Basic PECVD Plasma Processes (SiH_4 based)

PECVD SiNx:

$SiH_x + NH_x \rightarrow SiN_x (+H_2)$

or $SiH_x + N \rightarrow SiN_x (+H_2)$

PECVD SiOx: $SiH_x + N_2O \rightarrow SiO_x (+H_2 + N_2)$

PECVD $SiON_x$: $SiH_x + N_2O + NH_3 \rightarrow SiON_x (+H_2 + N_2)$

PECVD a-Si:H $SiH_x \rightarrow Si (+H_2)$

PECVD SiC: $SiH_x + CH_x \rightarrow SiC_x (+H_2)$

Types of SiH_4 supply

SiH_4 can be supplied as either pure SiH_4 or dilute in an 'inert' carrier gas , typically N_2, Ar, He.

Typical percentage dilutions are 5%, or 2% or 10%.

When converting a recipe for a different SiH_4 dilutions, always remember that it is the SiH_4 flow that is important:

400sccm 5%SiH_4/N_2 = 20sccm SiH_4 + 380 sccm N_2

So you will need to flow 1000sccm 2%SiH_4/N_2 to achieve the same SiH_4 flow.

The effect of the additional N_2 flow will be minimal, and can sometimes be compensated for by reducing the separate N_2 MFC flow (if applicable).

Important note: Always remember to check rotary pump purge is suitable for maximum SiH_4 flow:

Purge flow (litres/min) > 3 x max SiH_4 flow (sccm) / 14

PECVD Trends (SiH_4 based processes)

SiNx (Nitride)

	Dep. rate	Refr. Index	Dep. Rate Uniformity	Refr. Index Uniformity	Film Stress	BHF Etch rate
↑ SiH_4 flow	↑	↑↑			↓↓ (more compr.)	
↑ NH_3:SiH_4 ratio	↓	↓↓		↑↑	↑	↑↑
↑ 13MHz power	↑↑	↓	↓↓	↓↓	↓↓	
↑ pressure	↑↑		↑↑	↑↑	↑↑ (more tensile)	↑↑
↑ temperature	↓	↓?			↑	↓↓↓

SiOx (Oxide)

	Dep. rate	Refr. Index	Dep. Rate Uniformity	Refr. Index Uniformity	Film Stress	BHF Etch Rate
↑ SiH_4 flow	↑↑	↑	↓↓		↑↑ (more tensile)	↑↑
↑ N_2O:SiH_4 ratio	↓?	↓	↓?	↓?		
↑ 13MHz power	↑	↓	↑↑		↓↓ (more compr.)	↓↓
↑ pressure	↓?		↑?	↑?		
↑ temperature	↑	↑				↓↓↓

**Uniformity is measured as centre-edge

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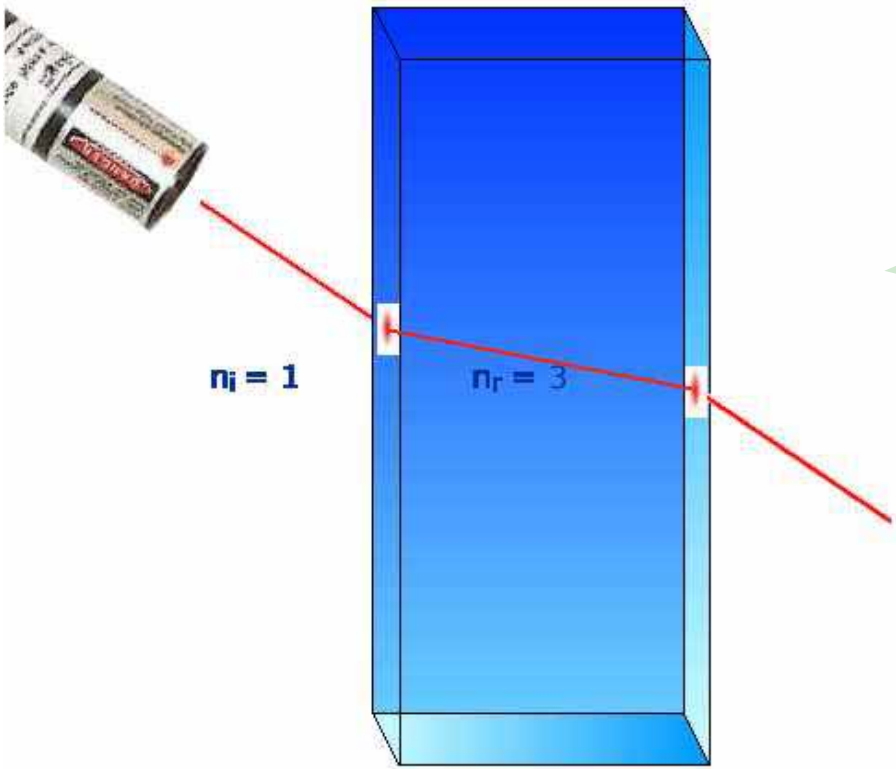
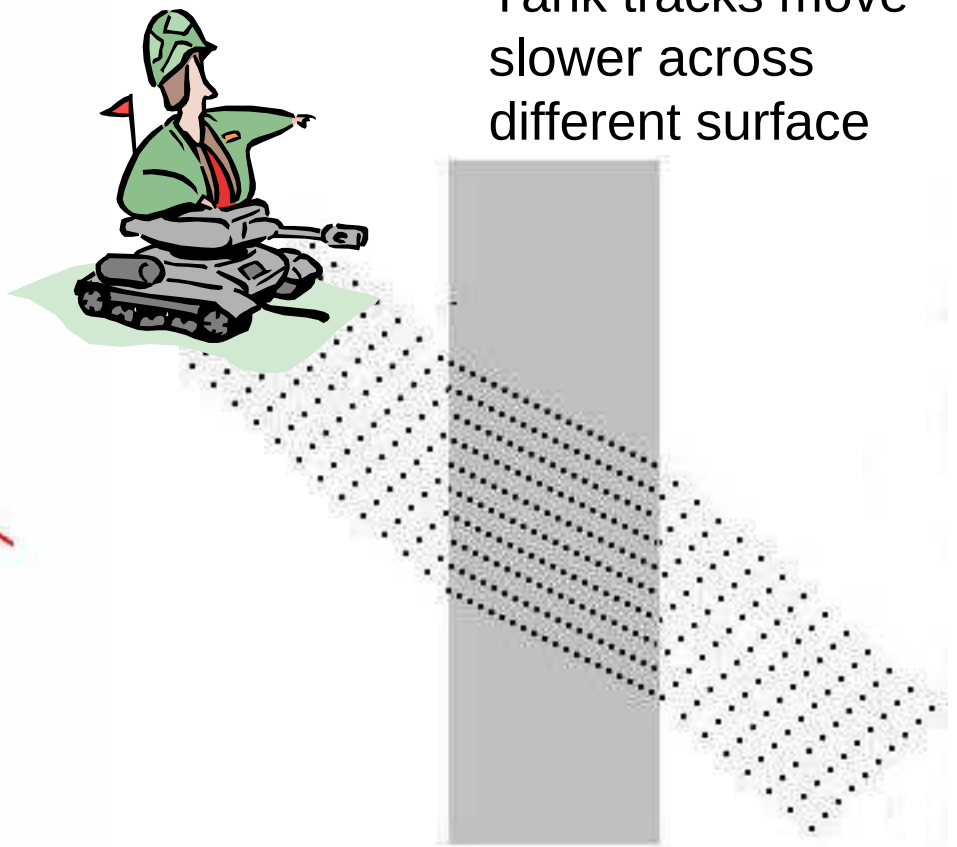
Refractive index – definition





Tank tracks move slower across different surface

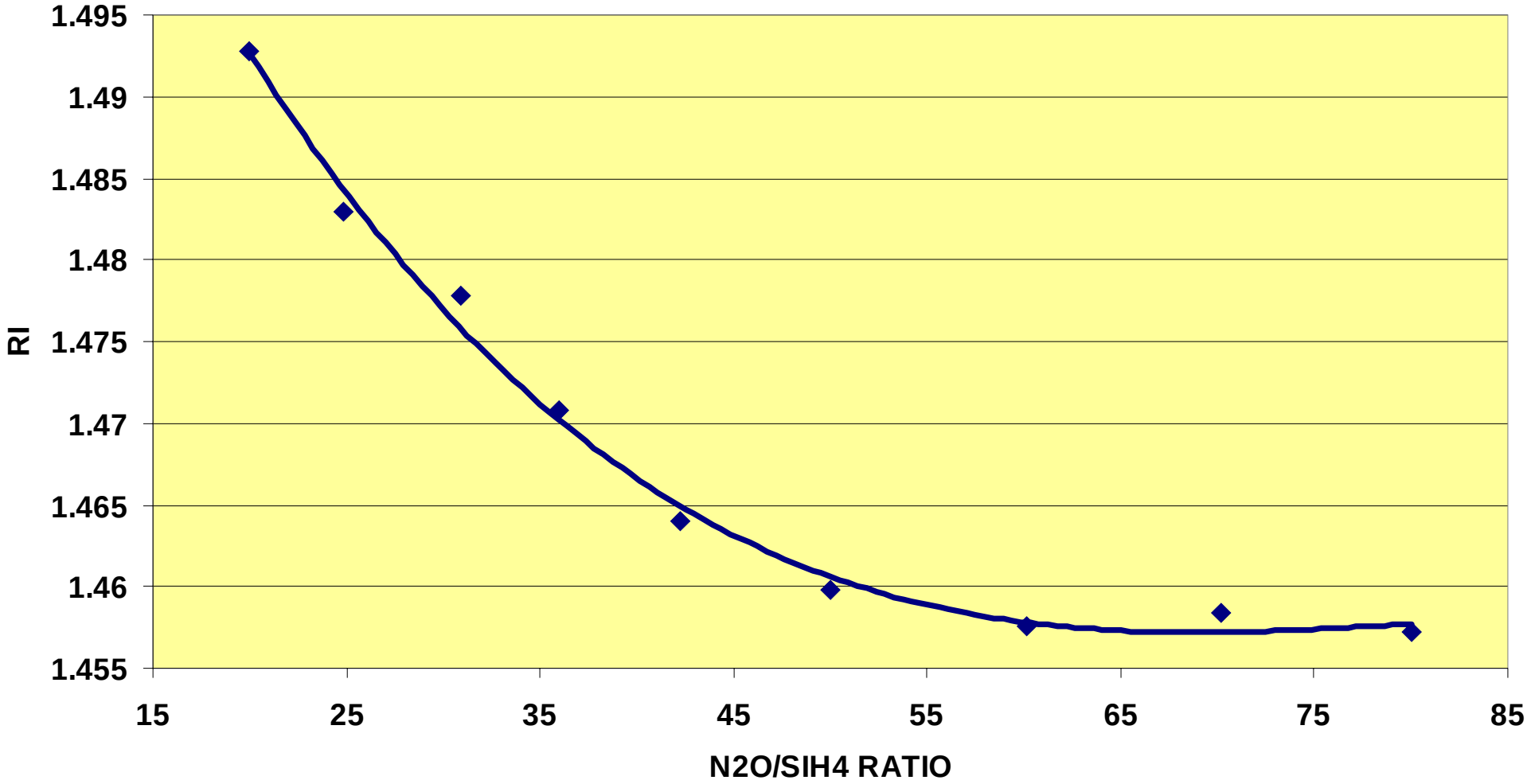
Refractive index – why is it important in PECVD?

