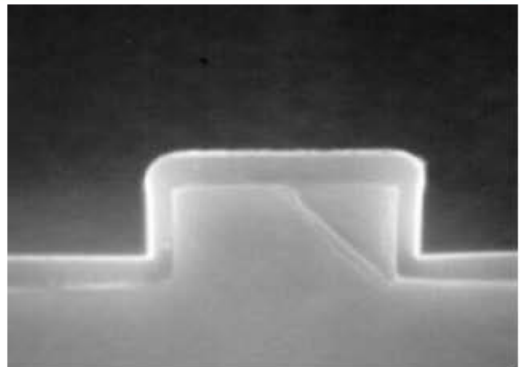




PECVD and HDPCVD Basics



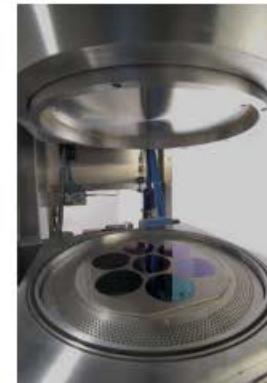
2015

Alidouble Inc. v. TSMC

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Outline

- Introduction to plasma enhanced deposition
- General equipment configuration
- PECVD film properties
- Films of interest
 - SiO_2 , SiN_x , a-Si:H
- HDP CVD
- Backup slides
 - General operational guidance
 - General process parameter trends (temperature, pressure, frequency, flow)



Good source of information:

http://www.timedomaincvd.com/CVD_Fundamentals/Fundamentals_of_CVD.html



Alidouble Inc. v. TSMC



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What is PECVD?

Plasma
Enhanced
Chemical
Vapor
Deposition

Goal: Deposition of thin films using plasma assistance to avoid undesirable temperatures



Alidouble Inc. v. TSMC



Technology for PECVD Applications

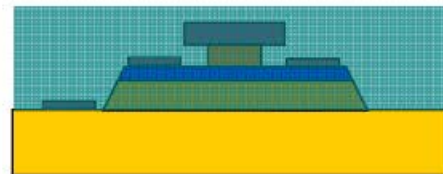
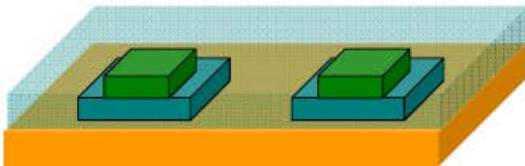
Masking



Capacitor dielectric



Passivation/Encapsulation/Insulation

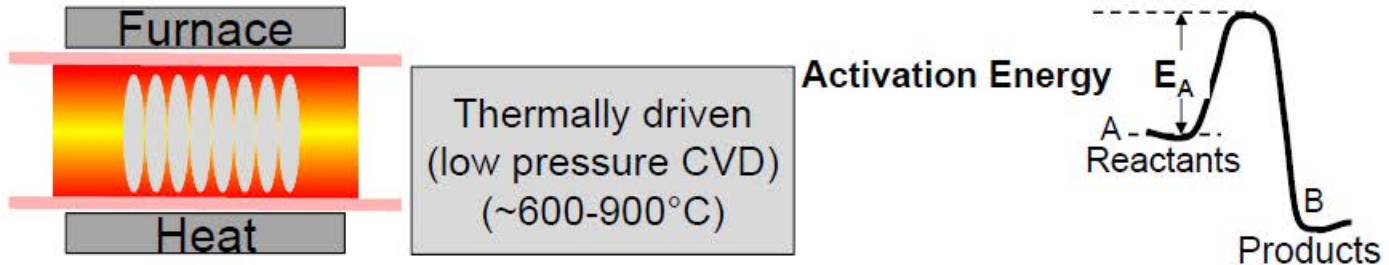


General Case of Chemical Vapor Deposition

- Precursors (reagents) are gases
- Reactions occur - solid (film) is formed as by-product
- Highly simplified examples:



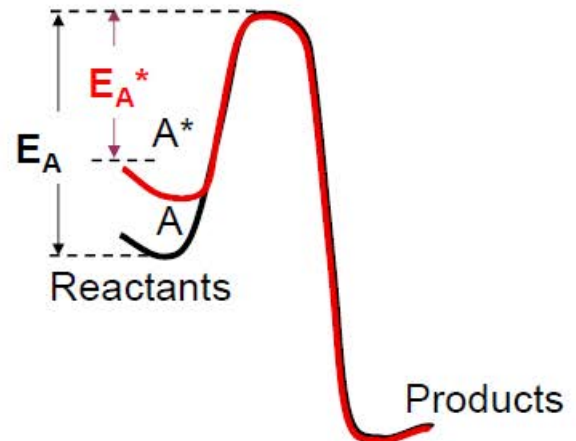
- Energy input is needed for chemical reactions to proceed



PECVD – Plasma Enhancement

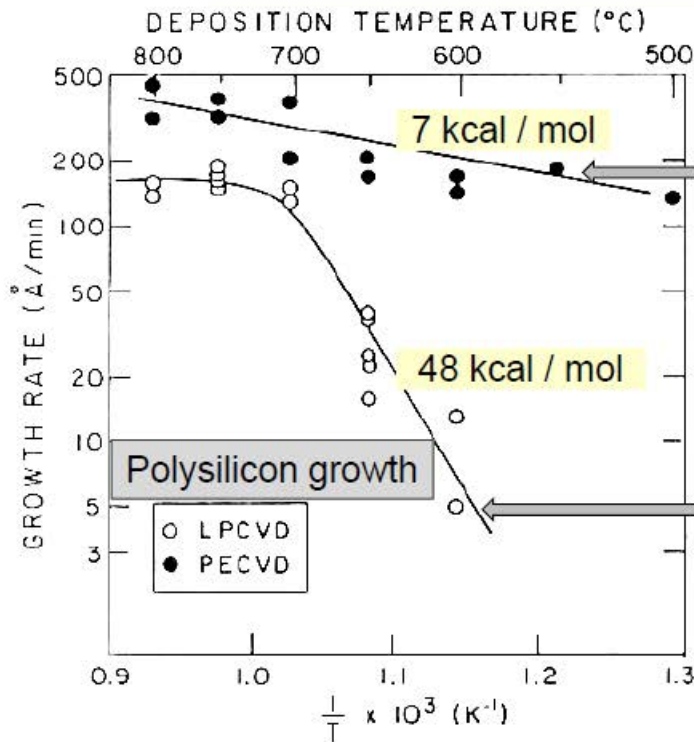
Plasma supplied energy (excited species)

- Reactions occur at lower temperature
 - Plasma input $E_A - E_A^*$
 - Attractive for temperature sensitive substrates (e.g. III-V materials, polymers, some silicon devices)
- Lowens activation energy ($\rightarrow$ lower temperature required), $E_A^* < E_A$
- Potential increase to deposition rate
- Affects on film characteristics (e.g. stress, density through energetic ions)



Temperature can be reduced to ~150 to 400°C

PECVD – Plasma Enhancement



Plasma enhanced
Low activation energy, E_A
Relatively weak dependence on temperature

Without plasma enhancement
High activation energy, E_A
Strong dependence on temperature
(e.g. ~ 0 Å/min vs. ~ 130 Å/min at $\sim 500^\circ\text{C}$)
Kinetic regime vs. diffusion regime at higher temperatures

Source: Hajjar et al, J. Electronic Mat., 15, 279 (1986)

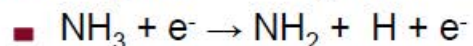
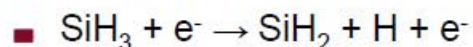
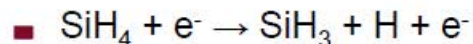
 **Plasma-Therm**

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Alidouble Ex. 2015, p. 7

PECVD – Film Formation

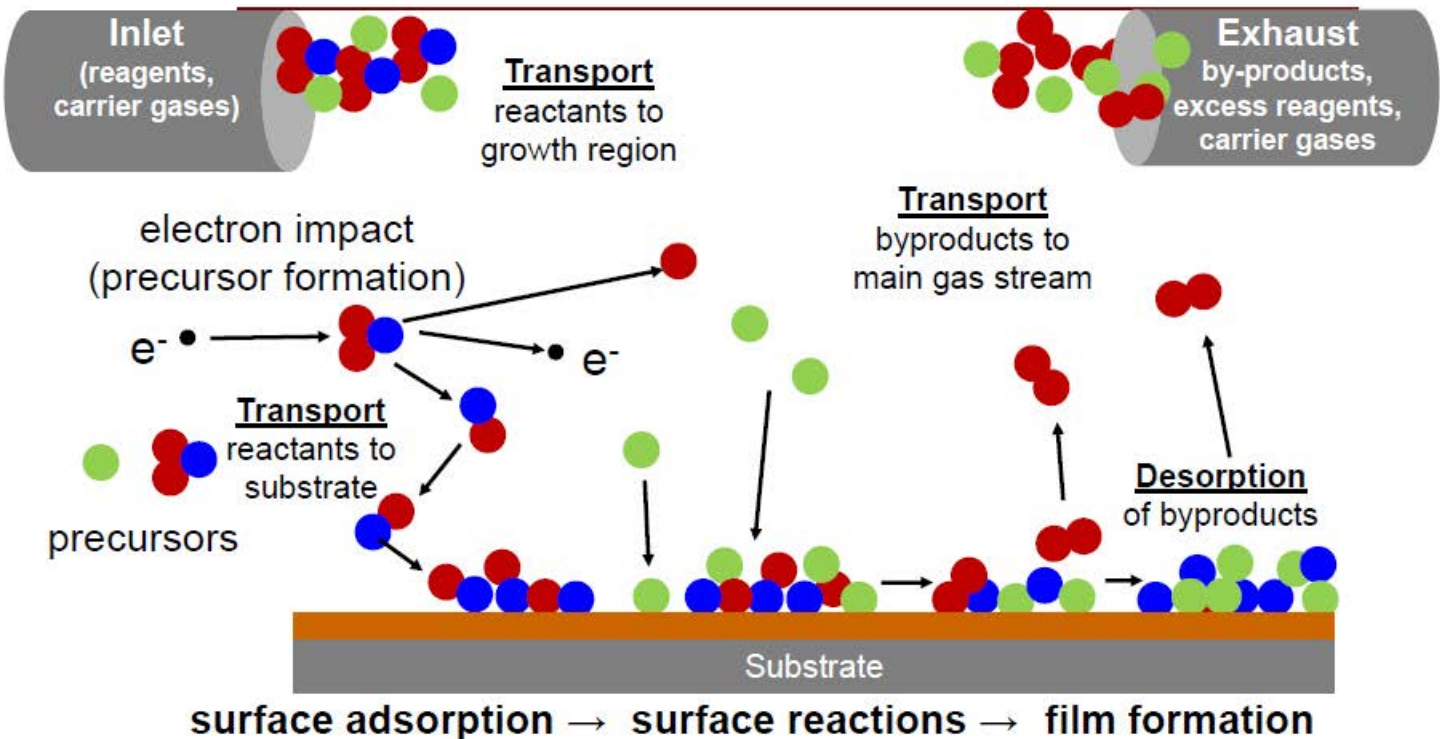
- Radicals are formed by electron impact



Plasma added energy

- Radicals adsorb on substrate surface
- Reactions occur on surface
 - Thermally driven, may be some plasma interaction
- Film forms and by-products generated

PECVD: Qualitative Model of Film Formation



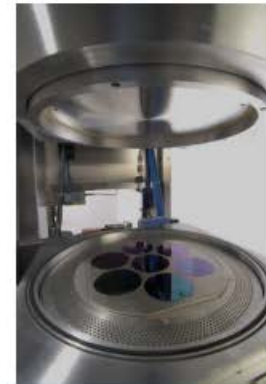
PECVD – Silane Based Films

Important films in semiconductor industry

- | | | |
|-------------------------------------|---|--|
| ■ Silicon dioxide, SiO_2 | $\text{SiH}_4 + \text{N}_2\text{O}$ | } Plus carrier gas
(He, N_2)
when dilute SiH_4
is used for
safety reasons |
| ■ Silicon nitride, SiN_x | $\text{SiH}_4 + \text{NH}_3$ or $+$ $\text{SiH}_4 + \text{N}_2$ | |
| ■ Silicon oxynitride, SiON | $\text{SiH}_4 + \text{NH}_3 + \text{N}_2\text{O}$ | |
| ■ Amorphous silicon, a-Si:H | $\text{SiH}_4 + \text{He}$ or Ar | |
| ■ Silicon carbide, SiC | $\text{SiH}_4 + \text{CH}_4$ | |

Outline

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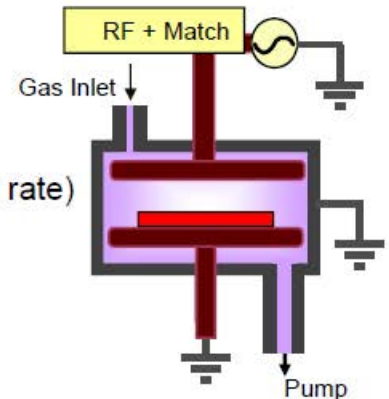
Alidouble Inc. v. TSMC



