Non-PFC Plasma Chemistries for Patterning Complex Materials/Structures

(Task Number: 425.038)

PIs:

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- **Michael Paine, UG student, Chemical and Biomolecular Engineering, UCLA**

Other Researchers:

- **(TBD)**

Objectives

- **Assess the thermodynamic feasibility of patterning etch-resistant materials (complex materials and structures)**

- **Identify the non-PFC alternative for through silicon via**

- **Establish collaboration with industrial members to validate the theoretical assessment (etching experiments)**

- **Identify priority test cases (such as TSV)**

ESH Metrics and Impact

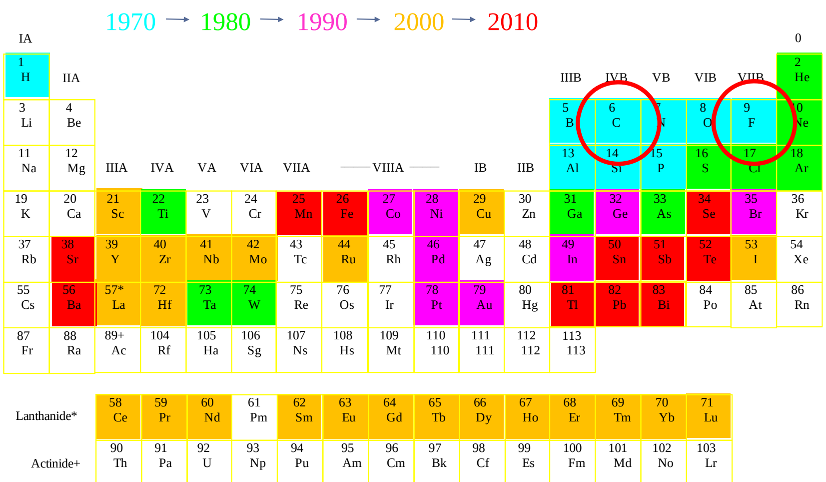
1. **Reduction in the use of PFC gases by focusing on non-PFC chemistries**

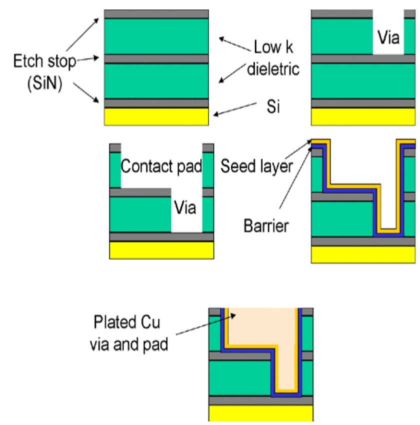
2. **Reduction in emission of PFC gases to environment**

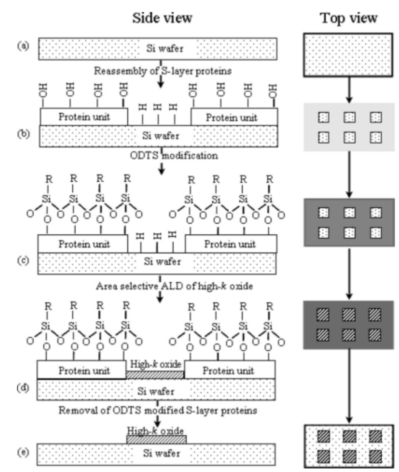
3. **Reduction in the use of chemicals by tailoring the chemistries to the specific materials to be removed**

Approach for Etch-Resistant Materials

- Use more aggressive etch chemistries such as PFC
  - Fluorine is the most electro-negative element
  - Carbon reaction products (CO and CO_2) are volatile





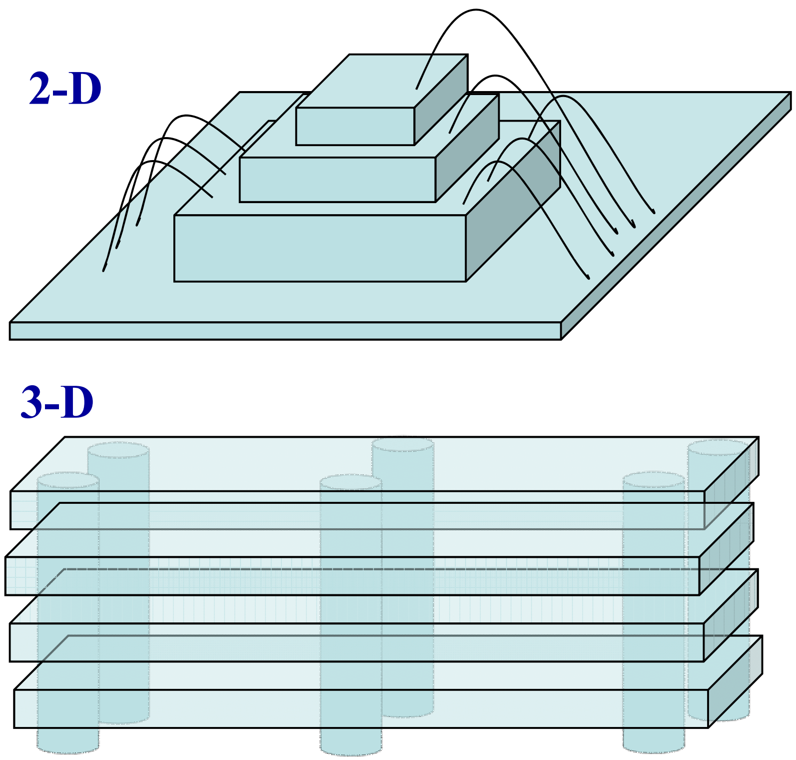


- Change processing approach to not etch these materials
  - Damascene process[1] for Cu
  - Area selective atomic layer deposition

[1] P.C. Andricacos, C. Uzoh, J.O. Dukovic, J. Horkans, H. Deligianni, IBM, J. Res. Develop., Vol. 42, No.5(1998).