Refractive index is a good indicator of film composition, i.e. Si:N ratio or Si:O ratio.

(If Si content is high, the refractive index will be high)

It can be easily measured by ellipsometer or prism coupler, allowing rapid evaluation of film composition (and unifomrity of composition).

REFRACTIVE INDEX OF SILICON DIOXIDE: GAS FLOW (N20/SIH4 RATIO)



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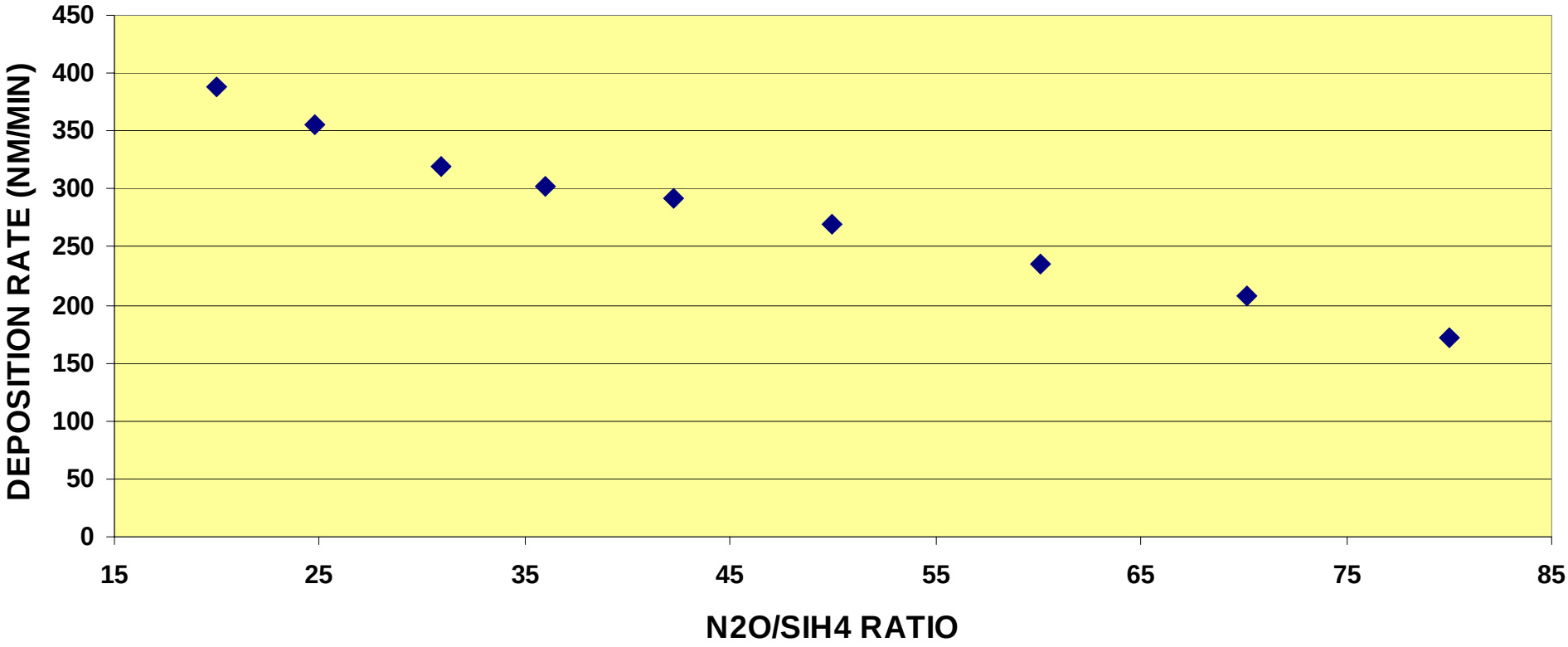
DEPOSITION RATE OF SILICON DIOXIDE: GAS FLOW (N2O/SIH4 RATIO) - (High rate process)



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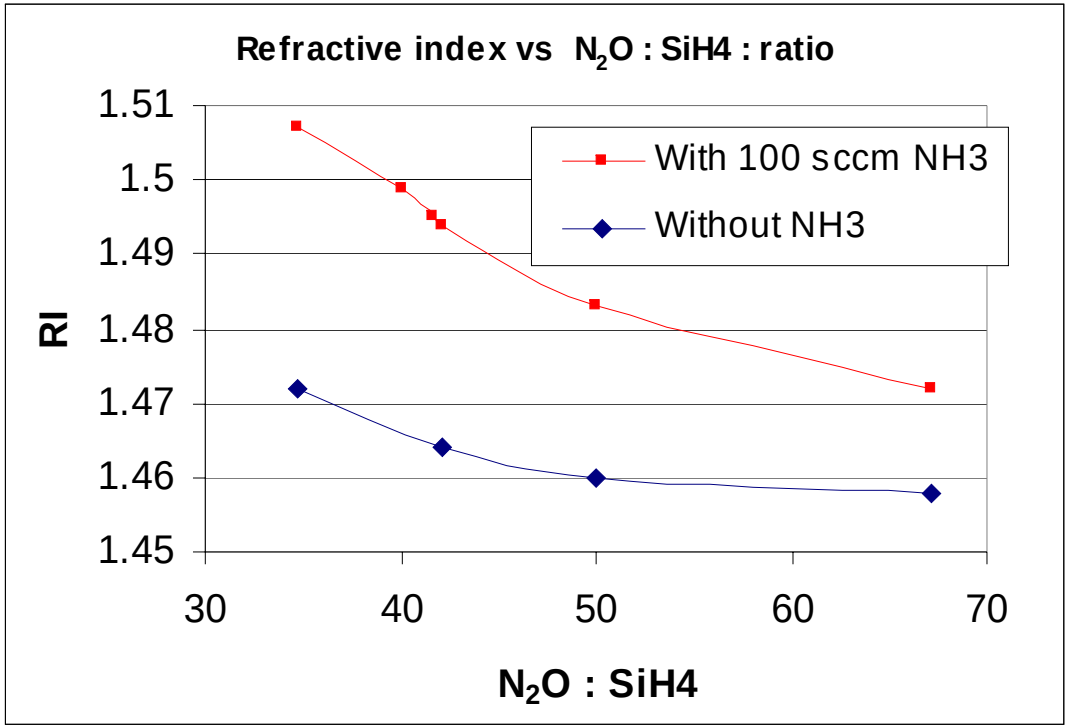
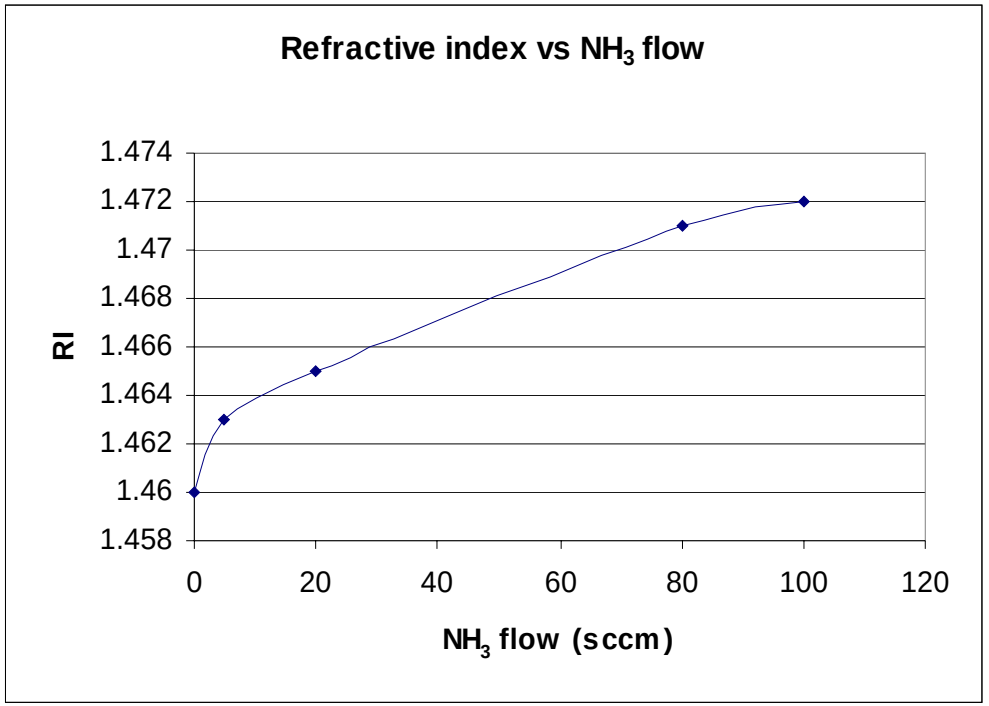
$SiON_x$ refractive index control