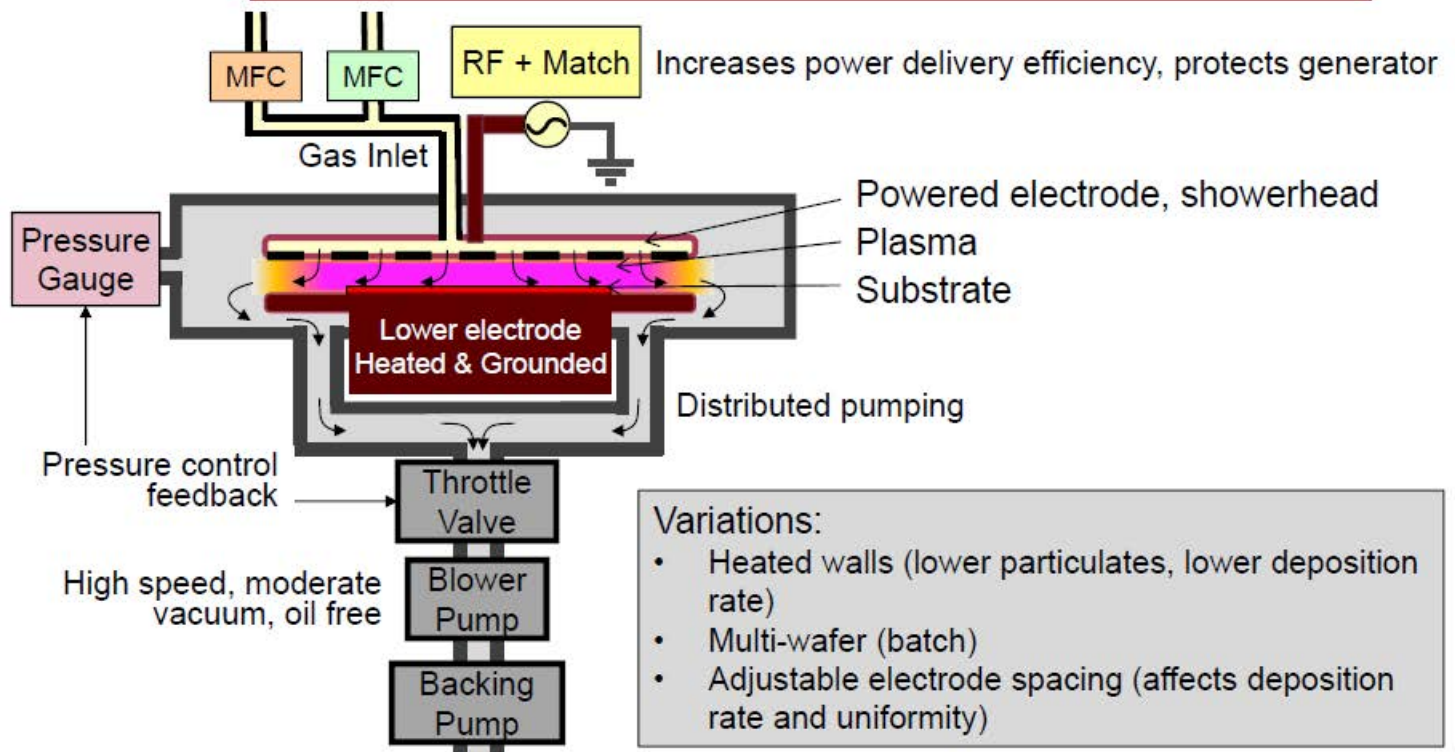
Alidouble Ex. 2015, p. 11

PECVD – Equipment Configuration

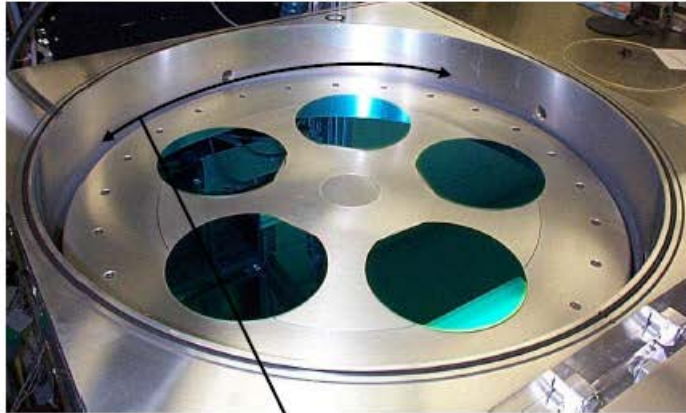
- **Geometry** (similar to plasma enhanced configuration)
 - Vacuum system configured for high gas flow – uniform pumping
 - Relatively high pressure regime (100's mTorr → few Torr)
 - Viscous flow regime, not diffusion
 - High speed pumping (500-2000 sccm)
 - Electrode Spacing
 - Confined plasma – need to be close (smaller gap $\Rightarrow$ higher rate)
 - Uniformity requires optimization (e.g. parallel)
 - Must consider handling limitations
- **Top electrode**
 - Powered (single or multiple frequencies)
 - Serves as gas inlet
 - High gas flows – litres/min (note: mass balance/dilute silane)
 - Showerhead gas inlet for uniform gas distribution (viscous flow regime)
- **Lower electrode**
 - Heated to drive thermal reactions
 - Single or multi-wafer loading capabilities



PECVD – Basic Reactor Configuration



PECVD – Distributed pumping



Peripheral pumping for uniform gas flow

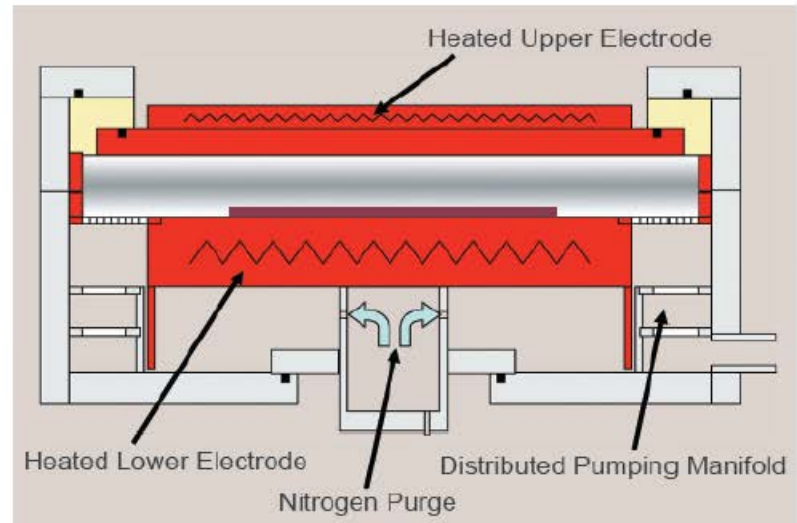
PECVD is in viscous flow regime ($\gg \sim 50\text{mTorr}$)
Distributed pumping needed to avoid nonuniform gas flow and film deposition ($\sim 500 - 2000\text{ sccm}$)



Productivity and Film Quality Design Aspects

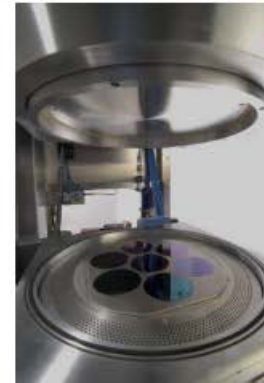
■ Isothermal Design

- Higher quality films
- Improved particle performance and uniformity
- Increased mean time between cleans
- Increased etch back (plasma clean) rates (2kW rf supply optional)
- *In situ* thickness monitor



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PECVD

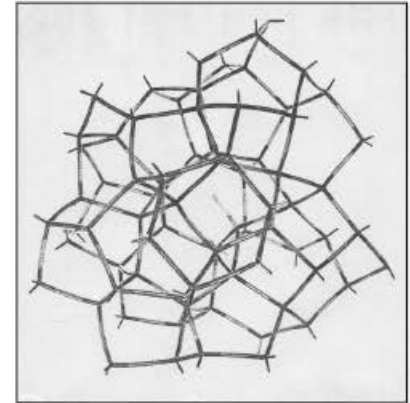
Process and Film Evaluation Criteria

- Electrical properties (breakdown)
- Mechanical properties (film stress)
- Adhesion
- Pinholes
- Conformal (step coverage)
- Induced damage
- Fill capability (without voids)
- Uniformity thickness, refractive index
- Particulates
- Composition (H conc. refractive index)
- Wet etch rate (BHF solution)
- Density

- Deposition rate
 - Fast for high throughput
 - Slow for control of thin films
- “Robustness”
 - Reproducible (within wafer, within batch, run-to-run)
 - Wide process window
 - Reliability
- Maintenance
 - Long intervals between cleans (MTBC)
 - Short, efficient clean cycles
- Handling (single, batch)
- Endpoint

PECVD: Basic Film Properties

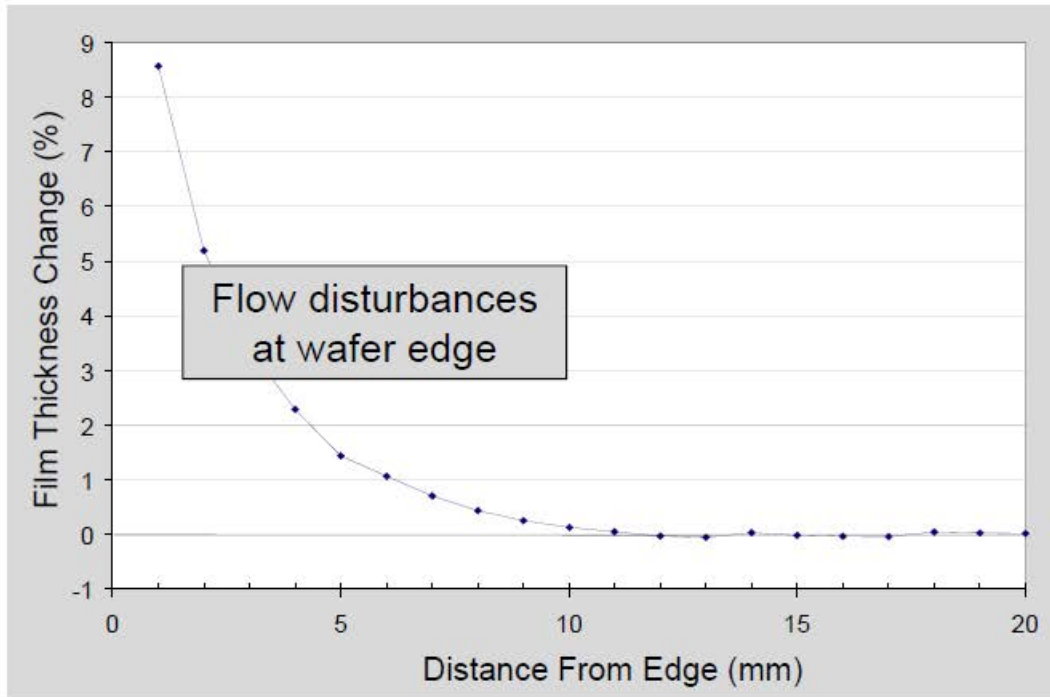
- Most films formed are **amorphous**
 - No crystalline structure (not even micro-crystalline except for some Si)
- Films formed are **not perfectly stoichiometric**
 - Often significant H incorporation
 - Silicon dioxide is not “ SiO_2 ” – but $\text{SiO}_x\text{:H}$
 - Silicon Nitride is not “ Si_3N_4 ” – but $\text{SiN}_x\text{:H}$
 - Amorphous Si is really a-Si:H
- Film properties depend on
 - Plasma conditions (pressure, flow, power, reactor geometry)
 - Substrate temperature
 - Substrate material (surface, thickness)



More on this later...

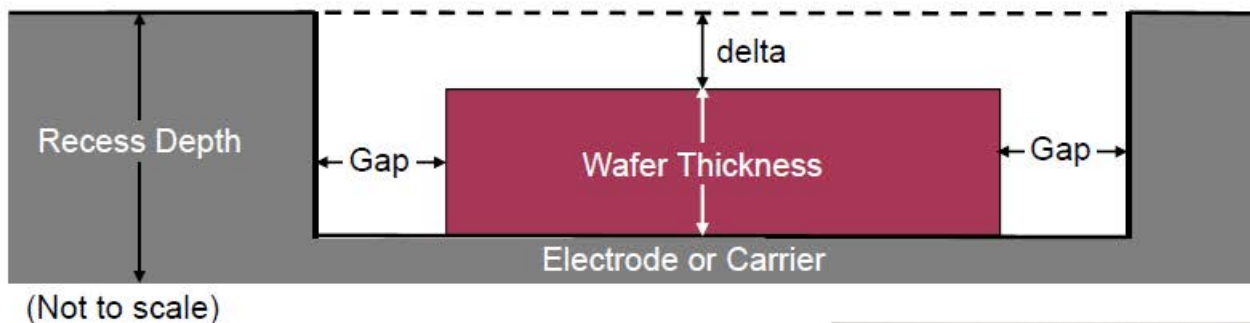
PECVD – “Edge Effect”

Typical Deposition Within Wafer Uniformity



PECVD – Controlling Edge Effects

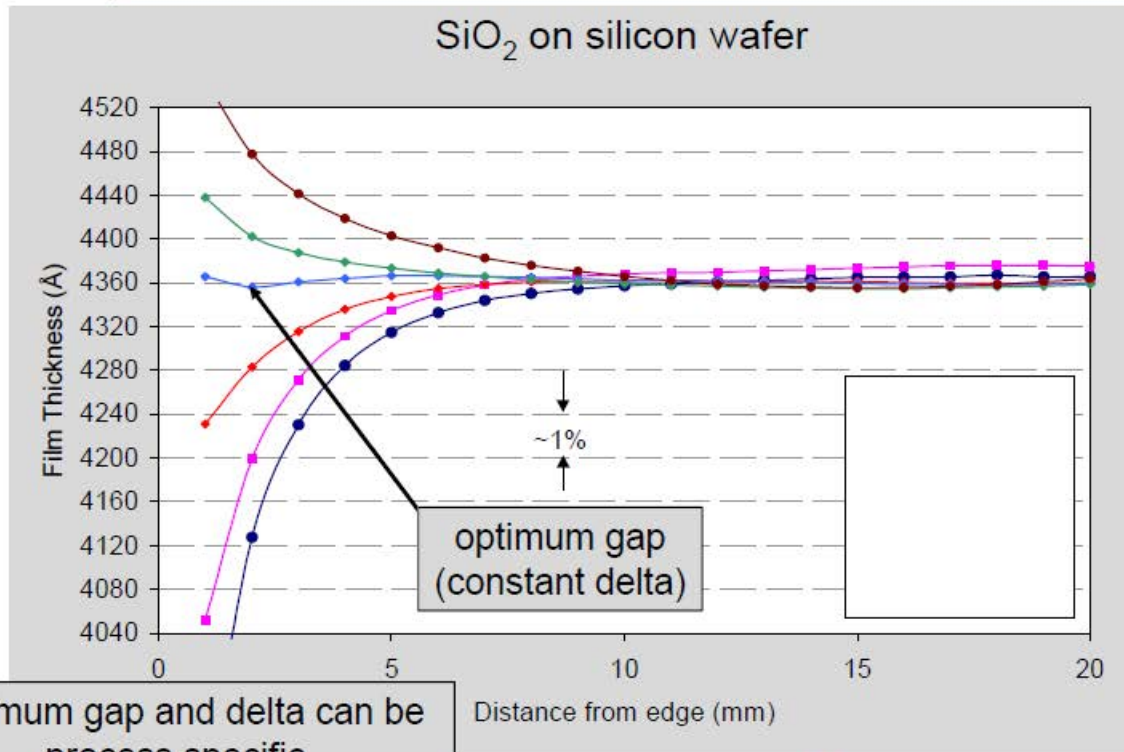
Recessed Wafer “Pocket”