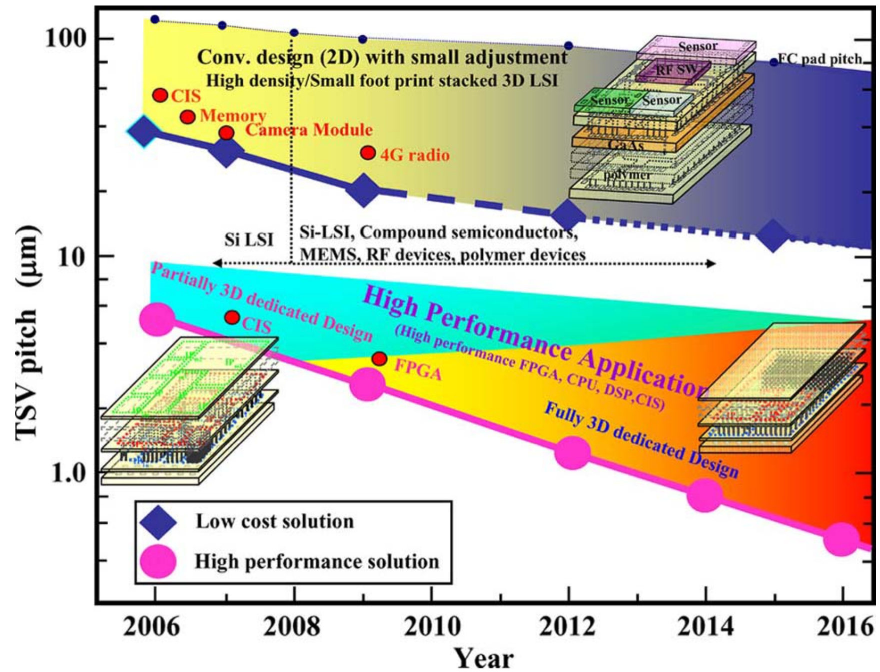
TSV (Through Silicon Via)

From 2-D to 3-D packaging



TSV for 3D-LSI technology road map

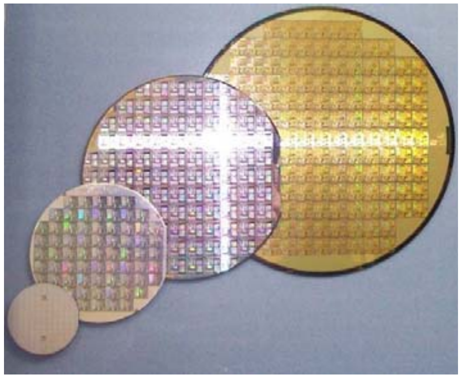
[M. Motoyoshi, IEEE, 2009]



- **According to Moore's Law, the density of IC devices doubles every two years, the 3-D packaging system is required.**

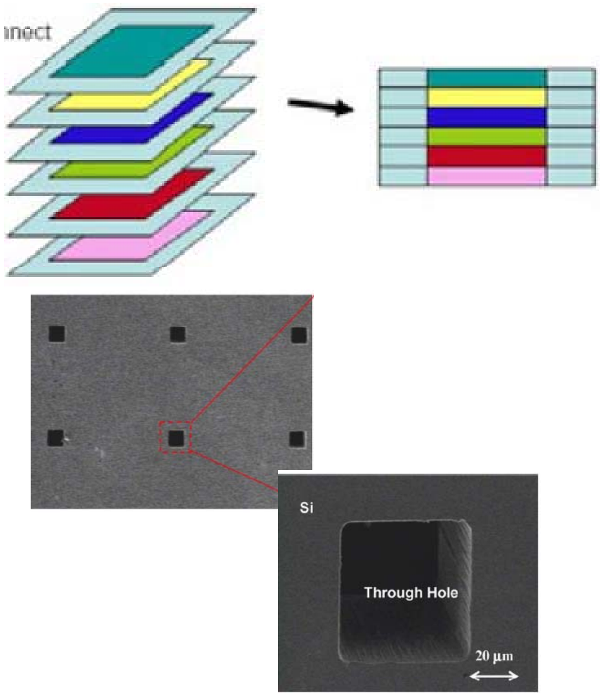
Challenges in TSV

High etch rate



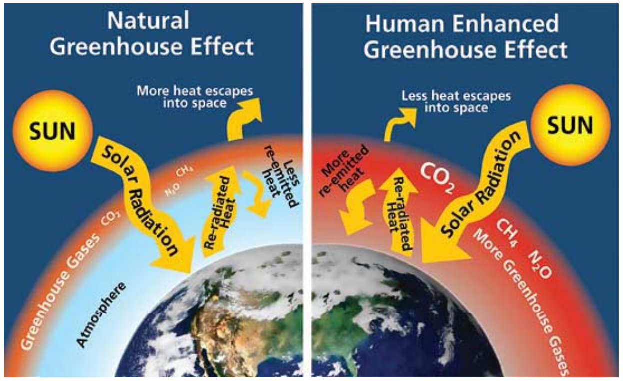
Silicon size (inch)	Thickness (um)
6	675
8	725
12	775
18	925

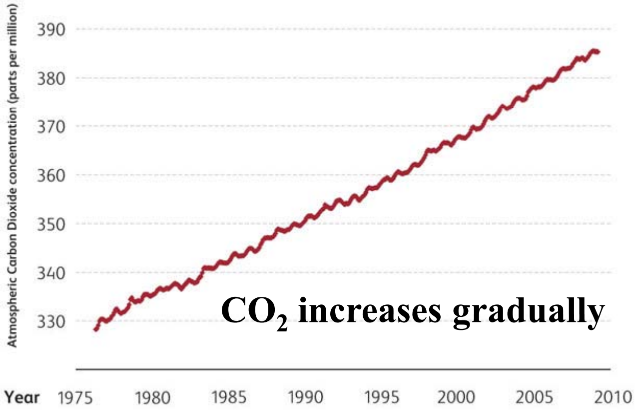
High aspect ratio



[M. Motoyoshi, IEEE, 2009]