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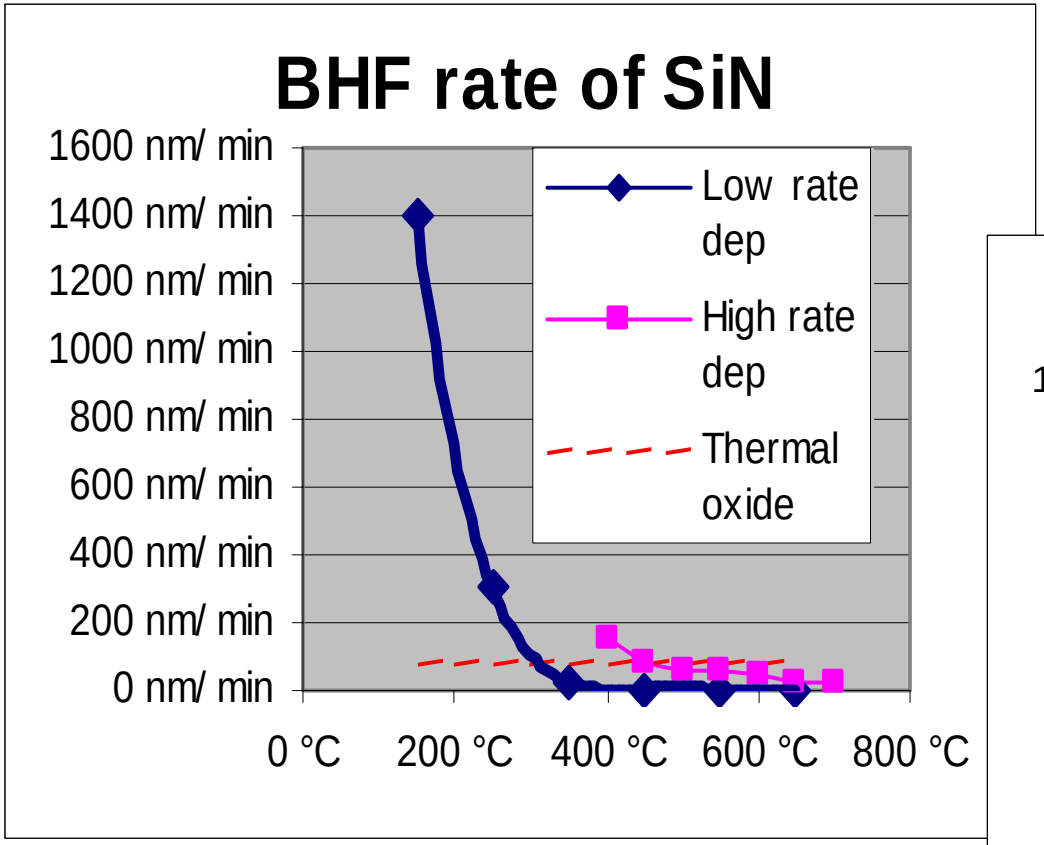
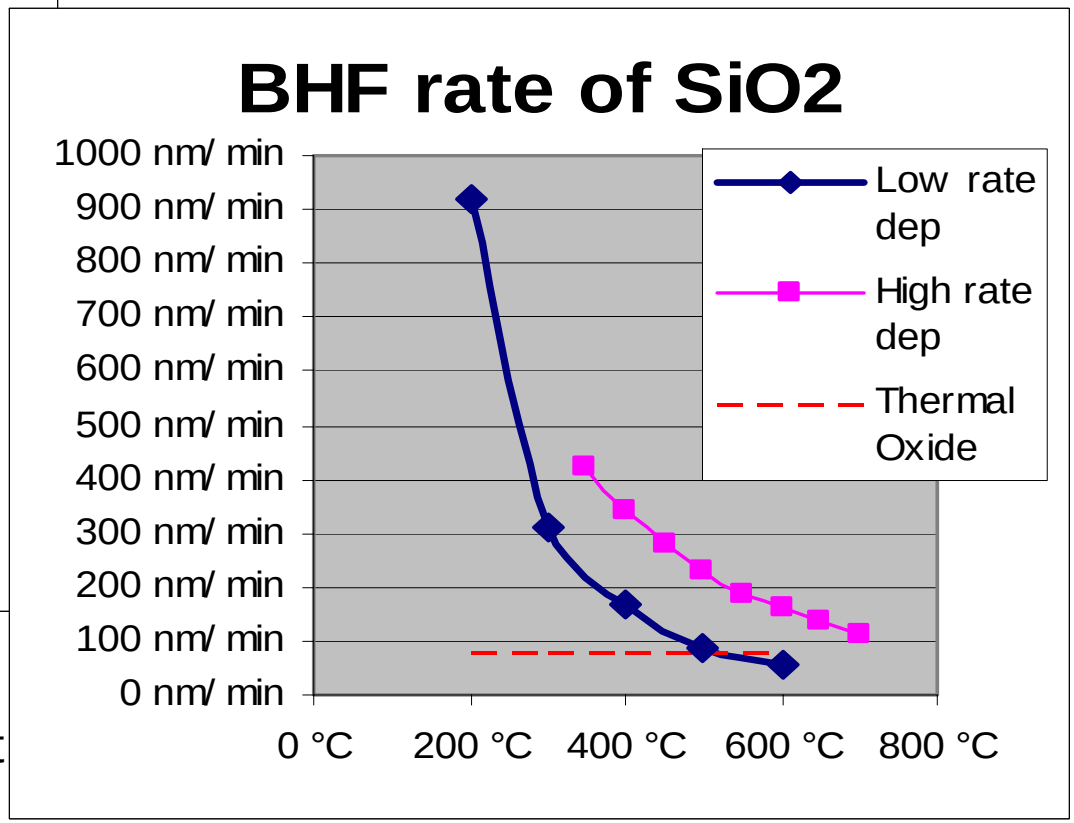
Film quality vs dep temperature





Warning: buffered hydrofluoric acid (BHF) is highly corrosive, please read safety datasheet and safe system of work before use.

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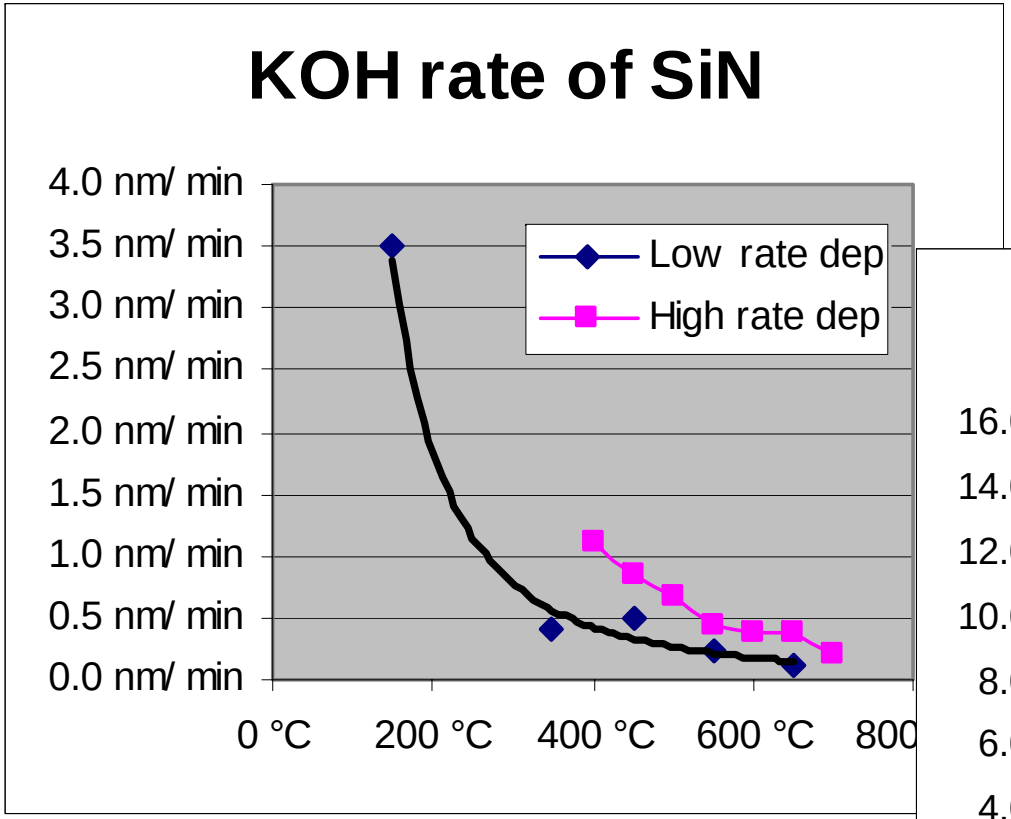
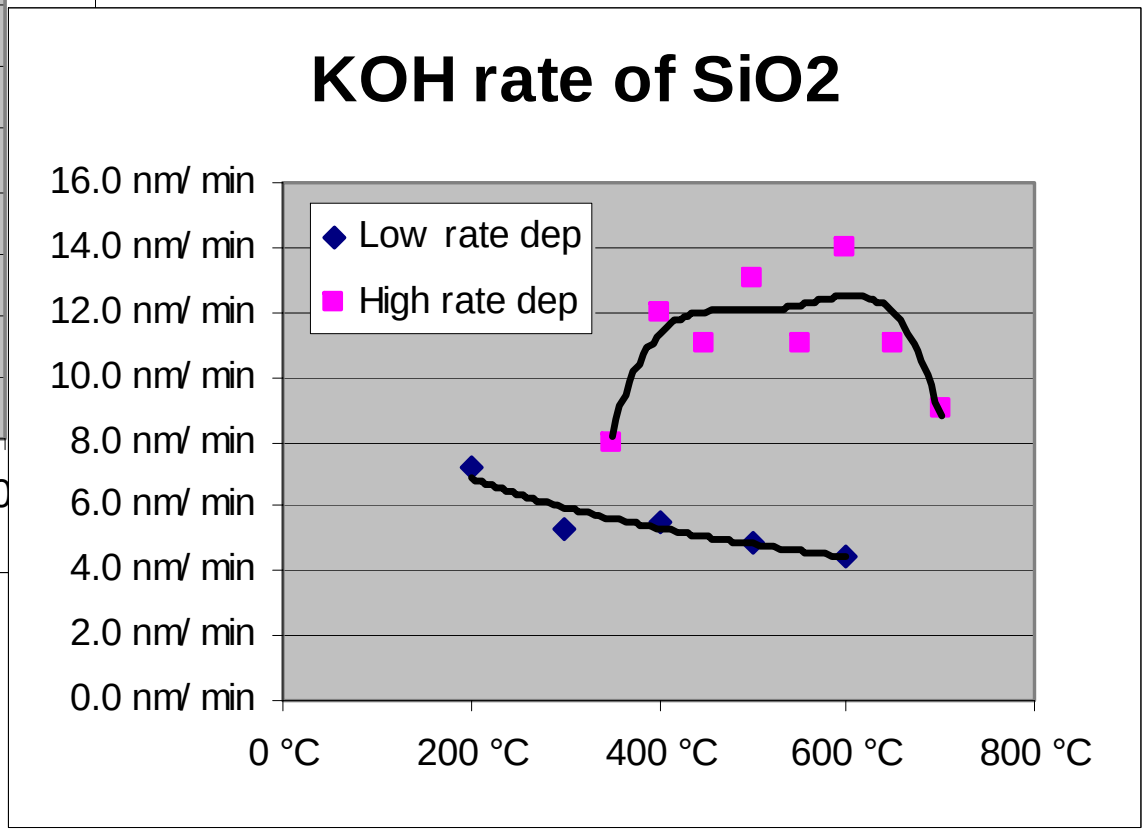
Film quality vs dep temperature