Gap and delta important for uniformity
(some gap needed to allow for reliable wafer transfer)



PECVD – Uniformity Dependence on “Gap” Example



PECVD Process Parameters: Frequency - Plasma Effects

- Low frequency (50-100 kHz)
 - Ions traverse sheath before electric field reverses
 - Electrons still preferentially diffuse out of plasma contributing to negative bias
 - Wider ion energy distribution at lower frequencies
- High frequency (>1MHz)
 - Electrons respond to plasma and less likely to diffuse to walls causing less bias and more reagent dissociation
 - Less bias corresponds to lower ion acceleration voltage
 - Ions cannot traverse sheath before field reverses - thus lower ion energy

**Increased stress not always bad –
Sometimes used as a stress
compensation layer to achieve a
desired stress for a film stack**

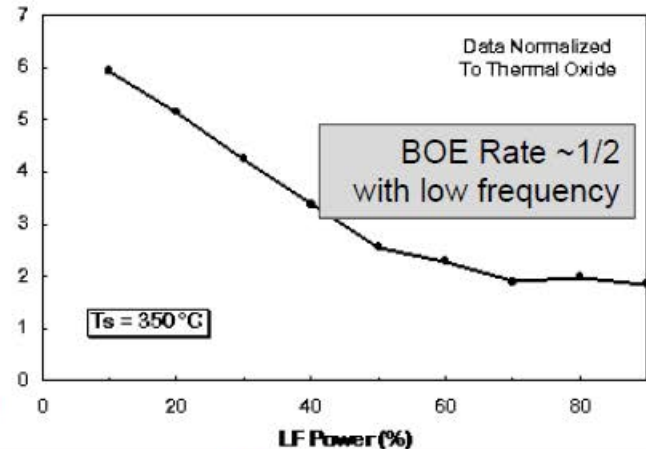
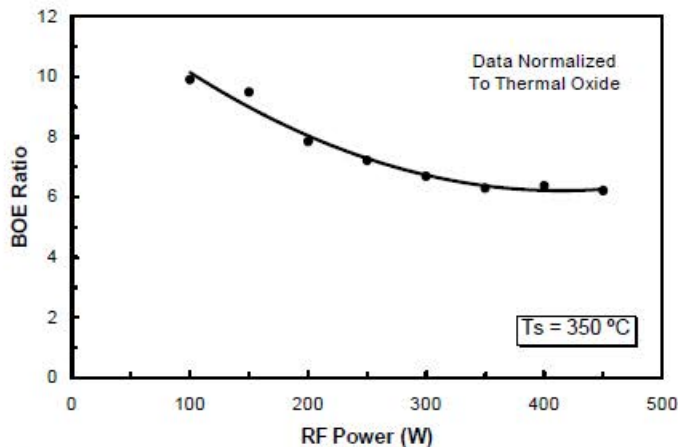


PECVD Process Parameters: Frequency Film Effects

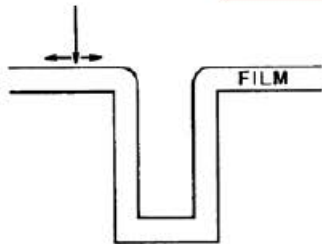
More LF power → increased ion bombardment and densification

- more compressive
- lower H concentration
- higher density
- lower refractive index
- lower wet etching rate
- **Potential damage to sensitive devices**

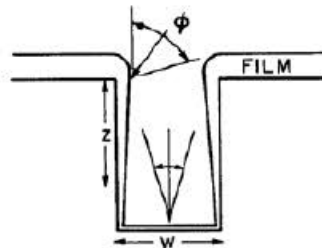
General statement since dependent on geometry, pressure, power, etc.



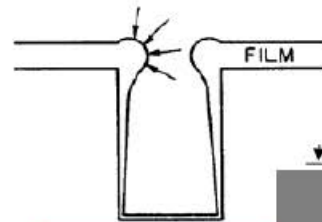
PECVD Step Coverage of Deposited Films



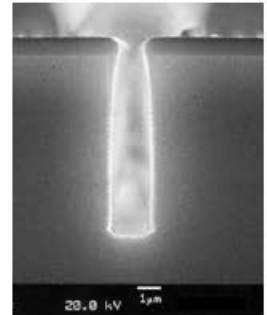
Uniform coverage resulting from rapid surface migration (e.g. high temp)



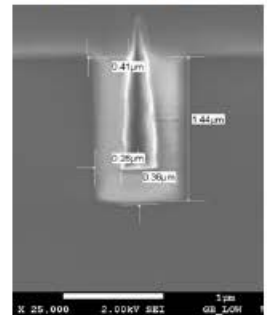
Nonconformal step coverage for long mean free path and no surface migration (e.g. PVD)



Nonconformal step coverage for short mean free path and no surface migration (e.g. PECVD)



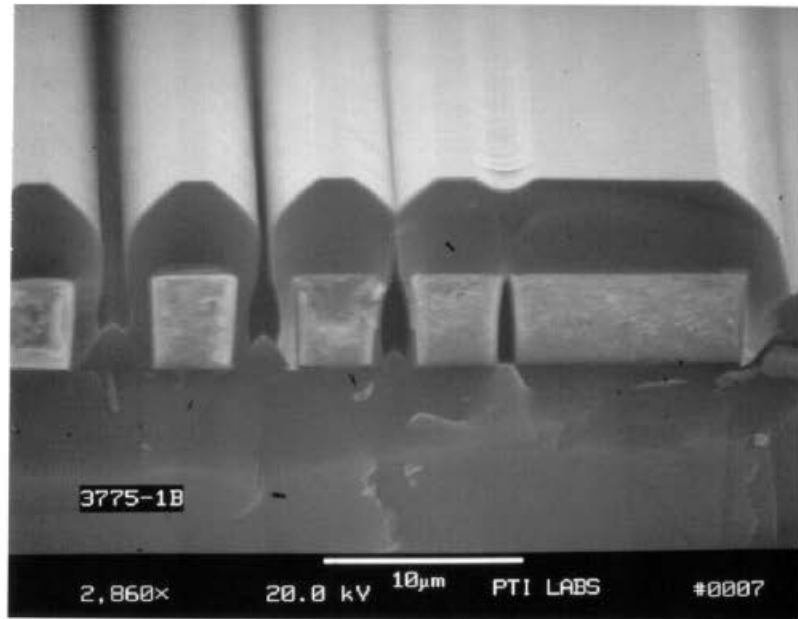
Example: SiO_2 (AR=4.2:1)



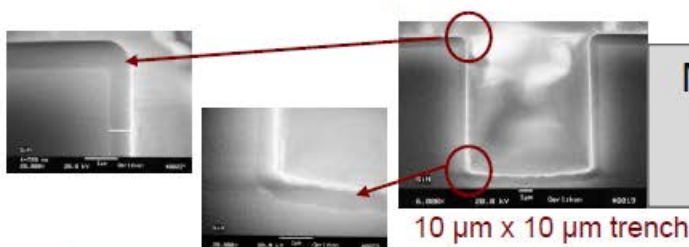
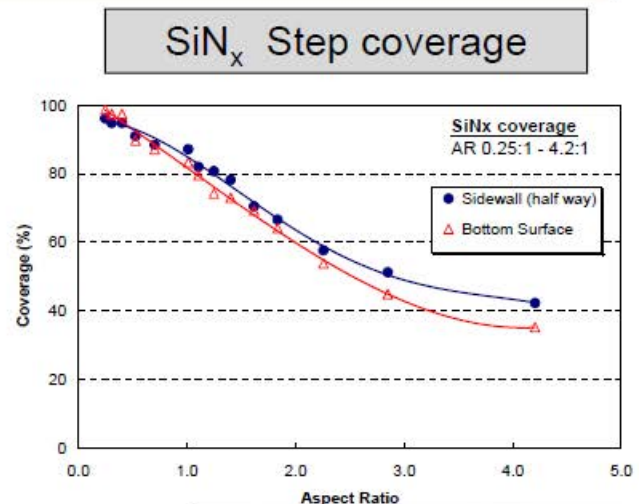
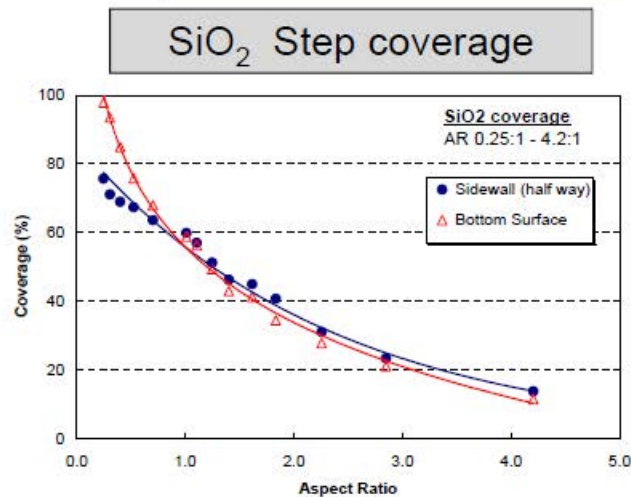
Example: SiN_x (AR=1.5:1)

Example of “keyhole” formation

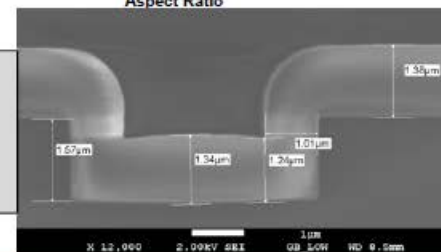
- As aspect ratio increases → keyhole more readily formed



Step Coverage (Aspect Ratio Dependence)

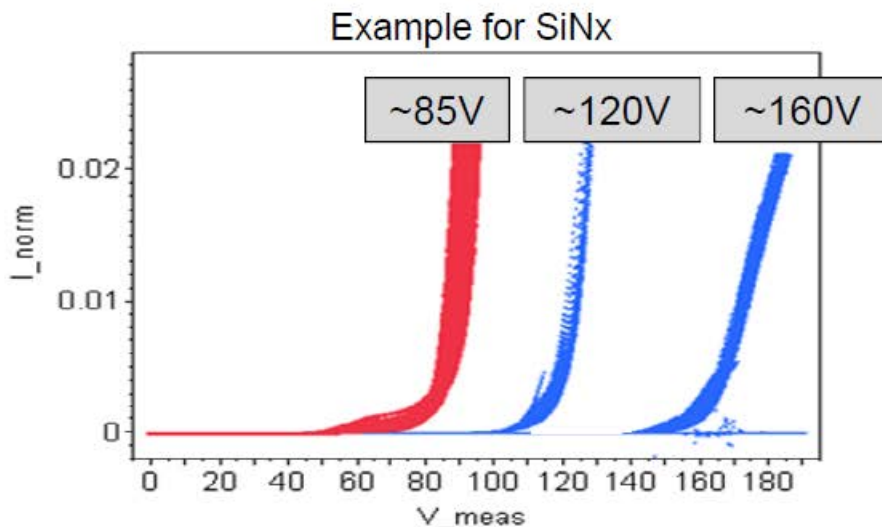


More surface
mobility for
SiN_x



Breakdown Voltage – Process Dependent and Metrology Dependent

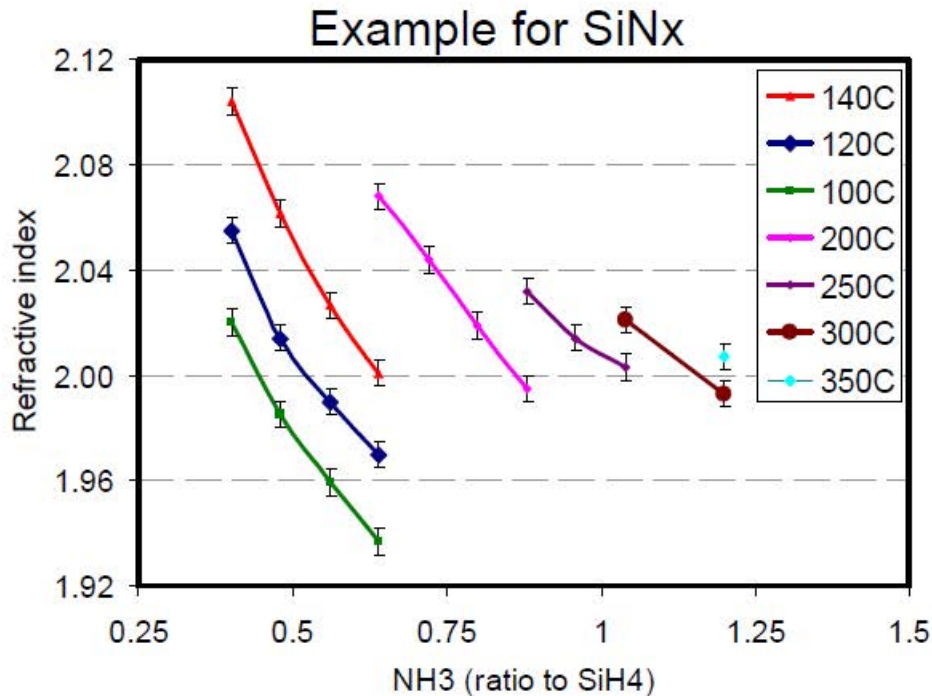
Strong Process
Dependence:
2 systems, 3 different
conditions