Greenhouse gas usage

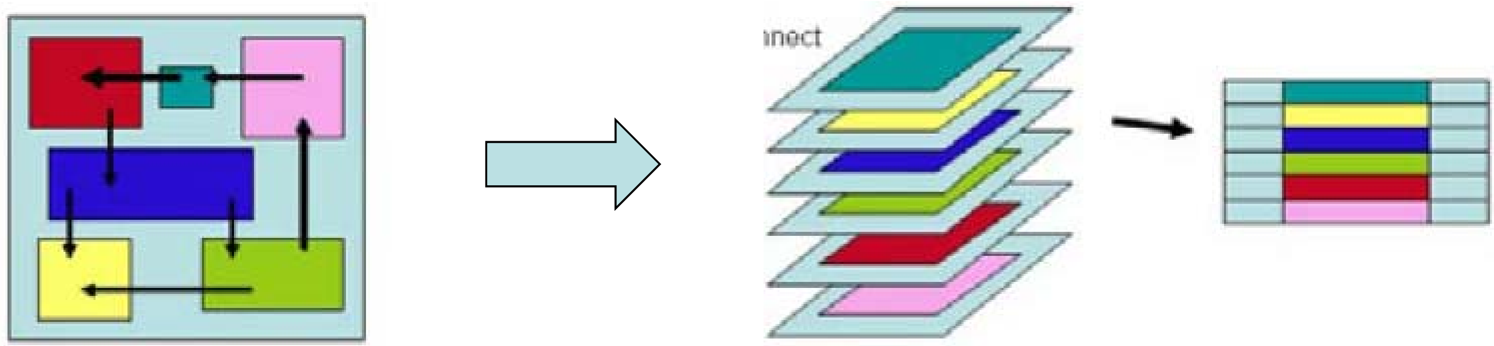




• **Requirement to increase etch rate, increase aspect ratio and reduce the usage of global warming gases**

3-D Stack with TSV

2D-Conventional **3D-TSV**



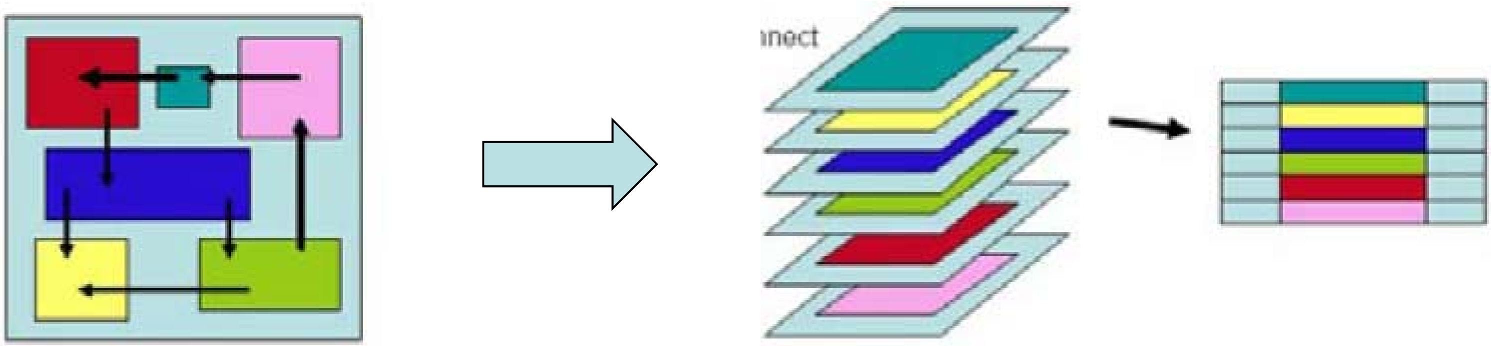
[P. Garrou, Samsung website, 2010]

- **Advantages:**
  - **Smaller footprint**
  - **Smaller form-factor**
  - **Less weight**
  - **Less power consumption**
  - **Potentially lower cost**

- **Challenges:**
  - **High etch rate**
  - **High aspect ratio**
  - **Large Depth**
  - **High yield**
  - **GWP gases**

3-D Stack with TSV

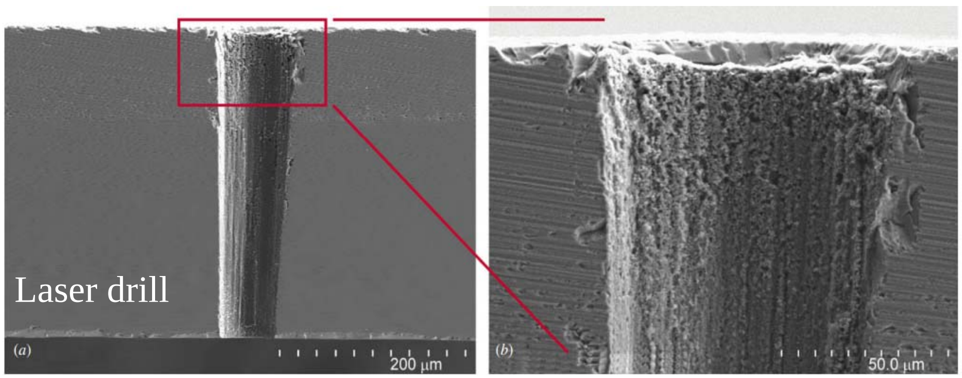
2D-Conventional **3D-TSV**



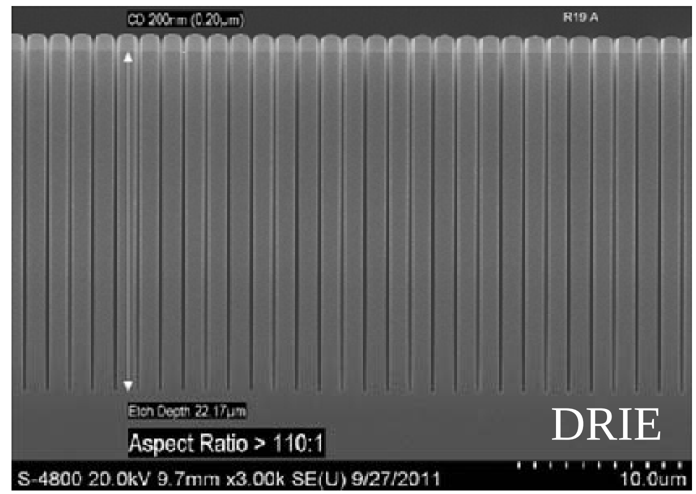
[P. Garrou, Samsung website, 2010]