Warning: Potassium hydroxide (KOH) is highly corrosive, please read safety datasheet and safe system of work before use.

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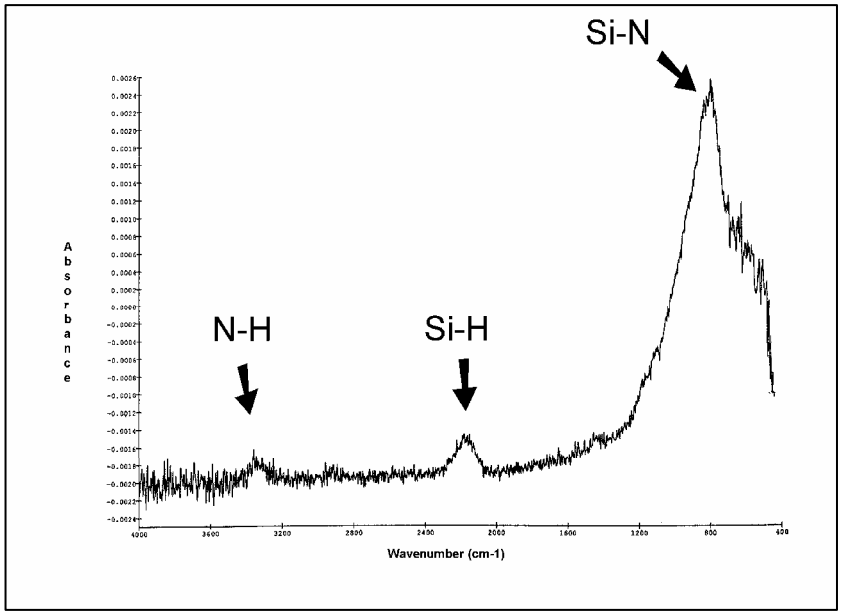
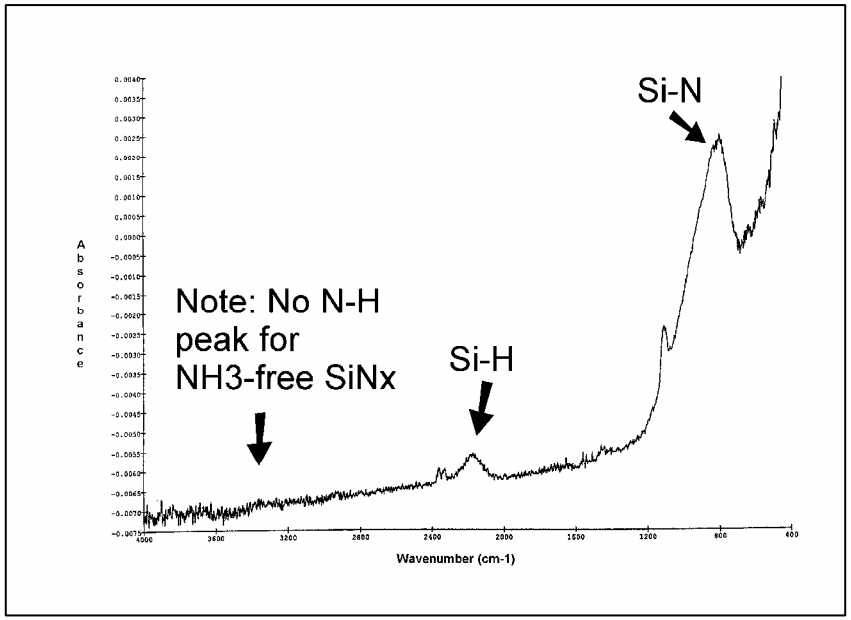
SiNx – FTIR traces

- 'Standard process' and 'NH_3 free process'



Standard SiNx



NH_3 free SiNx

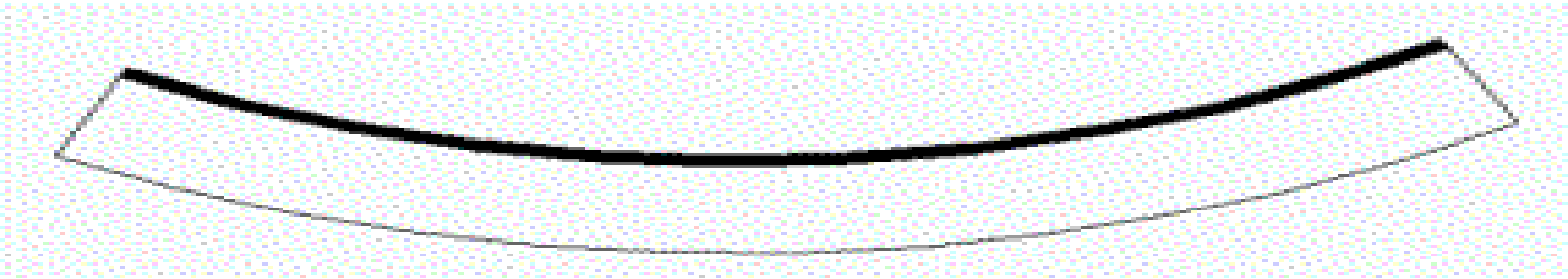
SiNx - NH_3 free process

Advantages	Disadvantages
•Low hydrogen content •Lower BHF etch rate •Better at lower temperatures (100°C)	•Lower deposition rate (7nm vs upto 20nm/min) •Slightly worse uniformity •Slightly worse repeatability

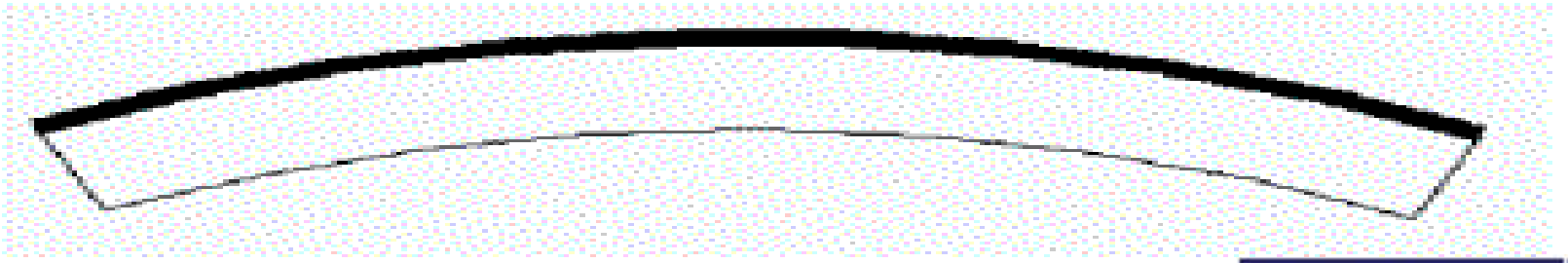
Film Stress - Definition

Original wafer

Wafer shape after depositing tensile film



Wafer shape after depositing compressive film



Film Stress - Definition

The causes of film stress can be visualised by imagining what happens when too many atoms are packed into the film - bond lengths are pushed shorter than normal – the film tries to relax back to its normal bond length – pushing outwards and forcing a convex ‘compressive stress’ curvature of the wafer.

The opposite happens for tensile stress – too few atoms per cm^3 – tensile films are usually less dense than compressive films.

The convention is: negative sign for compressive stress, positive sign for tensile.