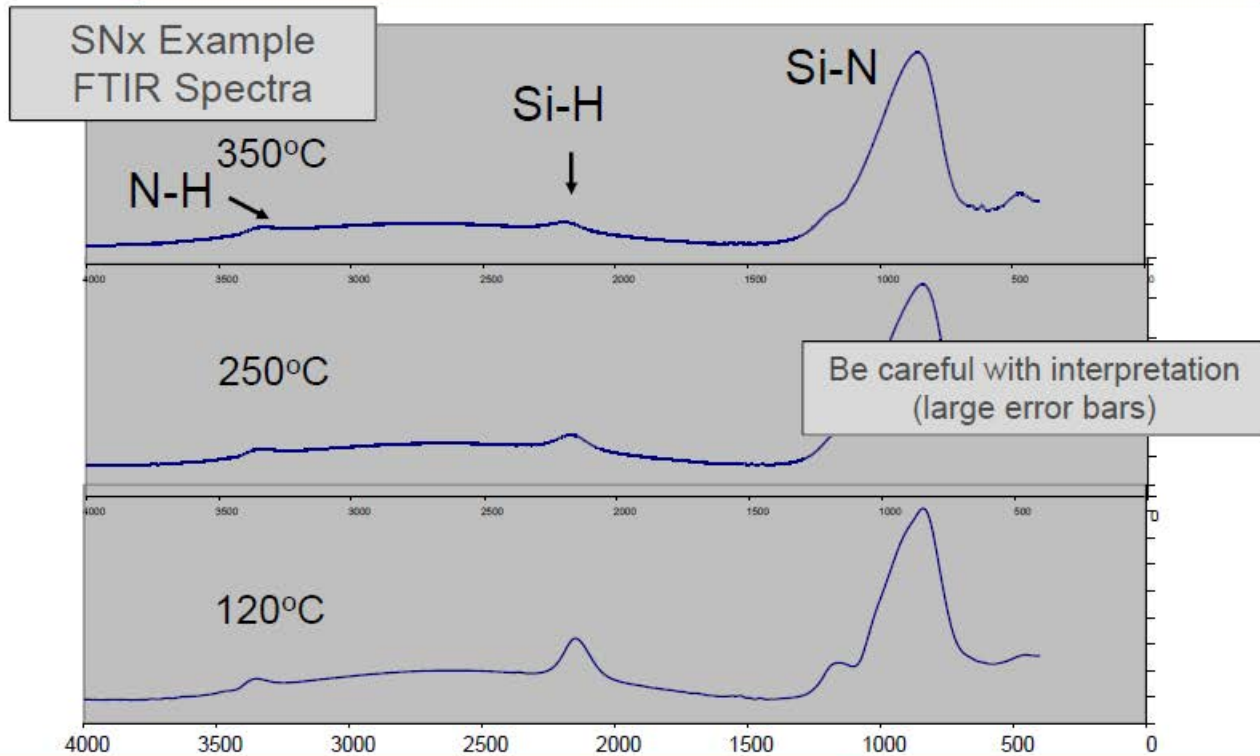
Note:

Breakdown must be defined: current, slope, device size (edge effects), etc.

Refractive Index Control Gas Ratios & Temperature



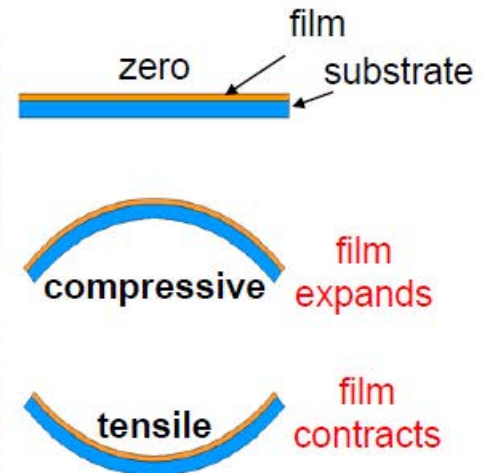
Hydrogen Content Strong Temperature Effect



Basic Thin Film Properties

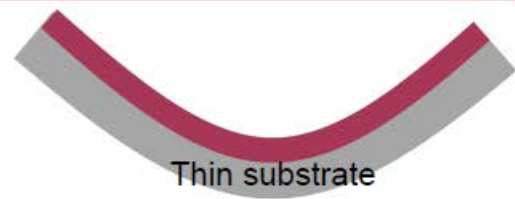
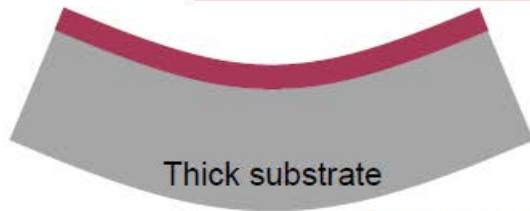
Stress

- Origin: Chemical, Ion Bombardment, Microstructure
 - Function of atoms per volume and forces affecting bond lengths
- Mechanical Integrity & Stability
 - Too compressive → film will buckle or blister
 - Too tensile → film will crack
 - Handling/clamping issues (bowing)
 - Photolithography (depth of focus)
 - Pattern distortion upon etching
 - Total stress proportional to total film thickness
- Electrical & Optical Performance
 - SiO₂ Optical waveguides, 10 - 20 μm
 - birefringence & mode distortion



Stress not always bad – compensation layers

What is Low Stress?



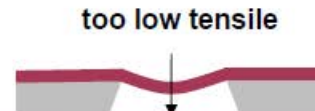
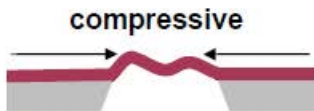
Bowing depends on substrate rigidity
and film thickness



Film thickness
and intrinsic stress



- Need determines acceptable stress. Example: MEMS membranes



General SiN_x Stress Guidelines

Nitride Thickness	Suspended Structure Stress Target
<0.05 μm	<350 MPa
0.05 to 0.1 μm	<300 MPa
0.1 to 0.5 μm	<250 MPa
0.5 to 1 μm	<200 MPa
1 to 1.5 μm	<150 MPa
1.5 to 2 μm	<100 MPa
2 to 3 μm	<50 MPa

Source: after Rogue Valley Microdevices, www.roguevalleymicro.com



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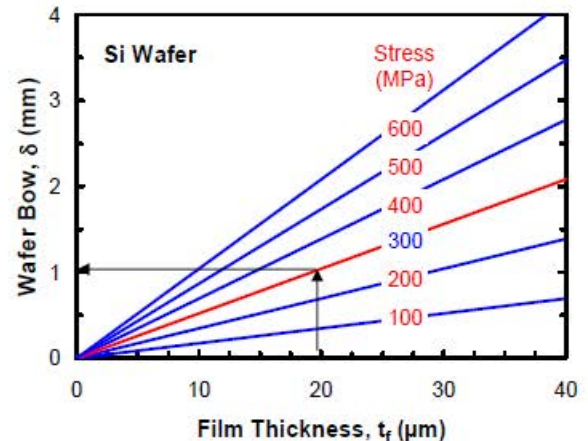
Alidouble Ex. 2015, p. 32

PECVD: Basic Film Properties

Stress

Bow ~2x typical wafer

- Total stress is function of film thickness
 - Thicker films need lower inherent stress
- Electrical & Optical Performance
 - Optical waveguides – SiO₂ Film thickness: 10 - 20 μm
 - Stress-induced bow
 - Birefringence & mode distortion
 - Packaging – Film thickness: 10 - 40 μm



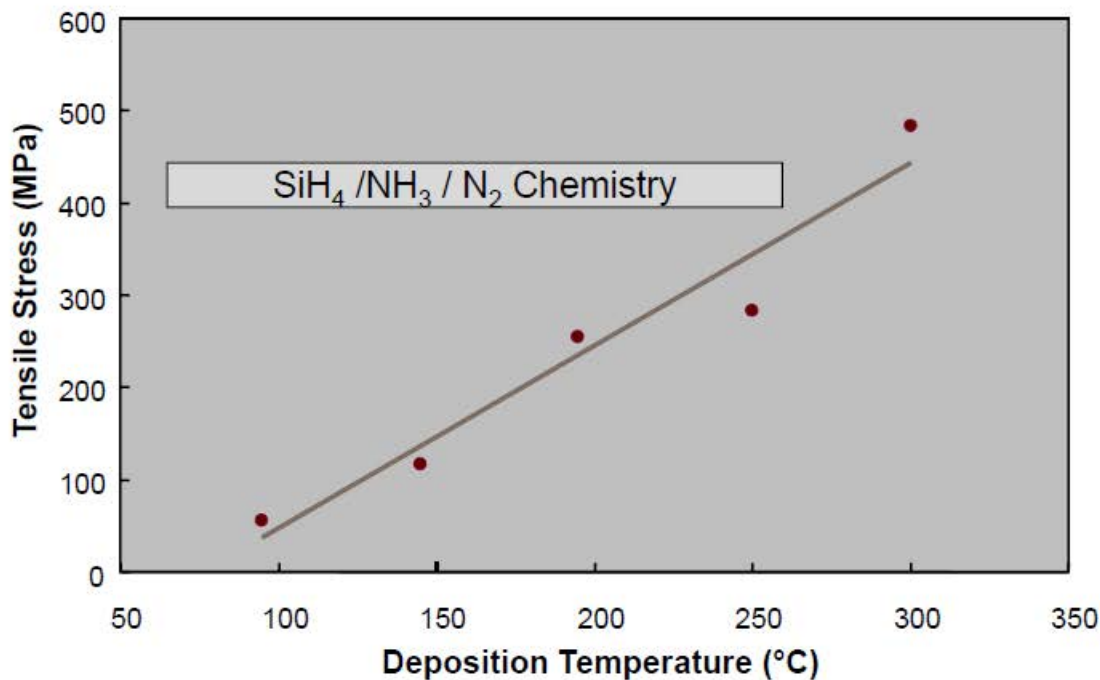
$$\text{Bow, } \Delta = \left[r^2 \left[\frac{3(1-\nu_s)}{Y_s} \right] \left(\frac{t_f}{t_s^2} \right) \right] \sigma_f$$

Stoney's equation

SiNx Stress Modification Techniques

Stress Control Parameter	Benefits	Limitations
Temperature	Provides ability to reduce stress @ low temperature	Film quality is reduced for most applications
Power/Pressure	Provides flexible stress control	Narrow process window
Chemical Composition (Refractive Index Shift)	Provides good stress control for applications not index sensitive	Not recommended for index sensitive applications or stoichiometric films
Mixed Frequency on Powered Electrode	Can provide some stress control for oxide films	Concerns for damage sensitive applications
Helium Dilution	Excellent control for critical thin films	Slower deposition rates. Requires He.

PECVD SiN_x Using Temperature to Adjust Stress



Plasma-Therm

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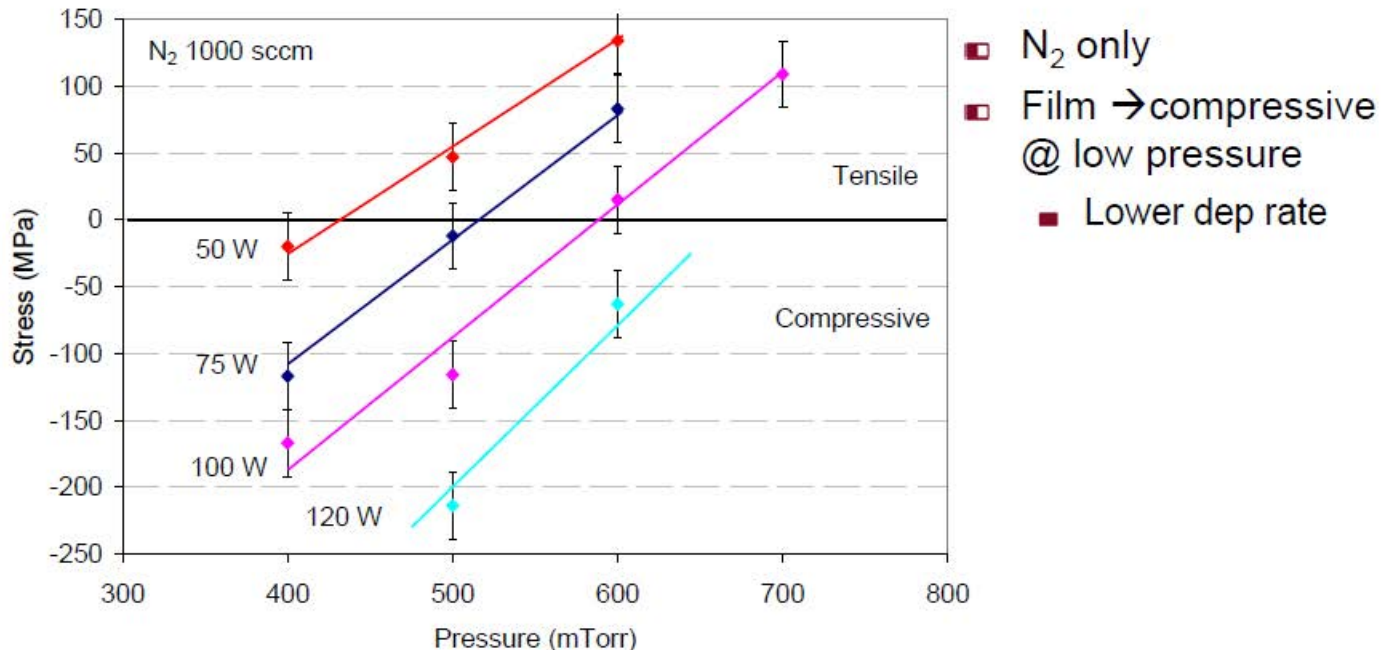
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PECVD SiN_x

Using Pressure and Power to Control Stress



PECVD Silicon Oxynitride ($\text{SiO}_x\text{N}_y\text{:H}$)