	Features	Goal	Ref.
1	Etch rate	50 μm/min	I. Sakai, J. Vac. Sci. Technol. A, 2011
2	Aspect ratio (Anisotropy)	70-100	I. Sakai, IEEE, 2012
3	Side wall angle	$90^o \pm 10^o$	M. Hooda, J. Vac. Sci. Technol. A, 2010

TSV Process Options

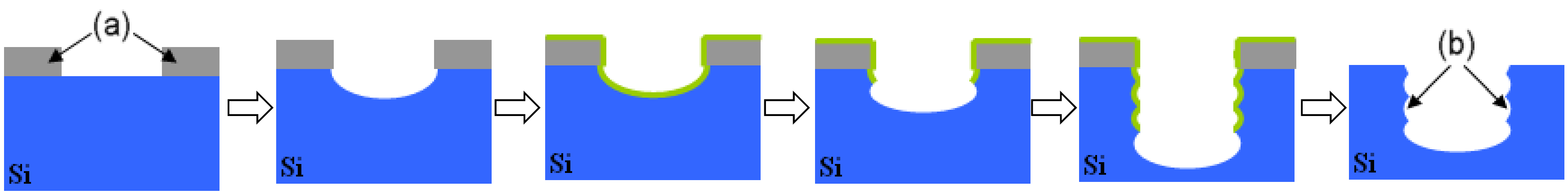


[C. Tang, J Micromech Microeng, 2012]



[Applied Materials Inc., website, 2012]

Bosch Process



[Gurgelgonzo, Public domain, 2007]

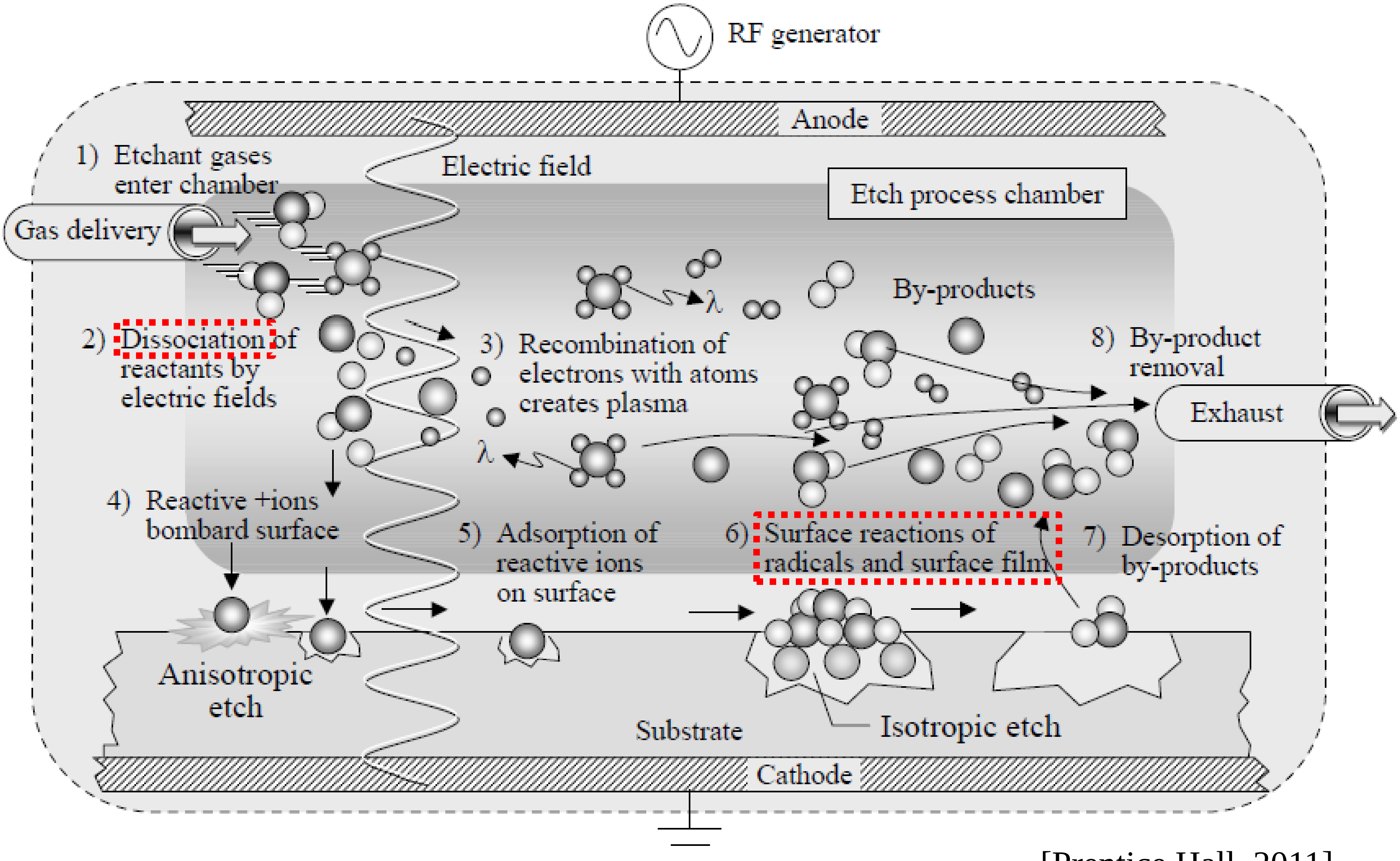
TSV Process Options

TSV Processes	Bosch DRIE*	Cryogenic DRIE#	Laser drill*
Width	<5μm	<5μm	<15μm
Aspect ratio	>20:1	>10:1	>7:1
Sidewalls	Vertical (90^o)	Vertical &smooth	80^o-90^o
Temp. affection	Negligible	-110°C ~ -130°C	Yes
Process	ICP	ICP	Laser
Potential applications	High-end	High-end	Low-cost
Example	Microprocessors	Microprocessors	DRAM/Flash