Film Stress - Definition

$$\sigma = \frac{\Delta}{r^2} \cdot \frac{(t_{substrate})^2}{t_{film}} \cdot \frac{E}{3(1-\upsilon)}$$

where : σ = film stress

Δ = change in wafer bow, r = radius of scan

$t_{substrate}$ and t_{film} = substrate and film thickness

E = Youngs modulus, υ = Poisson ratio

Δ, r, and thicknesses must be measured in the same unit, e.g. cm or µm

Then σ will be in the same units as E (e.g. dynes/cm^2 or GPa)

Film Stress - Definition

for silicon:

$$\sigma = \frac{\Delta}{r^2} \cdot \frac{(t_{substrate})^2}{t_{film}} \; x \; 6.16 \; x \; 10^{11} \; dynes \; / cm^2$$

(OR 61.6 GPa OR 61600 MPa)

Example: 10µm bow on 25mm radius scan, 500µm Si substrate, 0.5µm film:

$$\sigma = \frac{10}{(25000)^2} \cdot \frac{(500)^2}{0.5} \; x \; 6.16 \; x \; 10^{11} \; dynes \; / cm^2$$

$$\sigma = 4.93 \; x \; 10^9 \; dynes \; / cm^2 = 0.493 GPa = 493 MPa$$

Mixed frequency PECVD

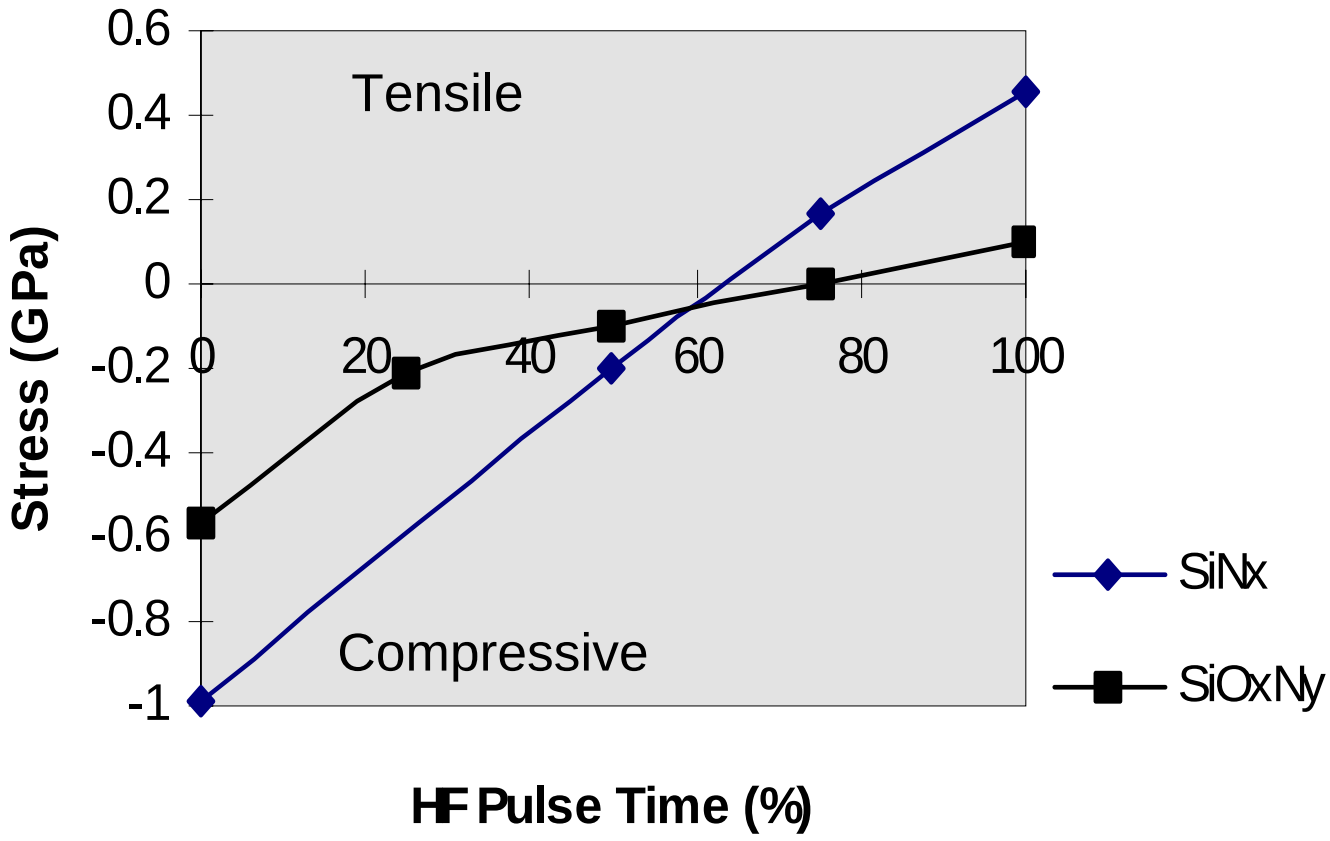
At 13.56MHz, ions do not respond to RF field

At 100-350kHz, ions can respond and give

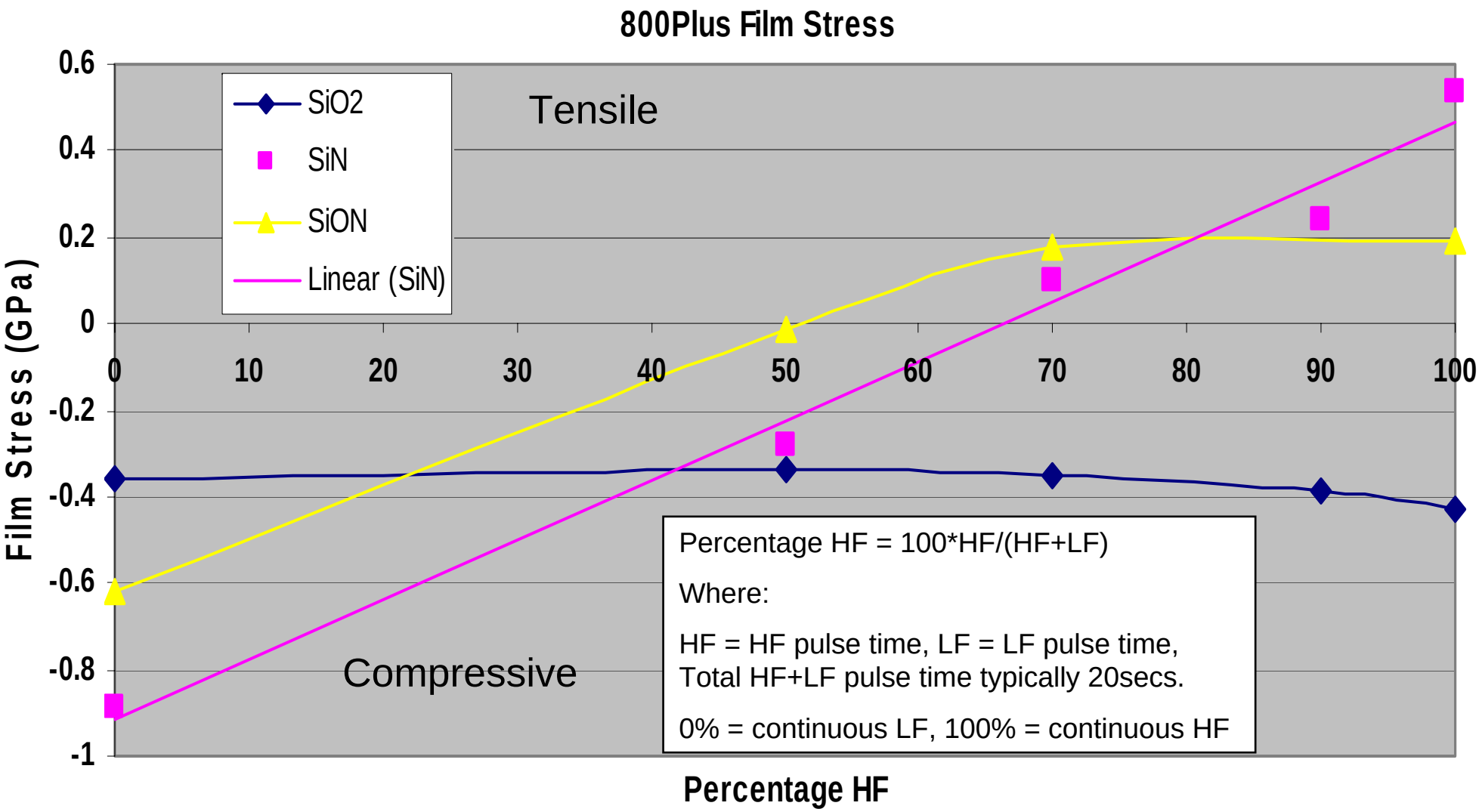
ion bombardment of growing film

Mixing of High and Low frequency power allows control over ion bombardment and hence control over film stress and film density