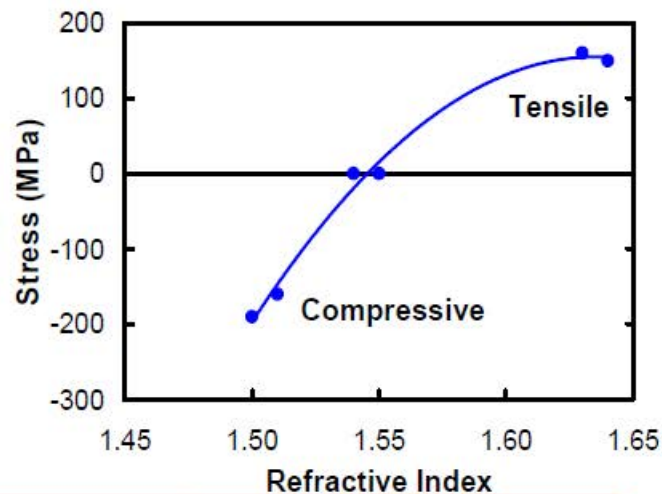
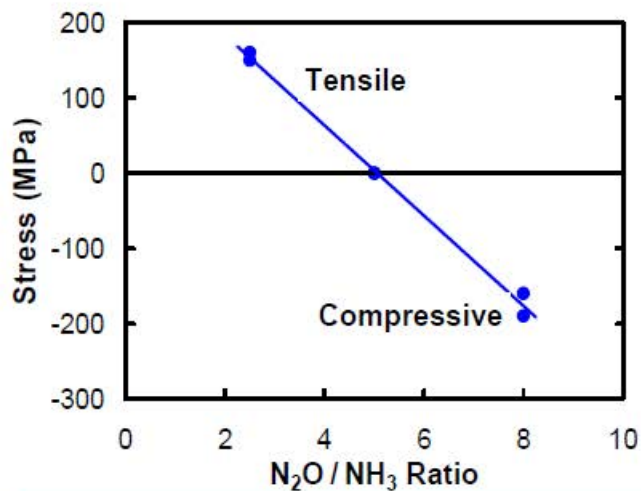
Useful Stress and Index Control

- Extremely useful film when index or stress control is essential
 - e.g. anti-reflection coatings (ARC)
- Plasma chemistry: $\text{SiH}_4 + \text{NH}_3 + \text{N}_2\text{O}$ with He or N_2 carrier gas
- Film is $\text{SiO}_x\text{N}_y\text{:H}$
- Film properties can be varied
 - High $\text{N}_2\text{O}/\text{NH}_3$ ratio – oxide like
 - Low $\text{N}_2\text{O}/\text{NH}_3$ ratio – nitride like
 - Refractive index $1.5 \rightarrow 1.9$
 - Stress compressive $\rightarrow$ tensile

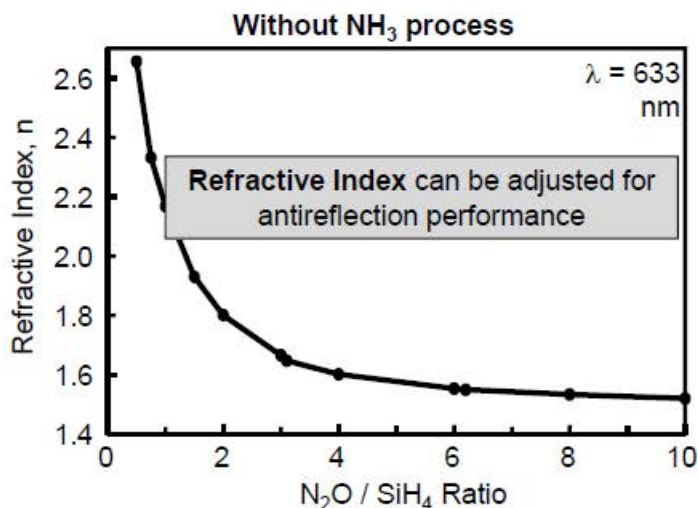
Stress Control

Adjustment of Film Stoichiometry – SiO_yN_x

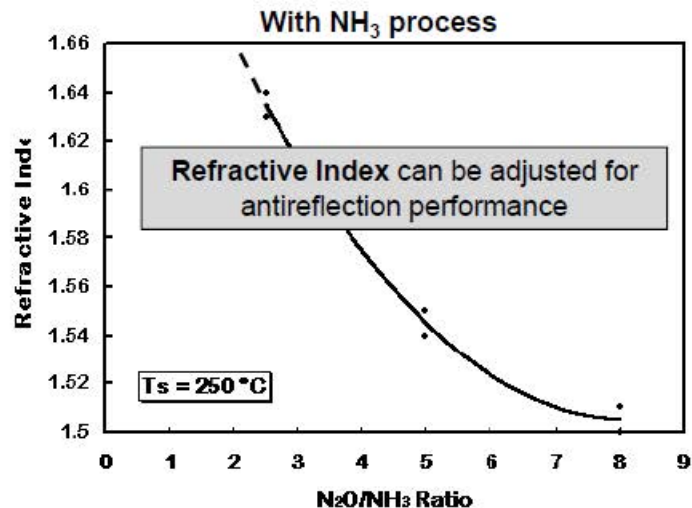
- Silicon oxynitride, SiO_yN_x formed from (SiH_4 , NH_3 , N_2O , N_2)
- Zero stress achieved by simple adjustment of $\text{N}_2\text{O}/\text{NH}_3$ ratio



PECVD $\text{SiO}_x\text{N}_y\text{:H}$ Refractive Index Control

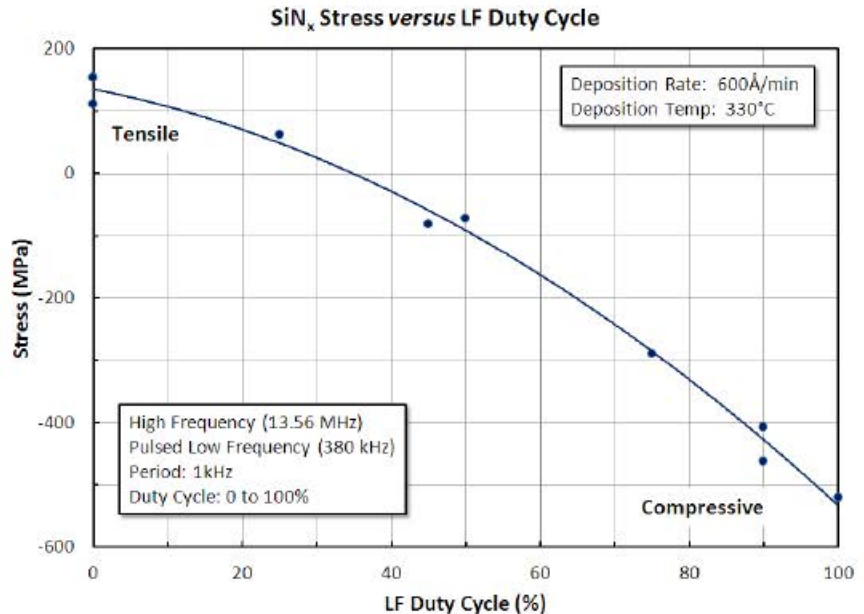


Nitrogen comes from N_2O (avoiding NH_3 for resist processing)
Note: Index increase is in Si rich regime

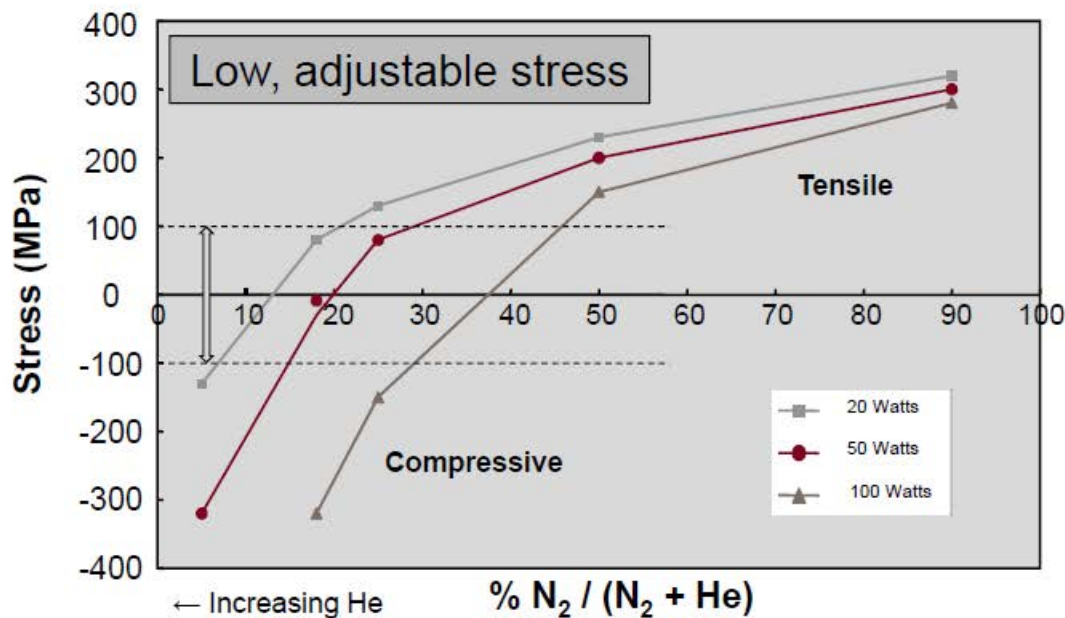


PECVD SiN_x Using Low Frequency to Adjust Stress

- Add LF (< 1 MHz) to RF power
- Stress control achievable
- High energy ion bombardment results in film compression
- Possibility of **plasma-induced damage**
- Additional hardware needed



PECVD SiN_x Stress Control with He Dilution



PECVD SiN_x Stress Control with He Dilution

- *Independent* comparison between low dual frequency and helium dilution process

W. S. Tan, P. A. Houston, G. Hill, R. J. Airey, and P. J. Parbrook
J. Electron. Mat. 33, 400 (2004).

- Conclusions:
 - Low frequency approach induces “irreversible damage” to III-V device layers
 - No detectable damage with helium dilution process
 - No additional hardware required

Damage Effects: Dual frequency vs. Helium Dilution (SiN_x example, GaN HEMT device)

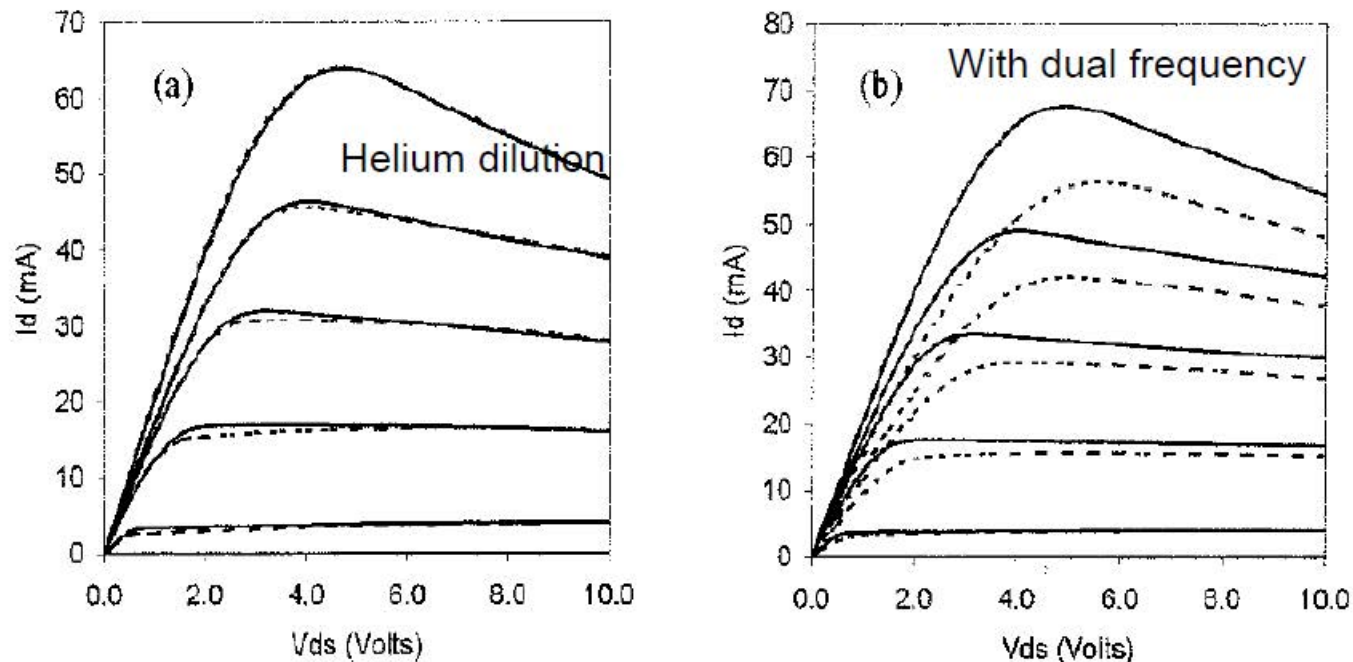
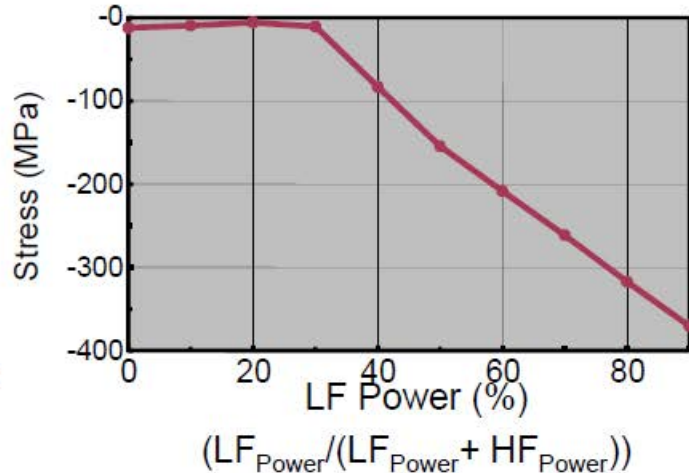
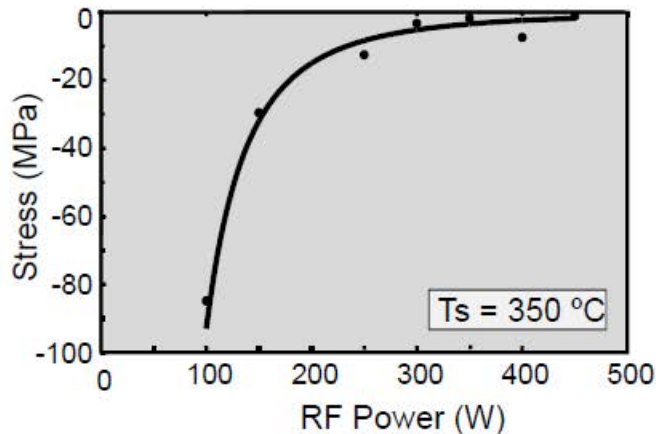


Fig. 6. Static I-V characteristics of the HFET devices before (solid) and after (dotted) (a) high-frequency only and (b) dual-frequency (30–30 recipe) plasma bombardment ($V_g = +1$ V, 0 V...–4 V).