[R. Landgraf, IEEE, 2008*; M. Walker, Proc. SPIE, 2001#]

- **As the critical dimension continues to decrease, DRIE becomes the most feasible technology for TSV**

Plasma Etch Process of a Silicon Wafer



[Prentice Hall, 2011]

Systematic Approach - Thermodynamics

- Thermodynamic approach can be systematic
  - If such data is available
    - NIST-JANAF Thermo-chemical tables
    - HSC Chemistry for windows, chemical reaction and equilibrium software with extensive thermo-chemical database
    - FACT, Facility for Analysis of Chemical Thermodynamics
    - Barin and Knacke tables (thermo-chemical data for pure substances and inorganic substances)
  - Determination of dominant surface/gas-phase species
  - Assessment of possible reactions

- Graphical Representation of thermodynamic analysis
  - Richardson Ellingham diagram
  - Pourbaix diagram
  - Volatility diagram

Important Chemistries for Silicon Etch

Chemistries	Radical	Volatile Product	Inhibitor
H_2	H	$HSiF_4$	Si_xF_y
CH_4	CH_3 CH_2	SiH_4 SiF_4	$Si_xC_yH_z$
F_2	F	SiF_4	Si_xF_y
NF_3	F, NF_2	SiF_4	$Si_xN_yF_z$
SiF_4	F, SiF_3	SiF_4	Si_xF_y
CF_4	F, CF_3	SiF_4	$Si_xC_yF_z$
SF_6	F, SF_5	SiF_4	$Si_xS_yF_z$
S_2F_2	F, S_2F	SiF_4	$Si_xS_yF_z$
Cl_2	Cl	$SiCl_4$	Cl
Br_2	Br	$SiBr_4$	Br
CBr_4	Br, CBr_3	$SiBr_4$	Br, $Si_xC_yBr_z$

Chemistries	Radical	Volatile Product	Inhibitor
CHF_3	CF_2	HF, SiF_4	$Si_xC_yH_z$
CH_2F_2	CFH C	HF	$Si_xC_yF_zH_a$
CH_3F	CH2 CFH	HF, H_2	$Si_xC_yF_zH_a$
CF_4/O_2	F, O, CF_3	COF2, O2F, OF, F2, SiF_4	$Si_xO_yF_z$
CF_4/H_2	F, H, CF_3	CHF, HF, SiF_4	$Si_xC_yF_z$
SF_6/O_2	SF_5, O, F	SOF4, SiF_4	$Si_xO_yF_z$
SF_6/H_2	SF_5, H, F	HF, SiF_4	$Si_xS_yF_z$
SF_6/N_2	SF_5, N_2, F	SiF_4	$Si_xS_yF_z$
SF_6/CHF_3	SF_5, F, CF_2	HF, SiF_4	$Si_xC_yF_z$
$CBrF_3$	F, Br	$SiBr_4$	Br, $Si_xC_yF_z$ $Si_xC_yBr_z$
CCl_4	CCl_3, Cl, C	$SiCl_4$	Cl

→***Fluorine-based gases remains the most effective chemistry***

[H. Jansen, 1996]

Global Warming Potentials (GWP)

Chemistries	Atmospheric conc. in 2005 (ppt)	Con. since 1994* & 1998 (ppt)	Annual emission in late 1990s (Gg)	Rafactive efficiency (W/m^2 –ppbv)	Lifetime (year)	Global warming potential	Ref.
CO_2	$278x10^6$	$358x10^6$*	-	-	variable	1	b
CH_4	$7x10^5$	$1721x10^3$*	-	-	12.2	21	b
N_2O	$275x10^3$	$311x10^3$*	-	-	120	310	b
$CHClF_2$	-	$105x10^3$*	-	-	12.1	1400	b
CF_4	74	-	~15	0.1	50,000	6500	a
CCl_2F_2	-	$503x10^3$*	-	-	102	7100	b
C_2F_6	2.9	3.4	~2	0.26	10,000	9200	a
CHF_3	18	22	~7	0.19	270	11700	a
SF_6	**5.6**	**7.1**	**~6**	**0.52**	**3,200**	**23900**	**a**
NF_3	**<0.1**	**-**	**~2.3**	**0.21**	**740**	**16800**	**a**

[W. Tsai, J Hazard Mater, 2008[a]; United Nations Environment Program(UNEP), 2010[b]]

→ **GWPs are one type of simplified index based upon radiative properties which estimate the potential future impacts of gases**

→ **At the annual review, industiral members suggested a study on NF_3**

Is NF_3 a Greenhouse Gas?