Film stress control



Pulsed film stress control



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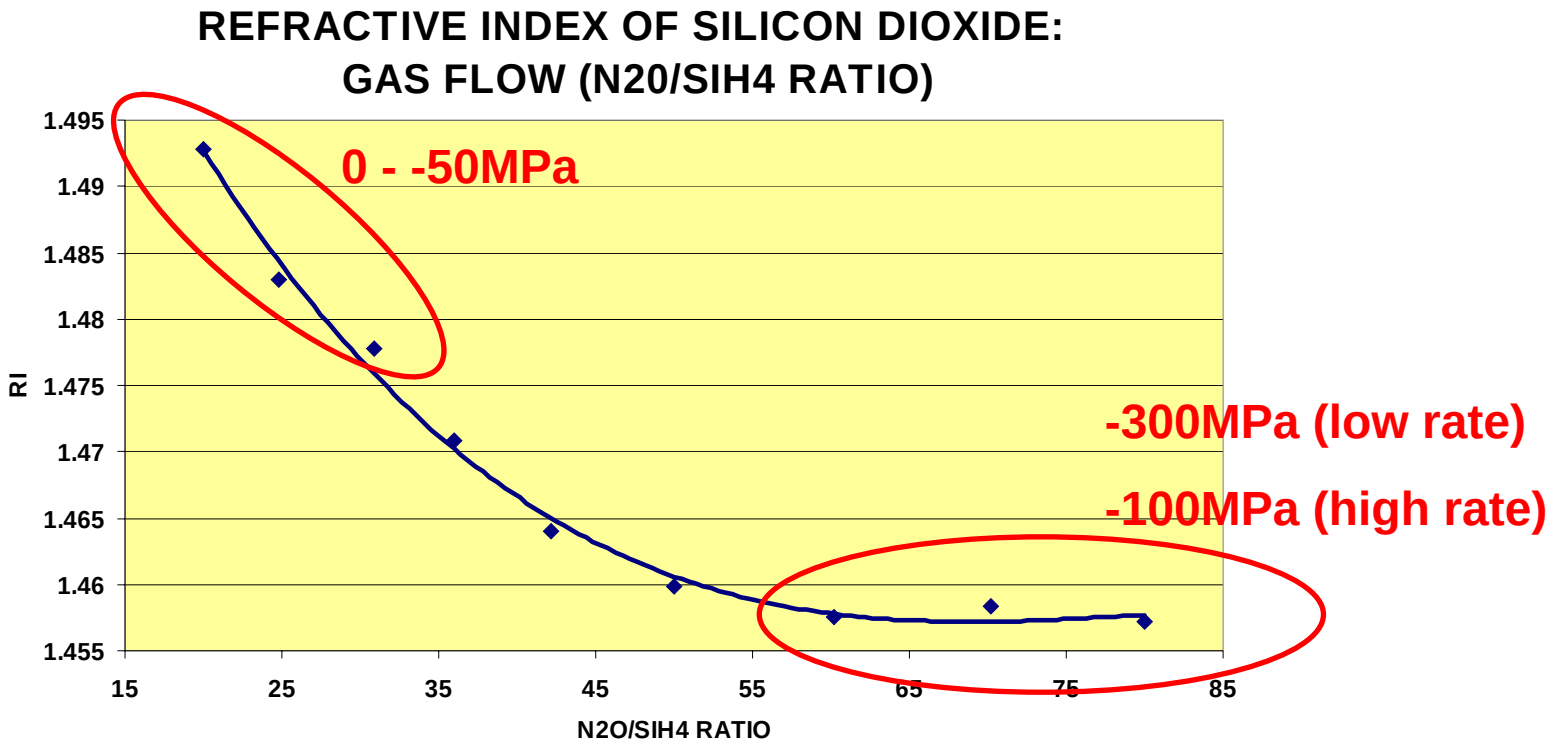
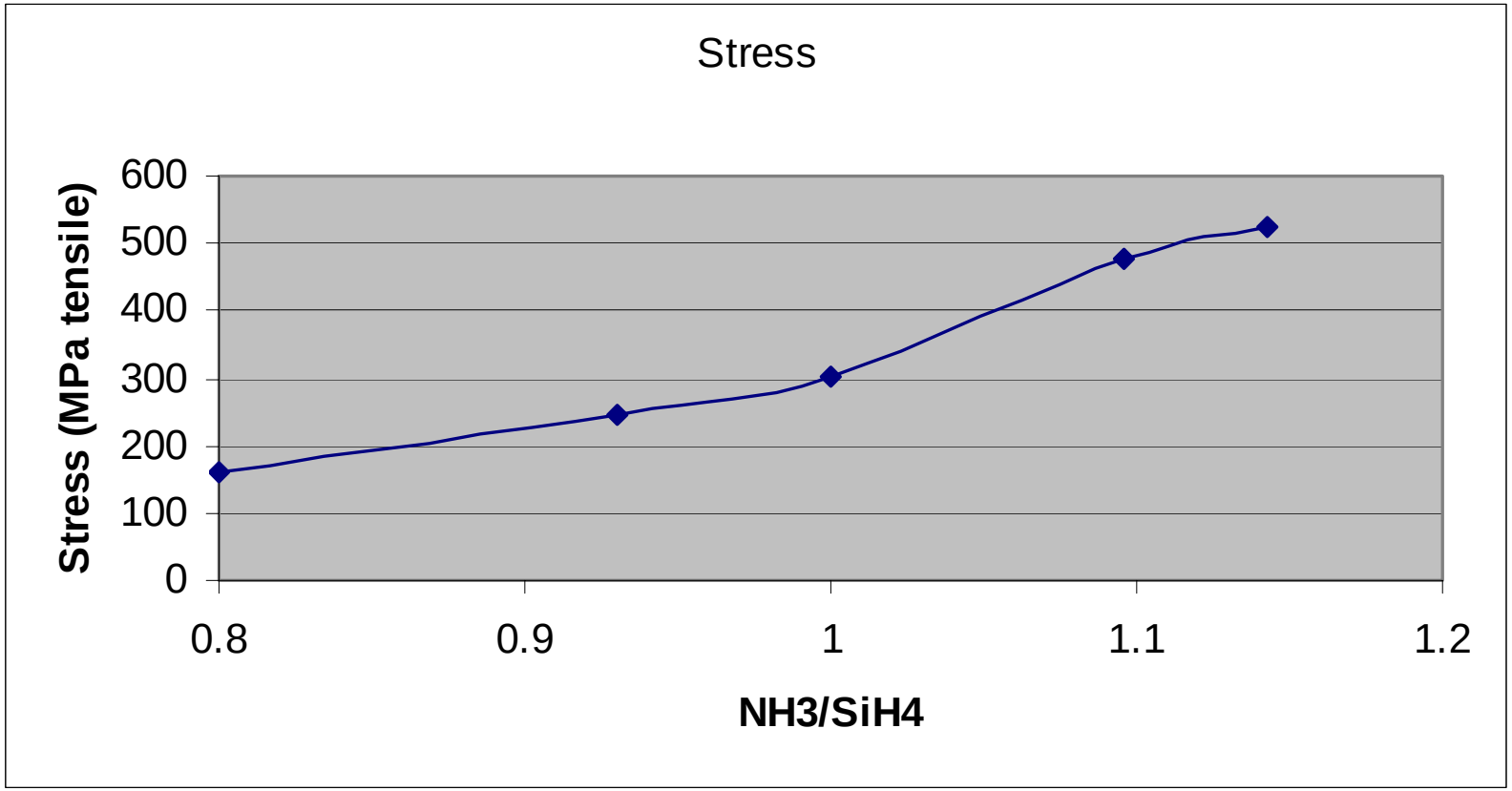
Stress control SiOx

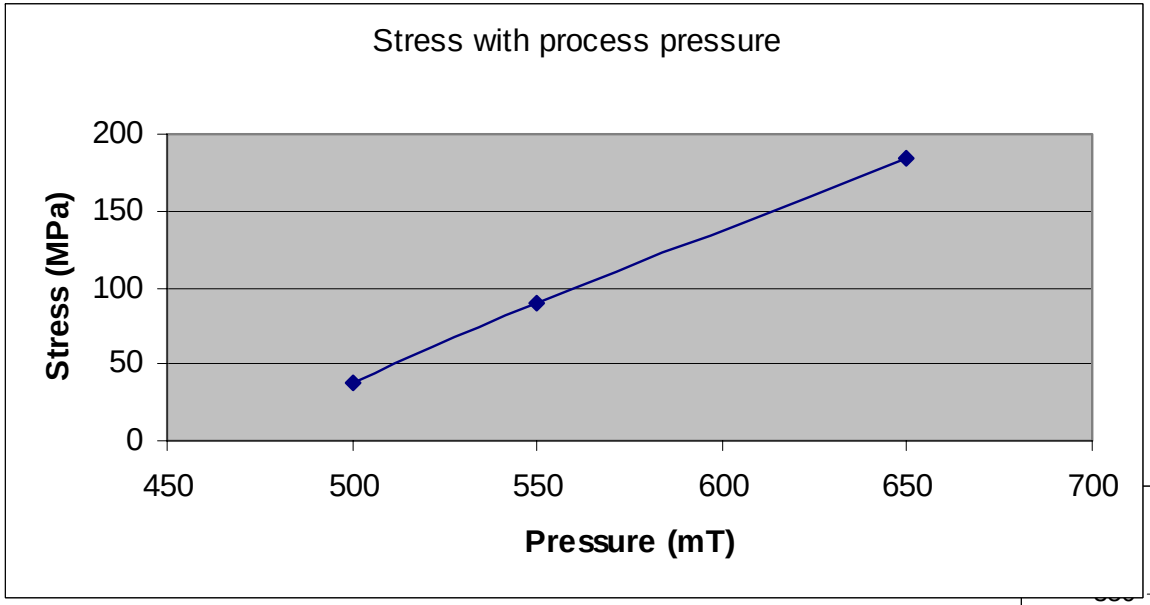
- Reduce RF power
- Adjustment of N_2O:SiH_4 ratio