PECVD SiO₂ (example): Stress vs. RF Power

- Compressive films
- Lower stress with at high deposition power (less dense → lower stress)



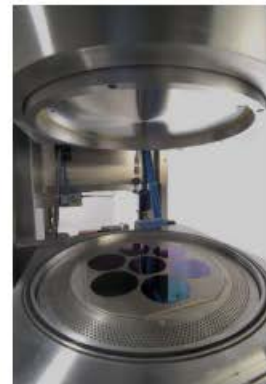
More LF power →
increased ion bombardment and densification →
more stress

PECVD – Process Parameter Effect Summary

	Pressure ↑	Gas Flow ↑	Power ↑	Electrode Spacing ↑	Temperature ↑	Frequency ↑	Residence Time ↑
Deposition Rate	↑	↑	↑	↑	↑↓—	—	↓
Uniformity	↓	↑↓	↓	↑↓	↑↓	—	—
Damage	—	—	↑	↑	—	↑	—
Step coverage	↑	—	—	—	↑	—	↓
Density	—	—	↓	—	↑	↑	—
Stress	↓	↑	↑↓	—	↑↓	↑	—
Refractive index	—	↑	↑	—	—	↓	—
Wet etch rate	—	—	↓	—	↓	↓	—

Outline

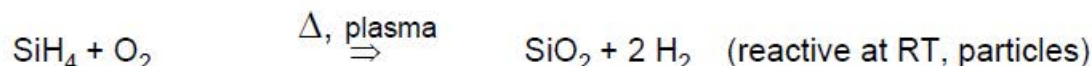
- Introduction to plasma enhanced deposition
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PECVD: Silicon Oxide Chemistry

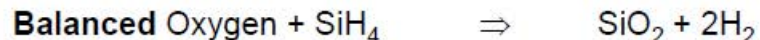
- Basic process: Silane + Oxygen source (O_2 , N_2O , NO , CO_2)

Low N-O bond energy (1.7 eV) makes N_2O preferred (vs. CO_2)



But O_2 spontaneously reacts with SiH_4 (best to keep separated!)

- Silane concentration affects dep rate ($\sim 500A/min$ to $5000A/min$)
- SiH_4/N_2O ratio affects refractive index and stress
- Three Regimes:**



Silicon Dioxide (SiO_2)

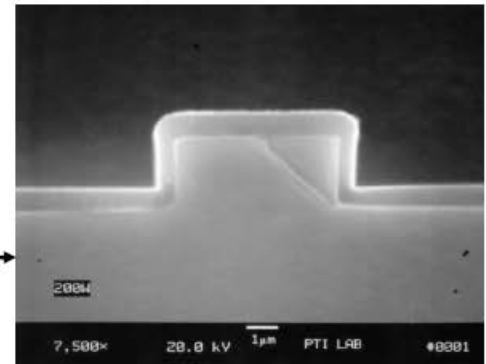
Typical Properties

<i>Parameter</i>	<i>Values</i>	<i>Comments</i>
Deposition Rate	~400-4000 Å/min	Function of SiH_4 concentration, temp, power
Hydrogen Content	2-9 %	Present mainly as Si-H
Resistivity	10^{13} - 10^{17} ohm-cm	Decreases with increasing Si/O ratio
Breakdown Field	$2 - 6 \times 10^6$ V/cm	Si rich has lower E_{break}
Refractive Index	1.45-1.50	Increases with increasing Si/O ratio
Film Stress	Compressive 0 – 300 MPa	Function of temp, gas composition, power, pressure
BOE Etch Rate	~2-6x Thermal oxide	Function of power, temp, comp, etc.
Temperature	200-400 °C	

PECVD: Silicon Nitride (SiN_x)

■ Advantages

- Good insulator/dielectric
- Good passivation film for III/V
- Wide range of deposition rates
 - Stable processes at low powers
- Controllable refractive index
 - SH_4/NH_3 ratio, temperature
- Excellent step coverage →
- Contains significant hydrogen
- Controllable stress
 - He dilution, low frequency, pressure, composition
 - Tensile to ~0 to Compressive



■ Concern over H and N incorporation

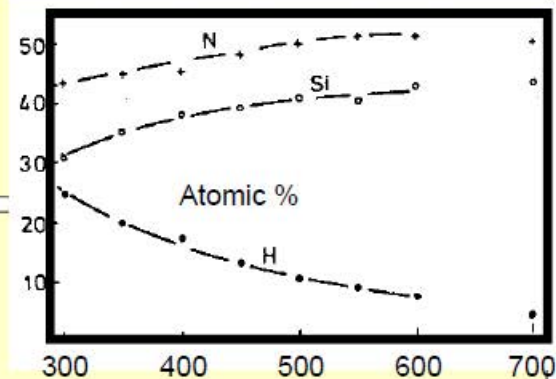
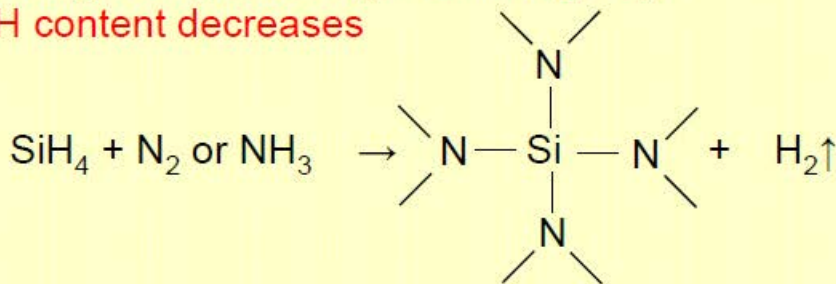
- Typically 15-30% hydrogen bonded to Si or N

PECVD SiN_x

SiH_4 + Nitrogen source (NH_3 , N_2)

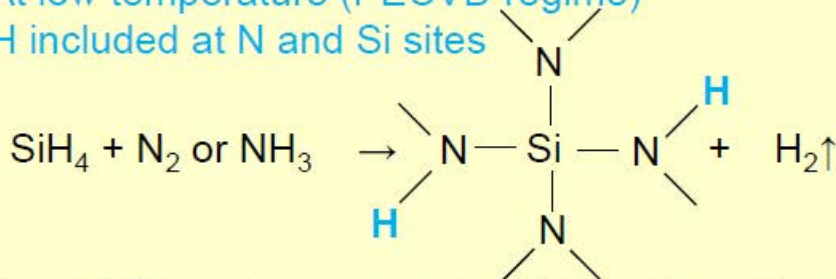
At high temperature (LPCVD regime)

H content decreases



At low temperature (PECVD regime)

H included at N and Si sites



Low N-H bond energy make NH_3 preferred for parallel plate PECVD

PECVD SiN_x: Typical Properties

Parameter	Values	Comments
Deposition Rate	100-500 Å/min	Function of Si-H concentration, temp, power
Hydrogen Content	15-30%	Present as Si-H and N-H
Resistivity	10 ⁵ -10 ¹⁹ ohm-cm	Decreases with increasing Si/N ratio
Breakdown Fields	1-6 x 10 ⁶ V/cm	Si rich has lower E _{break}
Refractive Index	1.90-2.10	Increases with increasing Si/N ratio
Film Stress	compressive to tensile	Function of temp, gas composition, power, pressure, frequency
BOE Etch Rate	<0.7 Å/sec	Decreases with increasing Si/N ratio. H content increases BOE.
Temperature	250-350°C	Lower wet etch rate with increased temperature
Optical Gap	3-4 eV	5 eV for stoichiometric Si ₃ N ₄



Plasma-Therm

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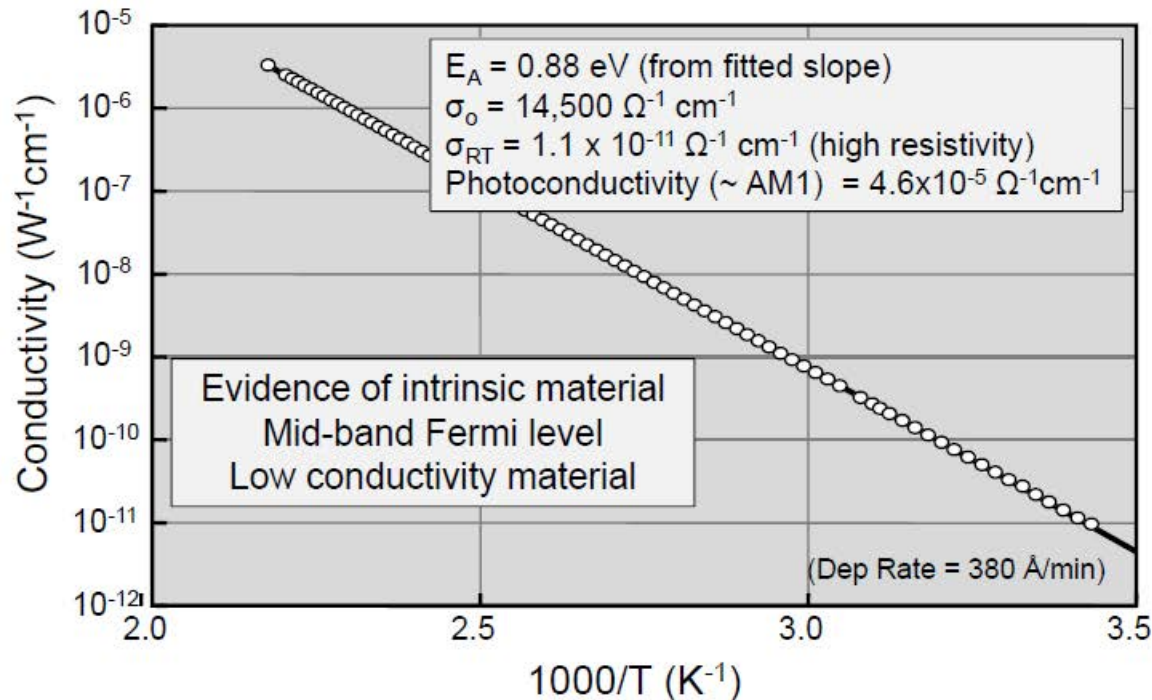
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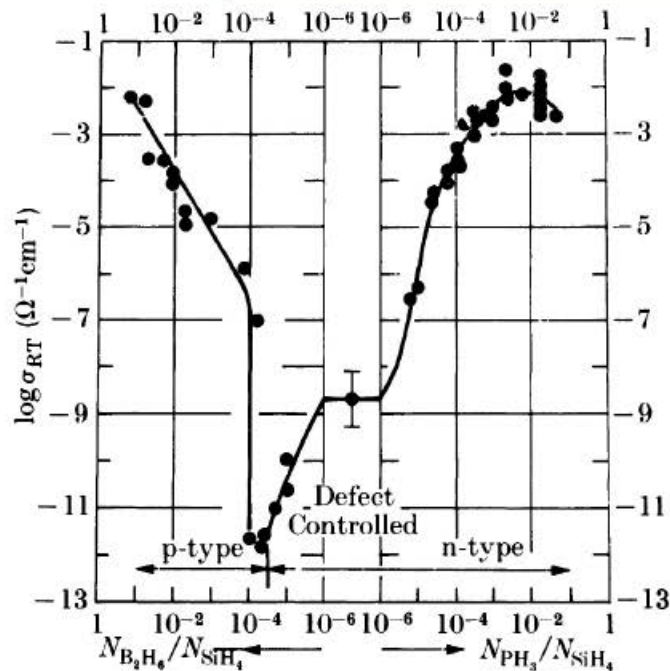
PECVD: Amorphous Si (a-Si:H)

- Plasma chemistry: SiH_4 with carrier gas e.g. He, H_2
 - 100% SiH_4 is best
- Film Formation:
$$\begin{array}{lcl} \text{SiH}_4 & \xrightarrow{\text{e}^-} & \text{SiH}_4^* \rightarrow \text{SiH}_3 + \text{H} \\ & \rightarrow & \text{SiH}_3 + \text{H}_2 \\ & \rightarrow & \text{SiH}_2 + 2\text{H} \end{array}$$
- Semiconductor
 - Highly photoconductive
 - Doped n-type or p-type (addition of PH_3 or B_2H_6)
 - Incorporation of H is *critical* to achieve semiconductor properties
 - H helps reduces concentration of electronic defects (dangling bonds) and allow sensitive doping. (removes mid gap states and better minority carrier lifetimes)
- Typical deposition rates: 100 - 1000 Å/min

PECVD Undoped a-Si:H Example



PECVD: a-Si:H Gas Phase Doping



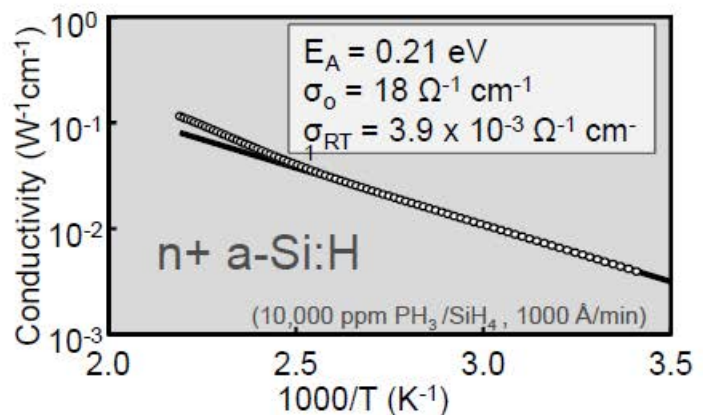
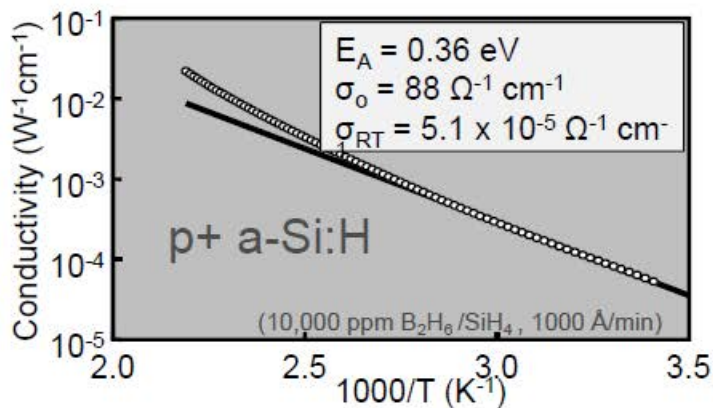
Example of Doping Curve (after Spear & LeComber)

- Toxic gases – requires loadlocks, sensors
- Gas-phase doping with PH_3 and B_2H_6 can change a-Si resistivity by $<10^{10}$
 - Undoped a-Si: $10^{10} \Omega\cdot\text{cm}$
 - n+ a-Si: $100 \Omega\cdot\text{cm}$
 - p+ a-Si: $1000 \Omega\cdot\text{cm}$
- Note: B_2H_6 thermally unstable and degrades in the gas cylinder and also contaminates the process chamber. $(\text{CH}_3)_3\text{B}$ is a better alternative. It has a similar doping efficiency to B_2H_6 .

