materials Etched in the Facility

Material Processing Chart						
Material	Abbr.	M4L	PT720	AMAT MERIE	PT Versalock	Tegal 6530
Strontium Titanate	SrTiO3		no			exp.
SU-8 resist	SU-8	yes	yes	probable		
Tantalum	Ta		yes		yes	yes
Tantalum Carbide	Ta2C / TaC		probable			ask
Tantalum Nitride	TaN		probable			probable
Tantalum Oxide	Ta2O5		probable		yes	probable
Tin	Sn		no			ask
Titanium	Ti		yes		yes	yes
Titanium Aluminum	TiAl		yes		yes	
Titanium Dioxide	TiO2 / TiOx		yes		yes	probable
Titanium Nitride	TiN		yes		yes	probable
Titanium-Diboride	TiB2		no			ask
Titanium/Tungsten	TiW		probable		yes	yes
Tungsten	W		yes		yes	yes
Vanadium	V		0		ask	ask
Vanadium Oxide / Vanadium Pentoxide	Va2O5 / VaOx		0			ask
Yttrium Oxide	Y2O3		0			exp.
Zinc	Zn		no			no
Zinc Oxide	ZnO		no			yes
Zinc Selenite	ZnSe		no			yes
Zinc Tin Oxide	ZTO		no		yes	
Zinc-Oxide/Aluminum Oxide	ZnO/Al2O3		no			ask

Key:
Yes = at least one recipe is working for a researcher
No = Cannot be etched in equipment
Probably = based on published papers the material can be etched on the equipment, but the process needs to be developed
Exp. = the etch is experimental and under development

Chamber Conditioning Strategies

- Setup Standard operating procedures for every user
- Every user must perform the following steps prior to running their samples
  - Chamber Clean Process
    - Slightly varied on each system due to types of materials etched in each
  - Chamber Conditioning
    - 3-5 minute chamber conditioning
      - Users use their recipe for running this step
  - Etch verification (optional)
  - Sample run

Future Plans

- Acquisitions:
  - Additional Complex Oxide Etching Tool
  - Ion Milling System
- Modifications
  - Software upgrades to some of the aging computer systems
  - New RF power Supplies on the PlasmaTherm Versalock etch tool (higher power 2500W)
  - Upgrade of PlasmaTherm Versalock matching networks
- Process Development
  - Looking at new materials for Complex Oxide Hard masks