- $NF_3 + 2H_2O \rightarrow 3HF + HNO_2$
- $2NF_3 + 3H_2O \rightarrow 6HF + NO + NO_2$
- $2NF_3 + 3H_2 \rightarrow N_2 + 6HF$
- **NF_3 and its reaction products are designated as toxic substances in Toxic Substances Control Act (TSCA)**

Title	Authors	Year	Journal	#Citation
NF_3,the greenhouse gas missing from Kyoto	Prather, M.J. and J. Hsu	2010	Geophysical Research Letters	55444
Environmental and health risk analysis of NF_3, a toxic and potent greenhouse gas	Tsai, W. T.	2008	Journal of Hazardous Materials	28060

Etch Rate of Si /poly-Si*

Etchant	Etch rate (nm/min)	Power (W)	Pressure (mtorr)	Ref
$SF_6/O_2/CHF_3$	3000	500		[c]
HBr(10sccm), Cl_2(70sccm), and SF_6(6sccm)	1100*		100	[e]
SF_6/O_2(25%)	880	300	25	[d]
SF_6(80%), $C_2Cl_3F_3$(20%),	700	140	47	[i]
SF_6(40sccm), O_2(14sccm), CHF_3(17sccm)	670		60	[j]
SF_6/O_2(25%)	490		100	[d]
F/F_2	460			[k]
CF_4/O_2	460			[k]
$CBrF_3$(80%), SF_6(10%), Ar(10%)	410	190	50	[h]
$CBrF_3$(90%), SF_6(10%)	310	100	50	[h]
SF_6	300		20	[g]
CF_4/O_2	300			[k]
O2(12%)/CF4(90%)/N_2(8%)	260*			[e]
$CBrF_3$	60	100	50	[h]
SiF_4/O_2	44			[k]
$CBrF_3$	40	100	20	[g]
CF_4	30			[k]
CF_4	20*			[f]

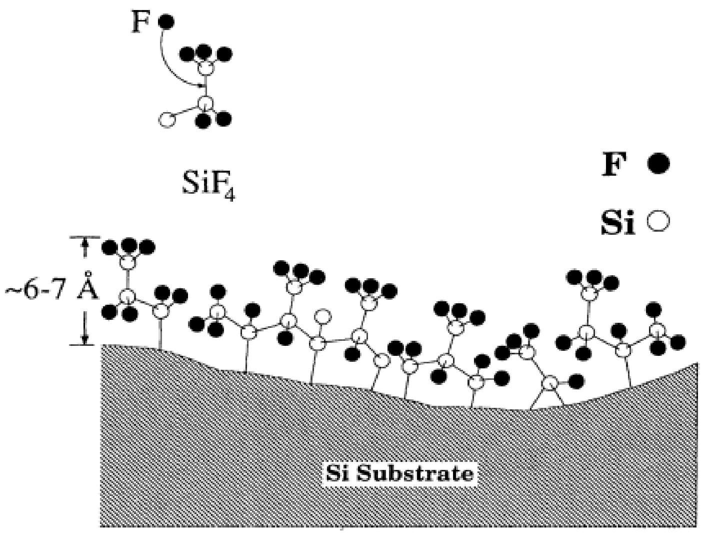
Etch Rate of $SiO_2/Si_3N_4/SiC$ by NF_3

Etchant	Etch rate_SiO_2 (nm/min)	Etch rate_Si_3N_4 (nm/min)	Power (W/cm^2)	Pressure (mtorr)	Ref
NF_3(25%)/N_2	860	7400	1.4	550	[l]
NF_3(25%)/Ar	670	8000	1.4	550	[l]
NF_3(25%)/He	560	7400	1.4	550	[l]
NF_3(25%)/O_2	520	5200	1.4	550	[l]
NF_3(25%)/N_2O	280	3600	1.4	550	[l]
NF_3(100%)	90	1000	1.4	550	[l]

Etchant	Etch rate_SiC (nm/min)	Bias (W)	Power (W)	Pressure (mtorr)	Ref
NF_3	437	150	900	12	[m]
NF_3/O_2	350	250	750	2	[n]
NF_3(60%)/CH_4(40%)	111	150	800	6	[m]

• **Not much is found on NF_3 for silicon etching but it has been used for etching other silicon containing materials**

Silicon Etching by Fluorine



	Reactions	G(eV)	log(K)
1	$Si(c) \rightarrow Si(g)$	4.2	-70.5
1'	$1/2F_2(g) + Si(c) \rightarrow SiF(g)$	-0.54	9.0
2	$F(g) + Si(c) \rightarrow SiF(g)$	-1.18	19.8
3	$F(g) + SiF(g) \rightarrow SiF_2(g)$	-6.31	105.9
4	$F(g) + SiF_2(g) \rightarrow SiF_3(g)$	-5.57	93.4
5	$F(g) + SiF_3(g) \rightarrow SiF_4(g)$	-5.82	97.7

- **Fluorine is the most effective etching chemistry for silicon, especially atomic fluorine, as produced by plasma**

Production of Fluorine from SF_6 and NF_3

	Reactions	G(eV)	Log(K)
S1	$SF_6(g) \rightarrow SF_5(g) + F(g)$	3.52	-59.1
S2	$SF_5(g) \rightarrow SF_4(g) + F(g)$	1.85	-31.0
S3	$SF_4(g) \rightarrow SF_3(g) + F(g)$	3.07	-51.5
S4	$SF_3(g) \rightarrow SF_2(g) + F(g)$	2.56	-42.9
S5	$SF_2(g) \rightarrow SF(g) + F(g)$	3.64	-61.1
S6	$SF(g) \rightarrow S(g) + F(g)$	3.25	-54.6

	Reactions	G(eV)	Log(K)
N1	$NF_3(g) \rightarrow NF_2(g) + F(g)$	2.17	-36.4
N2	$NF_2(g) \rightarrow NF(g) + F(g)$	2.58	-43.3
N3	$NF(g) \rightarrow N(g) + F(g)$	2.84	-47.7

[CRC handbook, 2010]

[CRC handbook, 2010*; Y. Tanaka, IEEE, 1997]

- **Under equilibrium conditions, the production of atomic F from SF_6 and NF_3 are comparable**

Production of Fluorine from SF_6 and NF_3

	Reactions	G(eV)	Log(K)
S1	$SF_6(g) \rightarrow SF_5(g) + F(g)$	3.52	-59.1
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[CRC handbook, 2010]

[CRC handbook, 2010*; Y. Tanaka, IEEE, 1997]