PECVD a-Si:H

Gas Doping Examples

Evidence of material doping
 E_A indicates Fermi level (p or n) type
Highly conductive materials



Amorphous Si (a-Si:H)

Typical Properties

<i>Parameter</i>	<i>Values</i>	<i>Comments</i>
Deposition Rate	~100-1000 Å/min	Function of SiH ₄ concentration, power, dilution
Hydrogen Content	~ 10 %	Present as Si-H
Resistivity	~ 10 ¹⁰ ohm-cm	undoped
	~ 10 ² ohm-cm	n-type (1% PH ₃ /SiH ₄)
	~ 10 ³ ohm-cm	p-type (1% B ₂ H ₆ /SiH ₄)
Film Stress	Low Compressive	
Refractive Index	~ 3.6	
Optical Gap	~ 1.8 eV	1.1 eV, crystalline Si
Temperature	~ 250 °C	

Sources for a-Si:H information

- Hydrogenated Amorphous Silicon: R. A. Street, (1991) Cambridge University Press
- Electronic Transport in Hydrogenated Amorphous Semiconductors (1989) Springer
- Thin-Film Silicon Solar Cells: Arvind Shah (ed.) (2010) EPFL Press



Plasma-Therm

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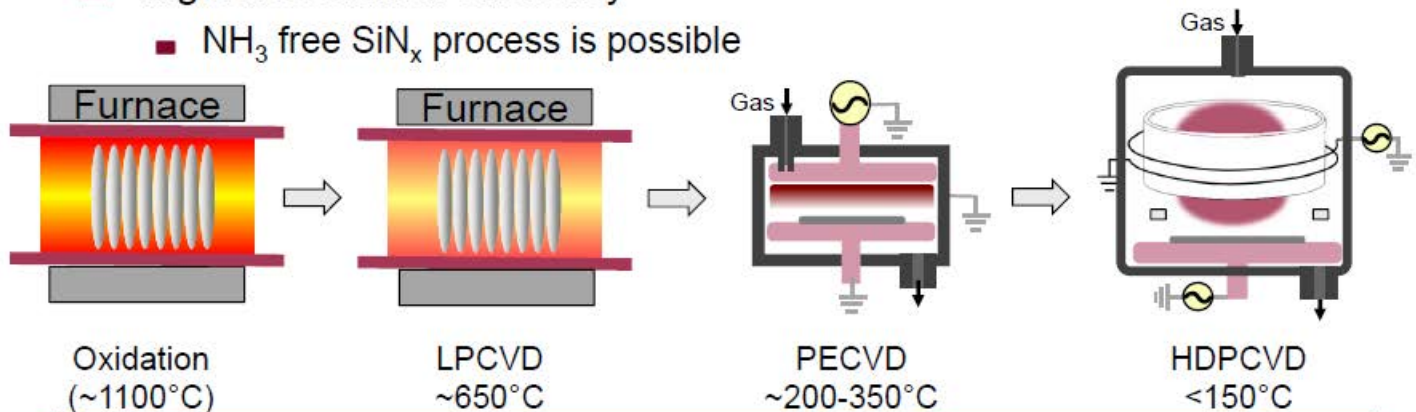
Outline

- Introduction to plasma enhanced deposition
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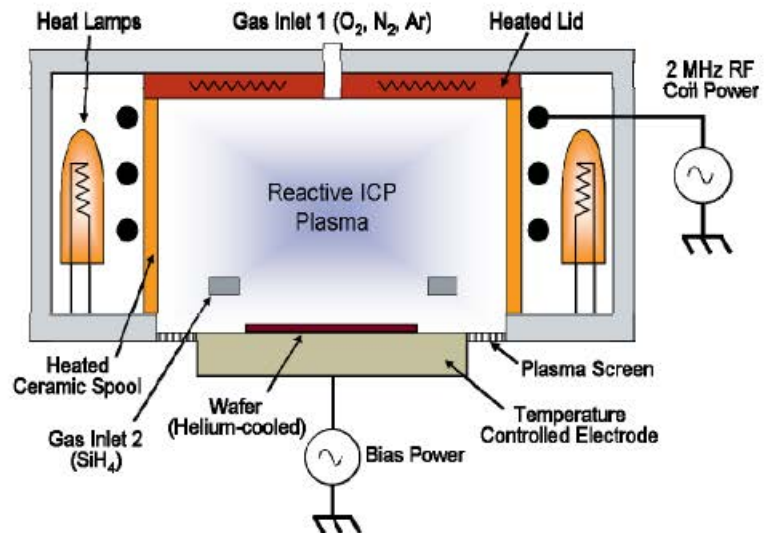
Why HDPCVD?

- Trend to lower temperature processing e.g. $<150^{\circ}\text{C}$
 - Better quality dielectric films than PECVD at lower temperatures
- Independent control of the ion flux and ion energy
 - Minimize ion damage
 - Efficient gap fill capability
- High dissociation efficiency
 - NH_3 free SiN_x process is possible

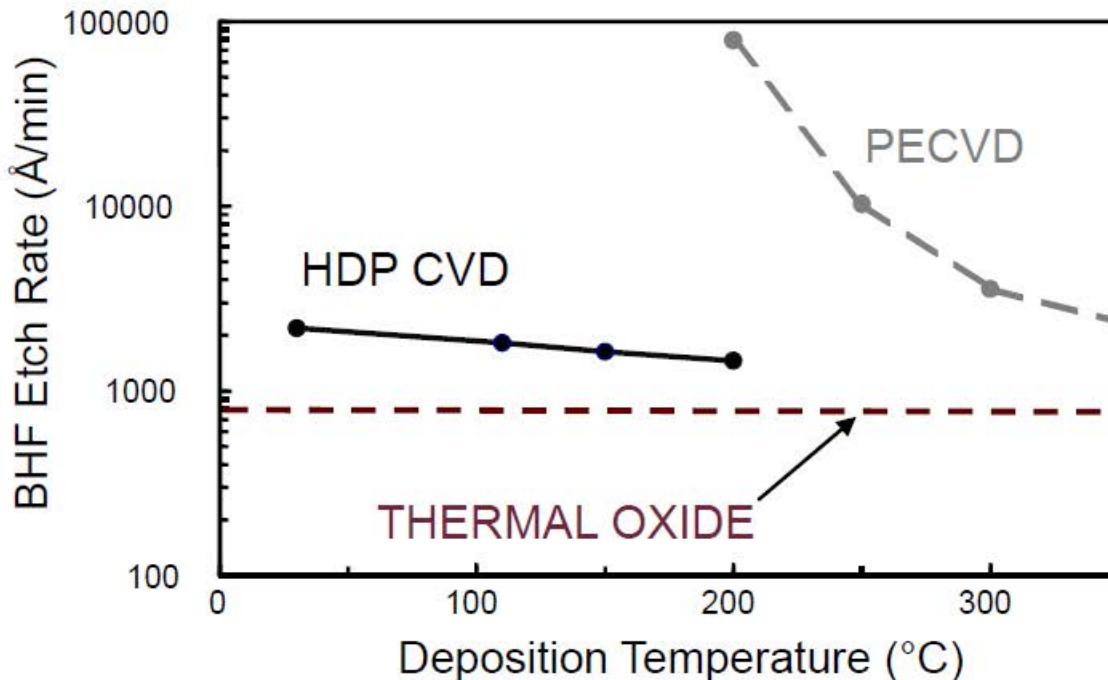


HDPCVD Reactor Inductively Coupled Plasma Source

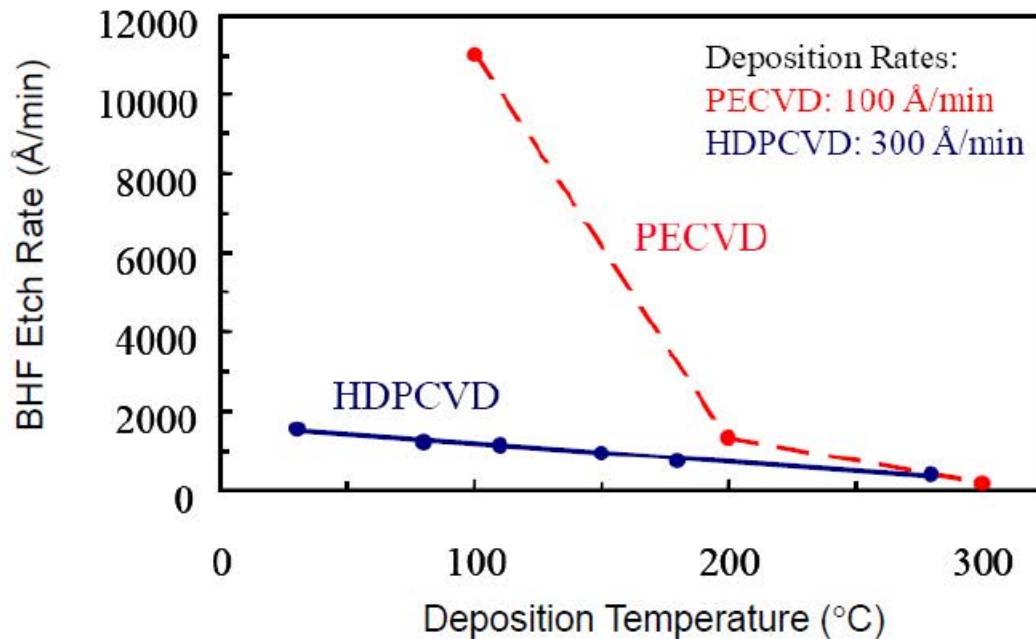
- ICP Source High ion density
- 13.56 MHz bias
 - Controllable ion energy
 - Deposition plus simultaneous ion bombardment
- Wafer clamped and He cooled
 - Allows low temperature deposition
- Secondary gas inlet (gas ring) for SiH_4 introduction
 - Allows use of SiH_4 and O_2 without hazard



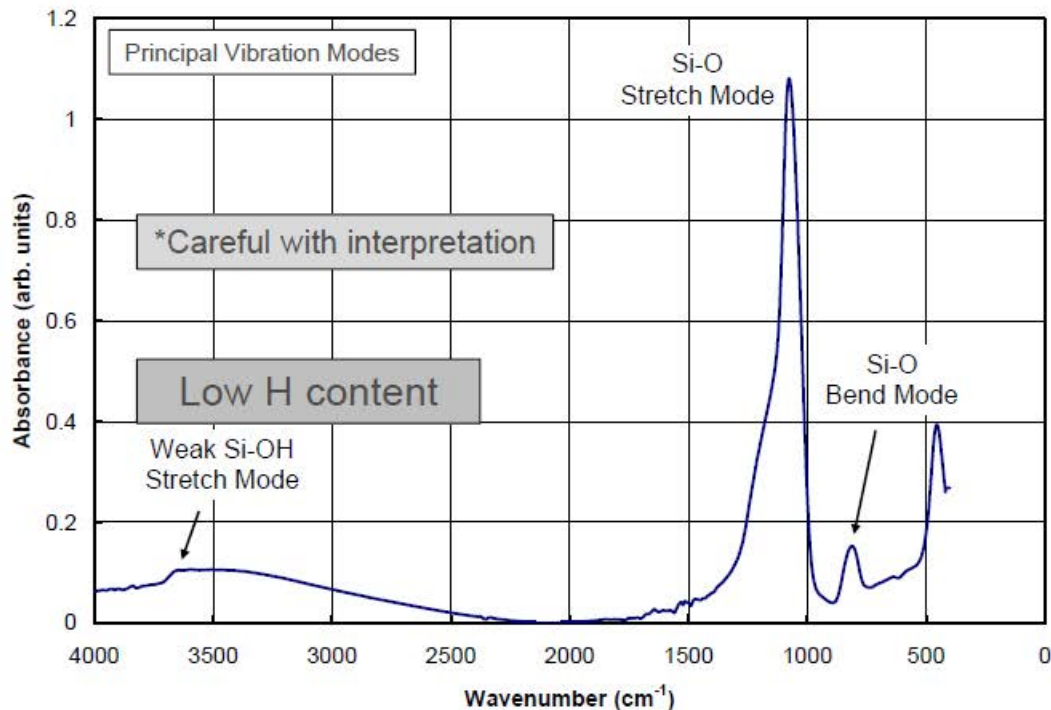
HDPCVD SiO₂ Comparison with PECVD and Thermal