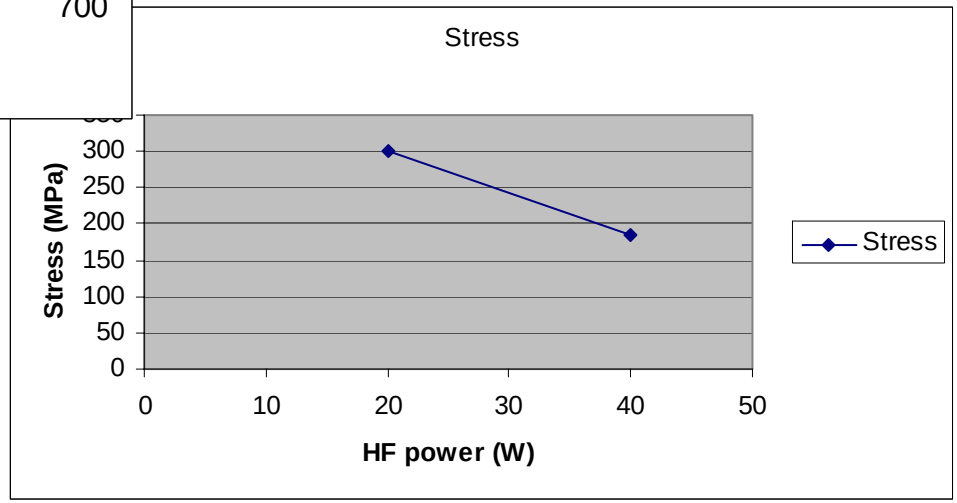


Stress control SiNx



Stress control: SiNx





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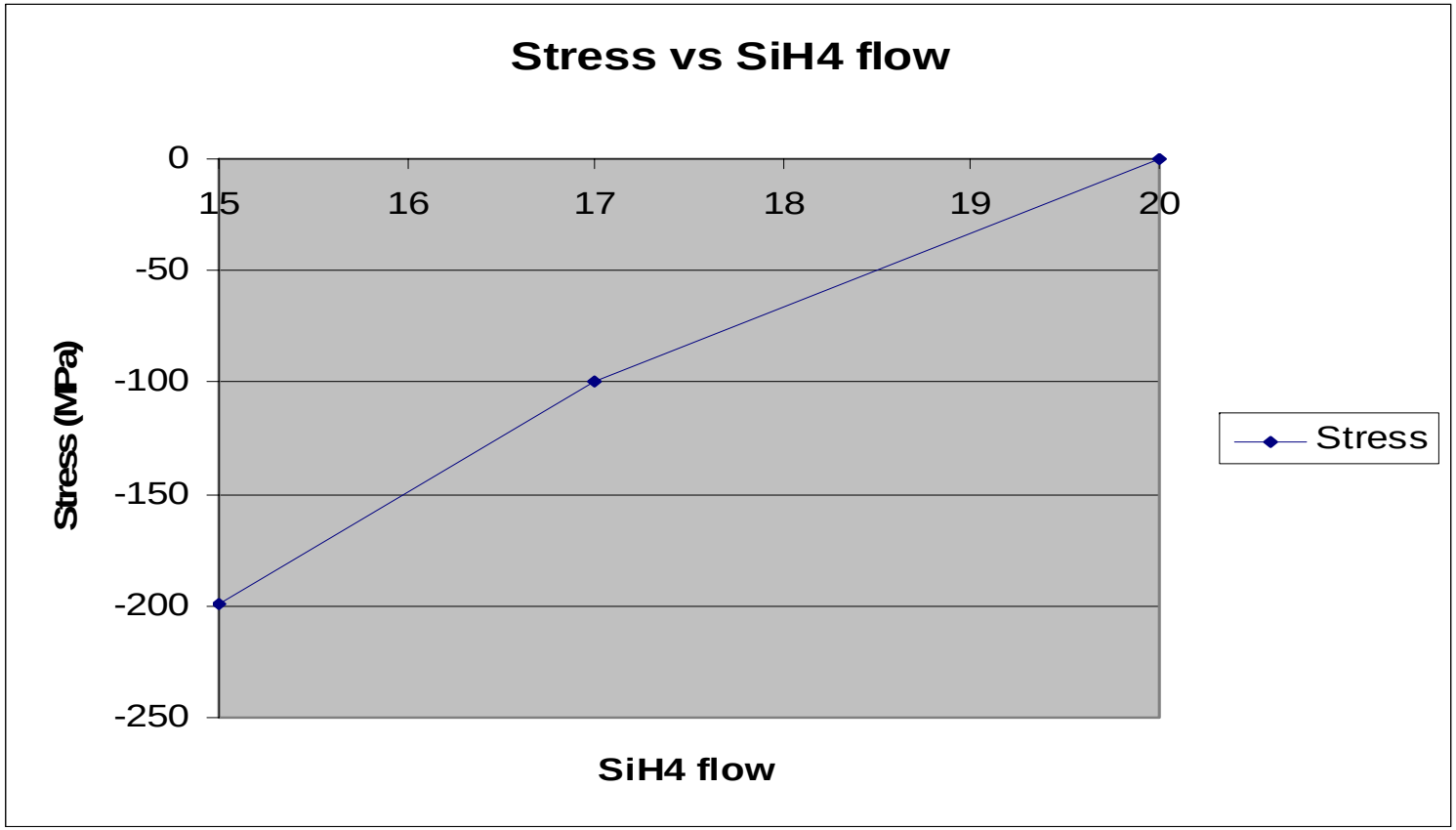
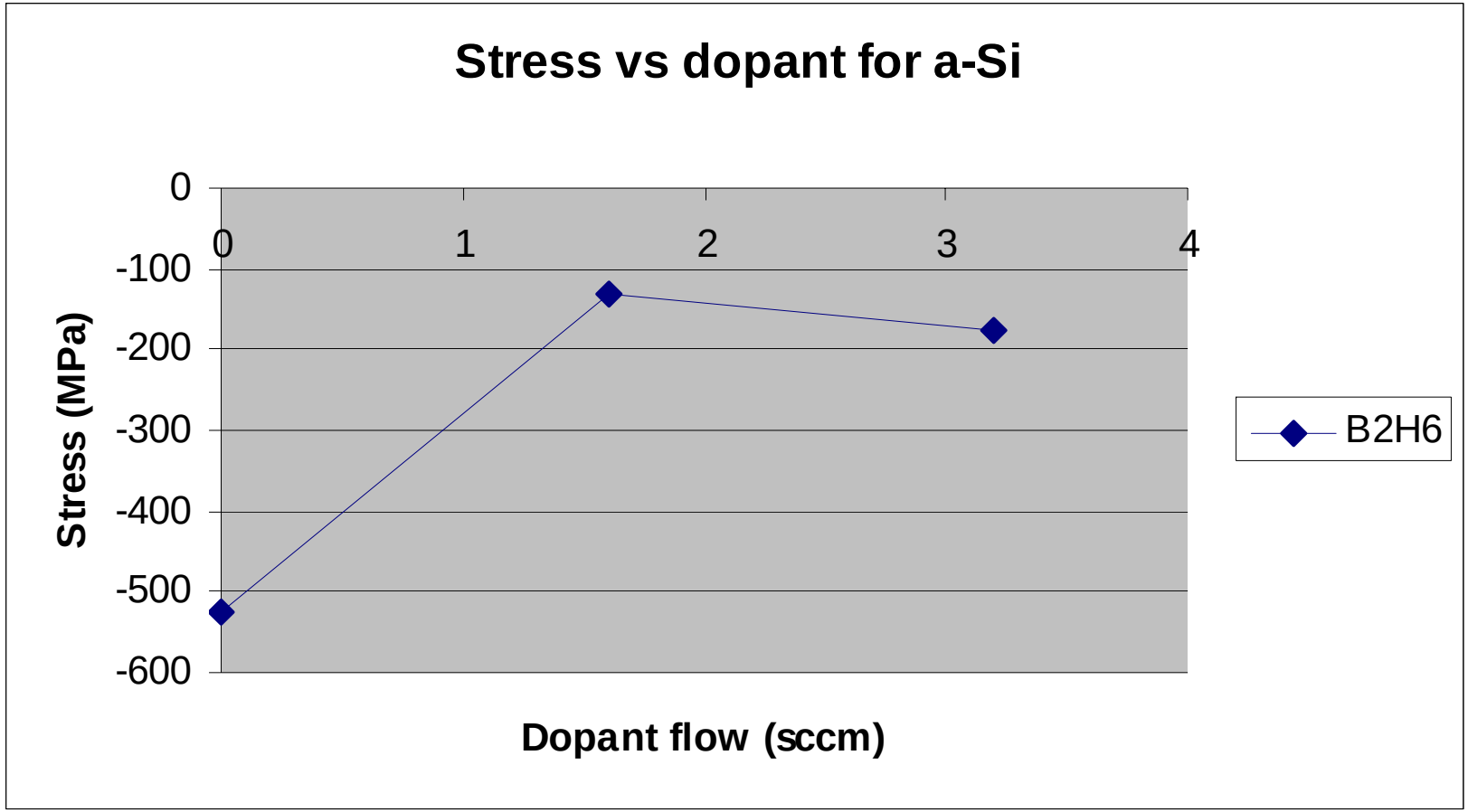
a-Si:H

- Deposited using SiH_4
- Either pure, He or Ar dilution
- Common for addition of PH_3 and B_2H_6 as dopant
- Surface pre-cleans useful for surface adhesion improvements
- Bubbling of film may result when depositing on to bare Si wafers
- Usually deposited on to SiOx or SiNx underlayer
- Stress dependant on underlayer