	Reactions	G(eV)
S1	$SF_6(g) + e \rightarrow SF_5(g) + F(g) + e$	4.00
S2	$SF_5(g) + e \rightarrow SF_4(g) + F(g) + e$	2.27
S3	$SF_4(g) + e \rightarrow SF_3(g) + F(g) + e$	3.47
S4	$SF_3(g) + e \rightarrow SF_2(g) + F(g) + e$	2.92
S5	$SF_2(g) + e \rightarrow SF(g) + F(g) + e$	4.01
S6	$SF(g) + e \rightarrow S(g) + F(g) + e$	3.52

- **For SF_6, electron impact dissociate energy is comparable and slightly higher than that from thermal equilibrium data (~0.4eV)**

Production of Fluorine from SF_6 and NF_3

	Reactions	G(eV)	Log(K)
S1	$SF_6(g) \rightarrow SF_5(g) + F(g)$	3.52	-59.1
S2	$SF_5(g) \rightarrow SF_4(g) + F(g)$	1.85	-31.0
S3	$SF_4(g) \rightarrow SF_3(g) + F(g)$	3.07	-51.5
S4	$SF_3(g) \rightarrow SF_2(g) + F(g)$	2.56	-42.9
S5	$SF_2(g) \rightarrow SF(g) + F(g)$	3.64	-61.1
S6	$SF(g) \rightarrow S(g) + F(g)$	3.25	-54.6

	Reactions	G(eV)	Log(K)
N1	$NF_3(g) \rightarrow NF_2(g) + F(g)$	2.17	-36.4
N2	$NF_2(g) \rightarrow NF(g) + F(g)$	2.58	-43.3
N3	$NF(g) \rightarrow N(g) + F(g)$	2.84	-47.7

[CRC handbook, 2010]

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S1	$SF_6(g) + e \rightarrow SF_5(g) + F(g) + e$	4.00
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S3	$SF_4(g) + e \rightarrow SF_3(g) + F(g) + e$	3.47
S4	$SF_3(g) + e \rightarrow SF_2(g) + F(g) + e$	2.92
S5	$SF_2(g) + e \rightarrow SF(g) + F(g) + e$	4.01
S6	$SF(g) + e \rightarrow S(g) + F(g) + e$	3.52

- **For SF_6, electron impact dissociate energy is comparable and slightly higher than that from thermal equilibrium data (~0.4eV)**

- **It is possible that the available equilibrium data on NF_3 can be used as a guide to the production of fluorine in a plasma**

Can SF_6 be Replaced by NF_3?

SF_6 | NF_3

Formation of non-volatile byproduct	G(eV)
$4Si(c) + 2SF_6(g) \rightarrow 3SiF_4(g) + S_2Si(c)$	-28.0

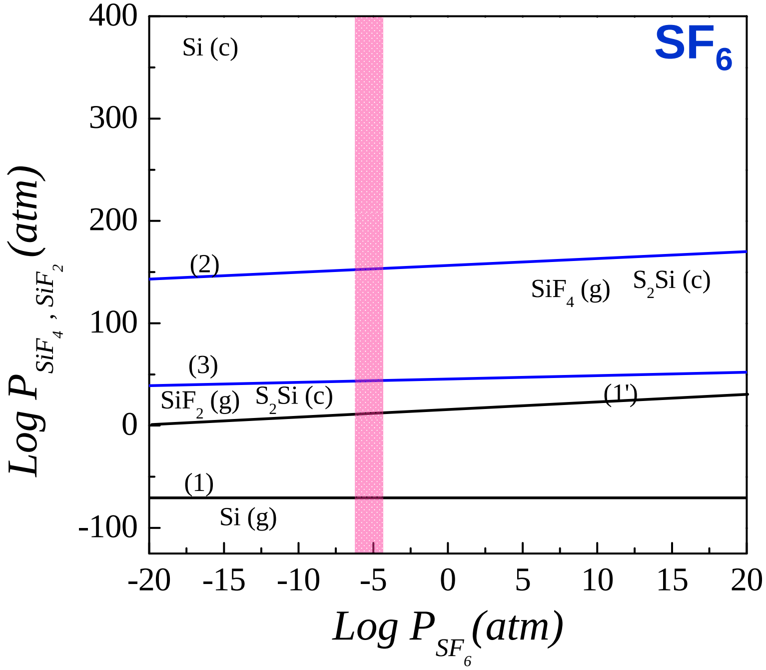
Formation $Si_3N_4(c)$	G(eV)
$6Si(c) + 4NF_3(g) \rightarrow 3SiF_4(g) + Si_3N_4(c)$	-51.8

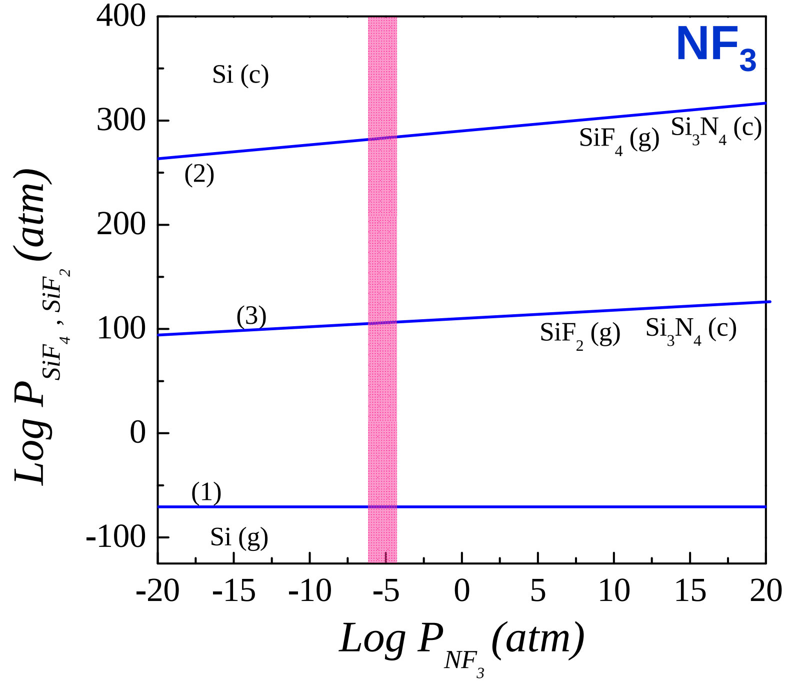
Removal of non-volatile byproduct	G(eV)
$S_2Si(c) + 16F(g) \rightarrow SiF_4(g) + 2SF_6(g)$	-47.5