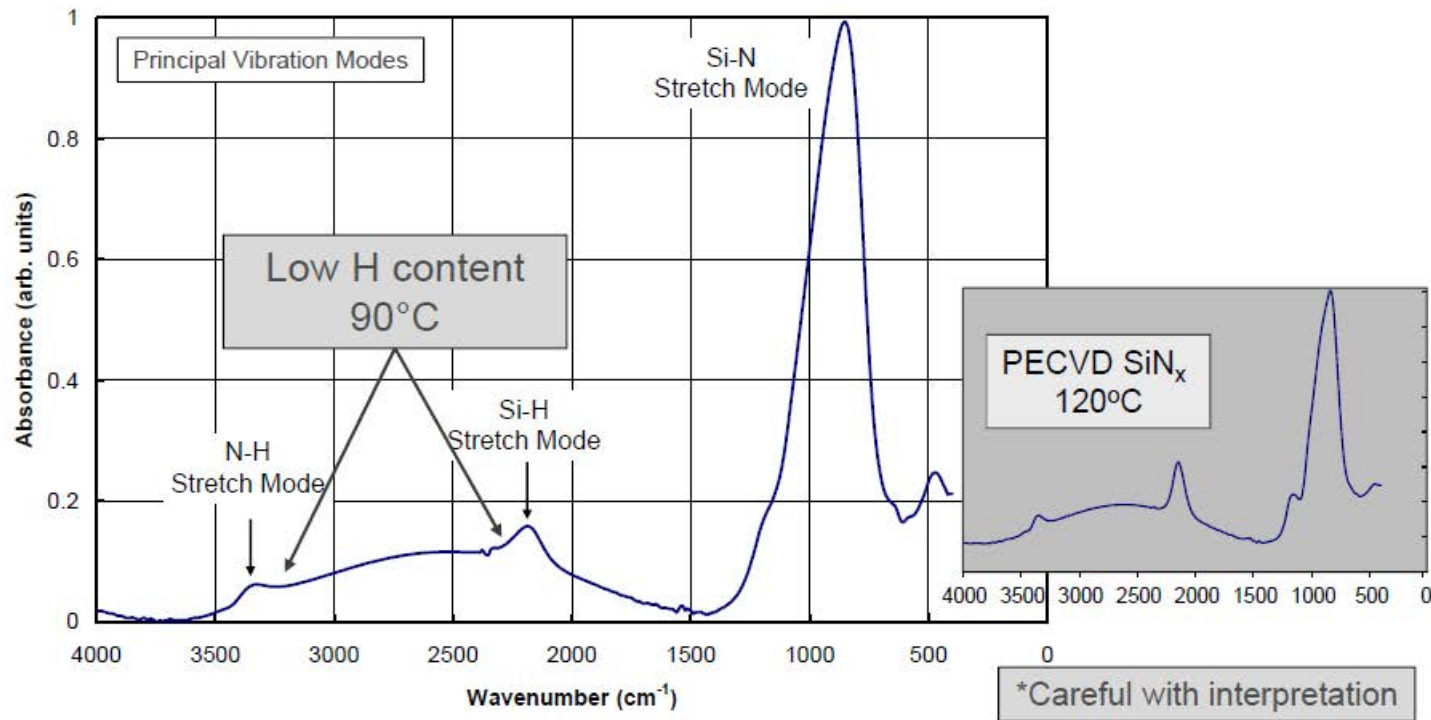
HDPCVD SiN_x: Wet Etch HDPCVD vs. PECVD



HDPCVD SiO₂ (90°C) FTIR Spectrum to Determine H Content

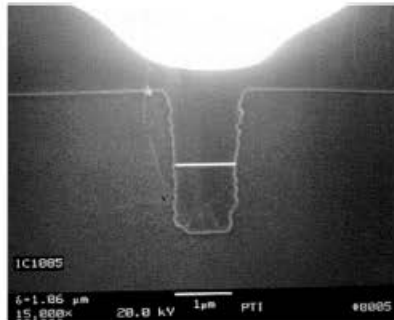


HDPCVD SiN_x FTIR Spectra to Determine H Content



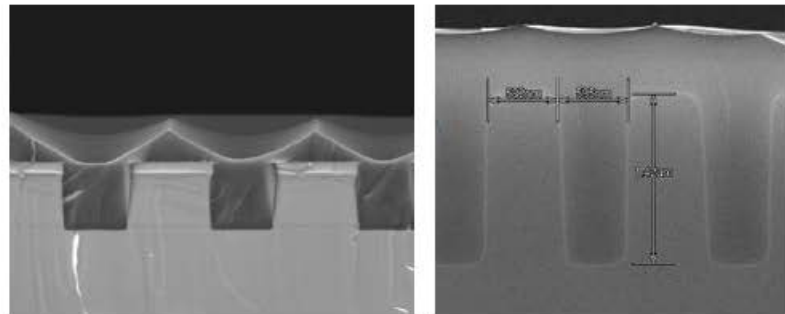
SiO₂ HDPCVD Improved Gap Filling

Isolated trench fill



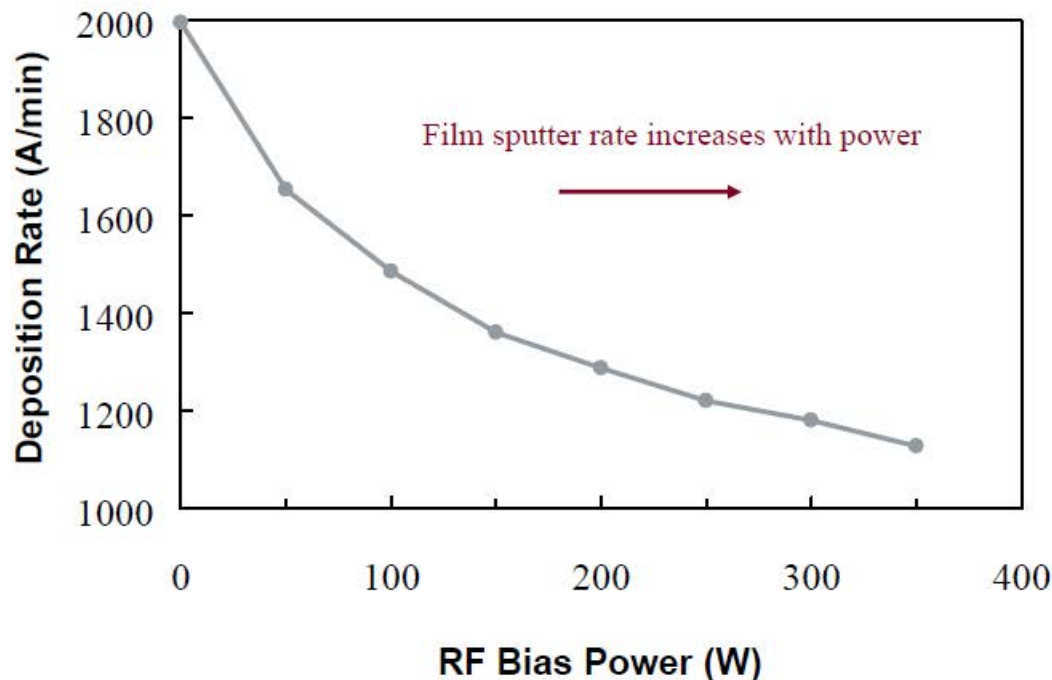
1 μm gap completely filled
AR ~ 2.5:1

Multiple trench fill



Gap completely filled
and surface nearly planarized

HDPCVD SiO₂ Deposition Rate Versus RF Bias Power



HDPCVD SiO₂: Example Process Capability and Typical Process Parameters

Deposition Temperature	<180°C
Plasma Chemistry	SiH ₄ , O ₂ , Ar (O ₂ :SiH ₄ ~1.2)
Chamber pressure	2 mT to 20 mT
ICP power	400 – 1000 W
Bias power	~5 – 200 W
Deposition Rate	1000 - 2000 Å/min
Refractive Index (controlled w/ SiH ₄ /O ₂)	1.46 – 1.50
Film Stress (controlled w/ RF bias)	~ -300 MPa (compressive)
BOE	~0.2x PECVD at 200°C

HDPCVD SiN_x: Example Process Capability and Typical Process Parameters

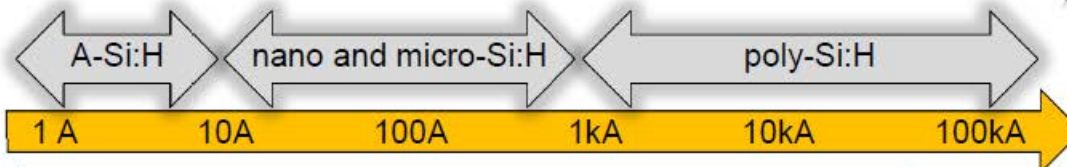
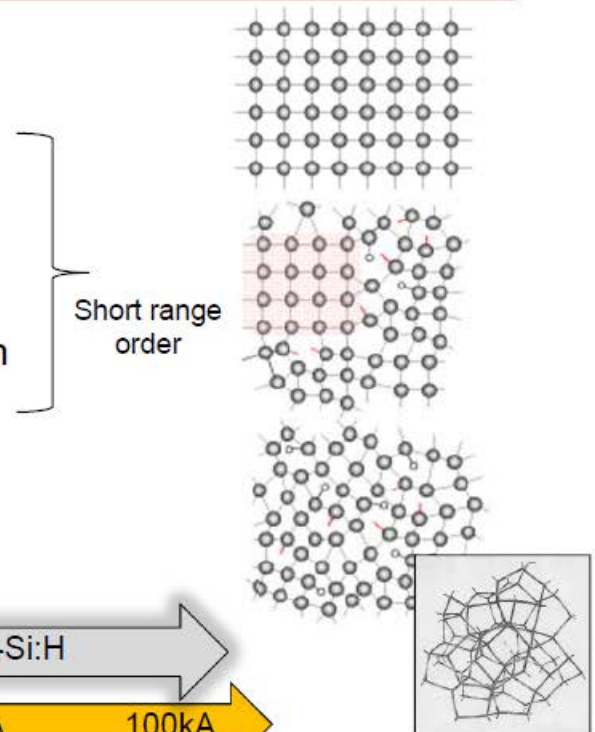
Deposition Temperature	<180°C
Plasma Chemistry	SiH ₄ , N ₂ , Ar
Chamber pressure	2 mT to 20 mT
ICP power	400 – 1500 W
Bias power	~5 – 200 W
Deposition Rate	500 - 1000 Å/min
Refractive Index (controlled w/ SiH ₄ /O ₂)	1.95 – 2.05
Film Stress (controlled w/ RF bias)	~ -300 MPa (compressive)

Tricky!

Film stress typically too compressive (film delaminates)

Definitions: Amorphous, Microcrystalline, Polycrystalline

- Crystalline: very long range order
- Poly-crystalline: composed of crystallites (often referred to as grains)
- Micro-crystalline: containing small crystals (typically microscopic)
- Nano-crystalline: containing crystals on the order of nanometers
- Amorphous: Non-crystalline, without long-range order



Extra Material



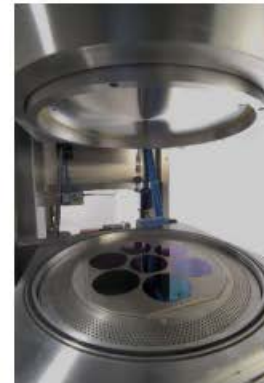
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Chamber Cleaning

- Films deposit on all plasma contacted surfaces
 - Powdery deposit on non-plasma contacted surfaces
 - Higher wall temperatures improves adhesion
- Deposition on chamber surfaces must be removed
 - Otherwise eventually flaking/particle formation
- Cleaning conditions in conflict with deposition conditions
 - Very different plasma conditions are optimum
 - SF_6 gas, low pressure, high RF power levels
- Endpoint technology (OES) can help minimize cleaning “downtime” and improve productivity

Chamber Cleaning Gas Choices

- F_2
 - Too dangerous and toxic
- SF_6 ~1000 to 2000 Å/min
 - Inexpensive
 - Relatively low toxicity
 - Good cleaning rate
- NF_3 ~2500-4000 Å/min
 - Relatively expensive
 - Toxic
 - Fast cleaning rate
- CF_4 ~500-1000 Å/min
 - Inexpensive
 - Okay cleaning rate

- Dependent on
 - Geometry
 - Pressure
 - Power
 - Temperature
 - Frequency

PECVD – General Guidance

■ Thermal equilibrium –

- Allow a thermal “soak” at ~1 Torr (without silane) for 1-2 min prior to run
- Time depends on process temperature, single wafer or carrier, open load or loadlock

■ Adhesion

- Si – quick HF dip
- Metals – short (~15s) Ar plasma (with low frequency if available)

■ Wet cleans

- Avoid scrubbing showerhead (particles can clog)

Troubleshooting Particles

Problem Cause	Potential Solutions
• Poor Process (too high a deposition rate)	• Process Adjustment (lower power, reduce reagent concentrations)
• Infrequent Cleaning	• Clean More Frequently (determine cleaning rate)
• Oxygen Leak	• Vacuum Integrity (leak test)
• Low Wall Adhesion	• Chamber Design (hot walls, rough walls, eliminate corners, nitrogen curtains)

Troubleshooting Process Drift

- Changes in deposition rates and/or film quality

Problem Cause	Potential Solutions
• Change in pumping speed	• Monitor pumping efficiency • Maintain pumping port with clean cycles
• Change in reagent flow (new gas bottle?)	• Keep MFCs calibrated
• Change in electrode temperature	• Periodic checks

PECVD Parameter Effects: Gas Flow

- Total Gas Flow vs. Partial Gas Flow of Reactants
 - Total gas flow includes carrier or dilution gas
 - Partial gas flow is only “active” species

- Deposition Rate: typically increases with gas flow
- Uniformity: gas dynamics (flow directions) have effect
- Damage: little effect
- Step Coverage: little effect
- Index: increases slightly (as SiH_4 flow increases)
- Density: minimal effect
- Stress: slight decrease (as SiH_4 flow increases)

PECVD Parameter Effects: Power

- Deposition Rate: Higher power increases concentration of reactive species. Increases deposition rate until reagent limited.
- Uniformity: Tends to worsen slightly
- Damage: slight increase with increased self bias.
- Step Coverage: little effect
- Index: typically increases
- Density: may decrease at high power
- Stress: strong effect

PECVD Parameter Effects: Temperature

- Probably the most important parameter.
- Higher temperatures produce higher quality films
- Deposition Rate: weak influences with temperature

$\text{SiO}_2 \uparrow$

$\text{SiN}_x \downarrow$

- Uniformity: Better temperature uniformity $\Rightarrow$ better uniformity
- Damage: Minimal effect
- Step Coverage: Improves slight with elevated temperature
- Density: Increases with temperature
- Stress: Increases slightly but overall a weak effect

PECVD Process Parameters: Residence Time

- Reactive species in steady state can be increased with shorter residence times

- Short Residence Time
 - Less time for gas phase nucleation
 - More reagent available for film forming thus faster deposition

- Long Residence Time
 - More time for gas phase nucleation
 - Less reagent available for film forming

PECVD Parameter Effects: Pressure

- Total Pressure vs. Partial Pressure of Reactants
 - Total pressure includes carrier or dilution gas
 - Partial pressure is only “active” species

- Deposition Rate: Increases with pressure
- Uniformity: Lower partial pressure improves uniformity
- Damage: Minimal effect
- Step Coverage: Higher pressure slightly improves coverage
- Index: Minimal effect
- Density: Minimal effect
- Stress: Typically low effect