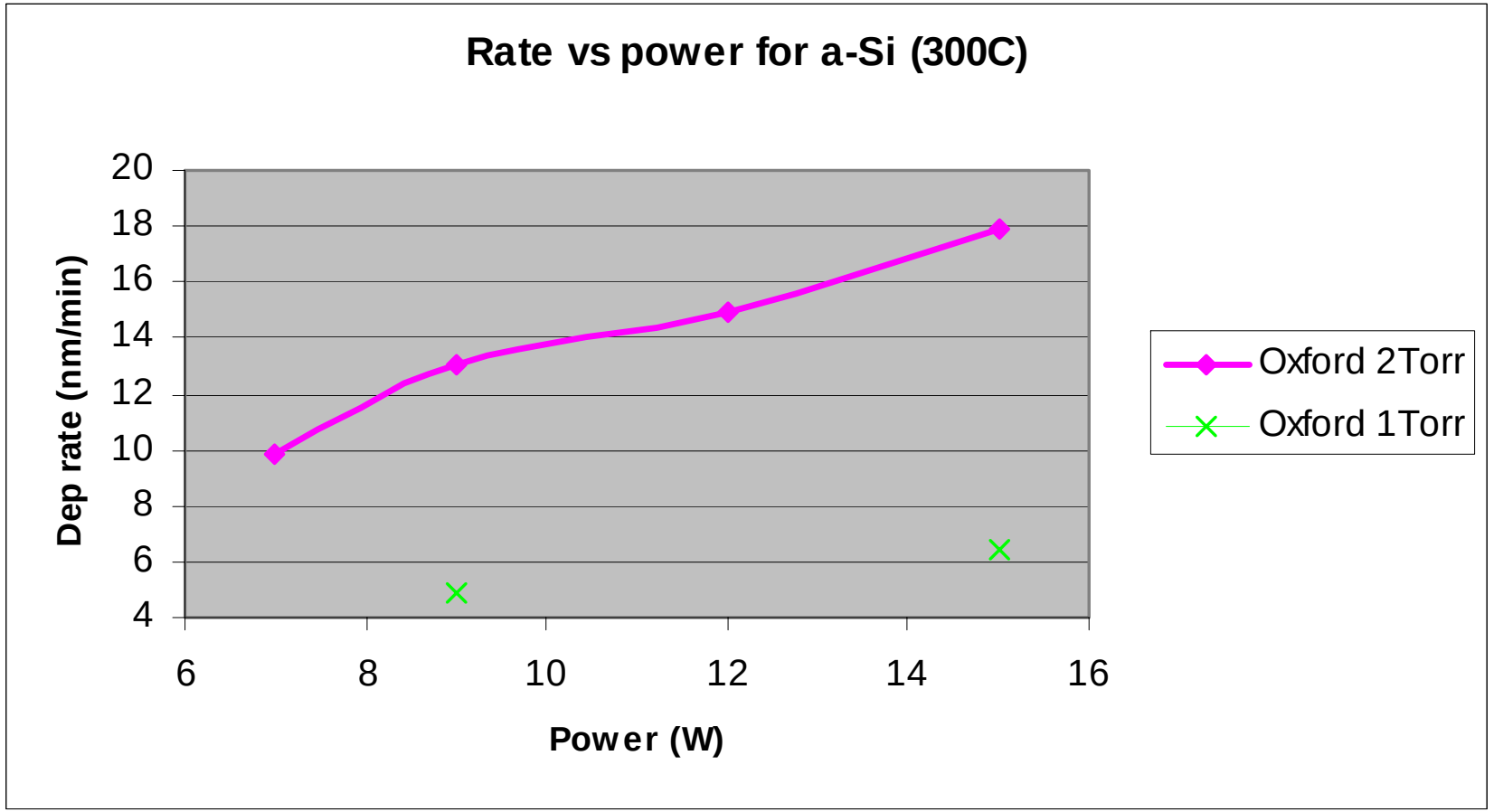
a-Si: stress control: SiOx underlying film



a-Si: stress control: SiNx underlying film



a-Si: deposition rate



Common PECVD problems

- Poor adhesion – change chemistry of, or lengthen, surface preclean step
- Surface interactions – deposit SiNx at <300C on InP to avoid rough/lumpy films - or use NH3-free SiNx
- Particles – if seen as silica dust in showerhead pattern on wafers then need to search for air leaks in gas lines or behind showerhead. Or increase pump/purge cycle after chamber cleaning.
- Particles - if random scattering of particles check chamber/showerhead condition – may need plasma cleaning or sandblasting clean.
- Pinholes – as for particles above.

Particle descriptions	When they most often occur	Possible causes	Remedy/Quick Fix –Test
Small particles less than 5um which appear in concentrated clusters. These clusters appear in a pattern which mirrors that of the showerhead holes. They are concentrated mainly in one focal plane of the microscope and appear to be at the bottom of the film.	The first run after a clean	Running the machine too soon after the completion of a clean process. Silane forms particles when it reacts with residual oxygen in the gas lines (remember all of the gas line up to the normally open, hardware interlock nupro valve is incorporated in the chamber vacuum and needs to de-gas at the end of a long clean run).	Wait 30 minutes before running a deposition process using silane after finishing a clean.
Small particles less than 5um which appear in concentrated clusters. These clusters appear in a pattern which mirrors that of the showerhead holes. They are concentrated mainly in one focal plane of the microscope and appear to be at the bottom of the film.	The first run after a long period of machine disuse (say overnight)	A small leak in the silane line, particularly around the mass flow, allowing a build-up of silane dust which is blown though on to the first wafer.	Fix the leak in the silane line. Flow silane gas after a significant period of machine disuse without a wafer in the chamber to clear the dust.
Small particles less than 5um which appear in concentrated clusters. These clusters appear in a pattern which may or may not mirror that of the showerhead holes. They appear in many different focal planes of the microscope, at regular intervals throughout the film.	Every run	A leak in the gas in-let assembly or a severe leak in the silane line. Plasma forming behind the showerhead or in the gas inlet assembly.	Leak check chamber and gas line. If both less than 1mT per minute contact Oxford service department and give this description. If greater than 1 mT per minute take apart gas inlet assembly and clean O-rings and PTFE part.

Flakes or larger non-metallic particles	First run after a clean	Residual particles not etched during the cleaning process	Vacuum the chamber inside, this is necessary periodically after cleaning. It may be a good idea to cool the chamber first to prevent risk of injury with the hot table.
	After a power failure or other reason which caused a significant drop in table temperature	When the lower electrode cools deposited film, particularly around the edges, cracks and is blown on to the wafer during subsequent deposition runs.	Clean the chamber.
	After a certain amount of deposition on the chamber, but it varies when they occur.	If you are depositing films of many different chemistries and stresses, particularly those with high stress, then the film will flake off much earlier than expected.	Clean more regularly.
	After a certain amount of deposition but it seems to be getting less and less after every clean.	The films are not adhering to the showerhead very well. Someone has cleaned the showerhead using solvent, leaving behind a residue that is giving poor adhesion for the deposited films. The showerhead has become dirty and the clean process is unable to clean it – the showerhead is ready for its periodic maintenance.	Beadblast the showerhead.
Metal particles which shine under normal cleanroom light and are greater than 20um in maximum dimension.	Mostly all the time	Showerhead holes may be lighting-up or the showerhead holes have become damaged due to normal wear and tear.	Beadblast the showerhead.
Particles or marks which appear randomly on the wafer, but look as if they are underneath the film.	Every run	The wafer has been cleaned using solvents which have not been properly washed off with de-ionised water.	Use a fresh wafer straight from a new box.

Common PECVD problems - Poor uniformity

1. Change process conditions as detailed in trend tables.
2. If processing involves LF then check;

   a) is the uniformity of the LF part of the deposition causing the problem?

   b) conditioning of chamber

      i. How much deposition; LF much more affected by insulation build up in chamber?

      ii. How clean?

Common PECVD problems - Poor uniformity cont'd

c) contact of sample to electrode

i. Flatness of electrode

ii. Recessed pin or starlift (approx 1mm)? Can become raised over time due to flakes/dust falling into starlift hole.

iii. If batch processing – do all of the recesses on the carrierplate have the same coating of film (i.e. the film on the carrierplate) – previous runs may have been carried out with a single wafer to check rate and RI. If not, then clean carrierplate/electrode.

d) or increase LF frequency

PECVD interlocks

PECVD clean gases (CF_4/O_2) are interlocked from all deposition gases as a safety feature to avoid reaction of O_2 and SiH_4. Such a reaction is a safety hazard as this is an explosive mixture, and is bad for the process since it will form white SiO_2 dust in gas lines.

The gas lines are ‘hardware interlocked’ by 2 Nupro valves (1 normally open, 1 normally closed) in gas pod to provide maximum safety.

However, in order to prevent dust build up in gas lines it is recommended that at least 2 pump/purge cycles (5min pump/5min purge 500sccm N_2, 2Torr) are carried out between cleaning and deposition or vice versa.

PECVD – Chamber cleaning

If the high pressure, high power clean process has been run for too long then attack of showerhead could occur forming a brown film/powder on showerhead. This can be removed by:

-wipe off with a dry clean room wipe

-Eventually may need to be beadblasted, but after beadblasting ensure that the holes are clear by using compressed air and a ‘paper clip’

PECVD - Typical Cleaning intervals

Material	80Plus	System100
SiO_2	10µm	up to 100µm
SiN	10µm	20µm

Cleaning interval is lower for 80Plus due to flaking/peeling of film from walls as a result of frequent chamber venting.

All figures given above may need to be reduced if a tight particle spec is required.

PECVD – Typical ‘wet clean’ interval

Every 500-1000µm of film it will be necessary to perform a ‘wet clean’ as follows:

1) Plasma clean chamber
2) Cool down of electrode (advisable to avoid hot surface hazard)
3) Examine chamber – vacuum any flakes/particles
4) IPA wipe of chamber walls if necessary
5) Dry wipe of showerhead, or beadblast showerhead if necessary
6) Re-install showerhead, pump/purge chamber, and condition

Beadblast using alumina powder (aluminium oxide beads) of 180 grit size or less - maybe 120. Do not use any solvents. Clean the showerhead after beadblasting using compressed air only. Hold the showerhead up to the light to check that none of the holes are blocked by any grit from the beadblasting. Clean out holes with paper clip or similar if blocked.

PECVD – showerhead bright spots

It is quite common to see PECVD showerhead holes becoming enlarged. This is caused during high-power processing (on an 80 Plus this is typically during plasma cleaning). Any holes which have slightly sharper edges will form an intense discharge over the hole (due to the high fields generated by the sharper edges). This can be seen as a 'bright spot' in the plasma located over the hole during the clean process.

This can cause some erosion of the hole and widening of the hole opening (on the outlet side only). Eventually, the bright spot burning itself out, i.e. the erosion removes the sharp edges and hence the bright spot no longer occurs at that hole. This may happen for several holes during the initial run-up of the system, until the showerhead 'stabilises' itself.
The bright spot may also result in some black/brown polymer deposition around the holes which, can cause premature flake-off of deposited films. It is recommended that the showerhead is bead-blasted clean to remove such residues.

The bright spots should not be observed during low power (<50W) 80 Plus deposition processes. If they are, it is recommended that the showerhead is plasma cleaned and bead-blasted cleaned until the bright spots are eliminated. It is sometimes possible to cure the bright spot by using a de-burring tool to clean out any machining residues from the hole in question. If bright spots are still present then it may be necessary to obtain a replacement showerhead.

The effect of the enlarged holes on the deposition results should be minimal, since they only enlarge the outlet of the hole, hence they do not affect the gas flow.