Removal of non-volatile byproduct	G(eV)
$Si_3N_4(c) + 24F(g) \rightarrow 3SiF_4(g) + 4NF_3(g)$	-61.4

- **From the thermodynamics analysis, NF_3 is more capable of removing silicon via the formation of SiF_4**
- **However, another significant reaction product from reaction with NF_3 is Si_3N_4, which has to be removed and competes for fluorine**

Comparison of SiS_2 and Si_3N_4





	Reactions	G(eV)	log(K)
1	$Si(c) \rightarrow Si(g)$	4.2	-70.5
1'	$1/2F_2(g) + Si(c) \rightarrow SiF(g)$	-0.54	9.0
2	$2SF_6(g) + 4Si(c) \rightarrow S_2Si(c) + 3SiF_4(g)$	-28.0	469.8
3	$2SF_6(g) + 7Si(c) \rightarrow S_2Si(c) + 6SiF_2(g)$	-16.3	273.5

	Reactions	G(eV)	log(K)
1	$Si(c) \rightarrow Si(g)$	4.2	-70.5
1'	$1/2F_2(g) + Si(c) \rightarrow SiF(g)$	-0.54	9.0
2	$4NF_3(g) + 6Si(c) \rightarrow N_4Si_3(c) + 3SiF_4(g)$	-51.8	870.2
3	$4NF_3(g) + 9Si(c) \rightarrow N_4Si_3(c) + 6SiF_2(g)$	-40.1	673.97

	BP(°C)	H(kJ/mol)	S(J/mol/K)	G(kJ/mol)
$S_2Si(c)$	1090	-213.36	80.812	-212.61

	BP(°C)	H(kJ/mol)	S(J/mol/K)	G(kJ/mol)
$Si_3N_4(c)$	1900	-744.8	113.5	-646.7

A Strategy to Remove Si_3N_4

NF_3 - O_2

Formation $Si_3N_4(c)$	G(eV)
$6Si(c) + 4NF_3(g) \rightarrow 3SiF_4(g) + Si_3N_4(c)$	-51.8

Removal $Si_3N_4(c)$ by NF_3	G(eV)
$Si_3N_4(c) + 24F(g) \rightarrow 3SiF_4(g) + 4NF_3(g)$	-61.4

SF_6

Formation of non-volatile byproduct	G(eV)
$Si(c) + SF_6(g) \rightarrow SiF_4(g) + S_2Si(c)$	-28.0

Removal of non-volatile byproduct	G(eV)
$S_2Si(c) + 16F(g) \rightarrow SiF_4(g) + 2SF_6(g)$	-47.5

Removal of $Si_3N_4(c)$ & $SiO_2(c)$ by NF_3 & O_2		G(eV)
Removal of $Si_3N_4(c)$	$Si_3N_4(c) + 7O_2(g) \rightarrow 3SiO_2(c) + 4NO_2(g)$	-17.8
Removal of $SiO_2(c)$	$SiO_2(c) + 5/2NF_3(g) \rightarrow SiF_4(g) + 1/2NO_2F(g) + NOF_3(g) + N_2(g)$	-6.5
Total reaction	$Si_3N_4(c) + 7O_2(g) + 15/2NF_3 \rightarrow 3SiF_4(g) + 4NO_2(g) + 3/2NO_2F(g) + 6NOF_3(g) + 6N_2(g)$	-37.1

- **From the analysis of ΔG, the non-volatile byproducts, Si_3N_4 could be removed by NF_3 - O_2 plasmas**

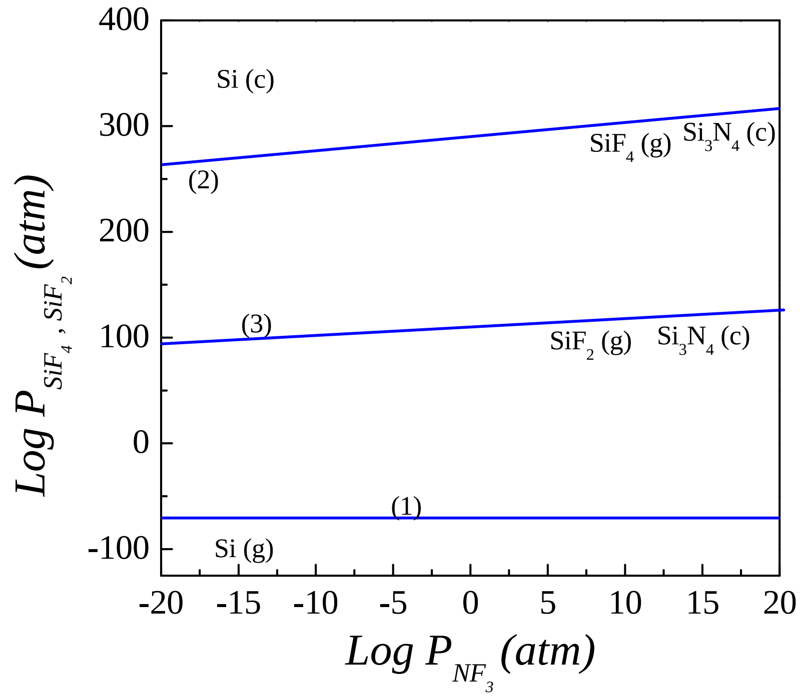
Silicon Etching by NF_3 - O_2

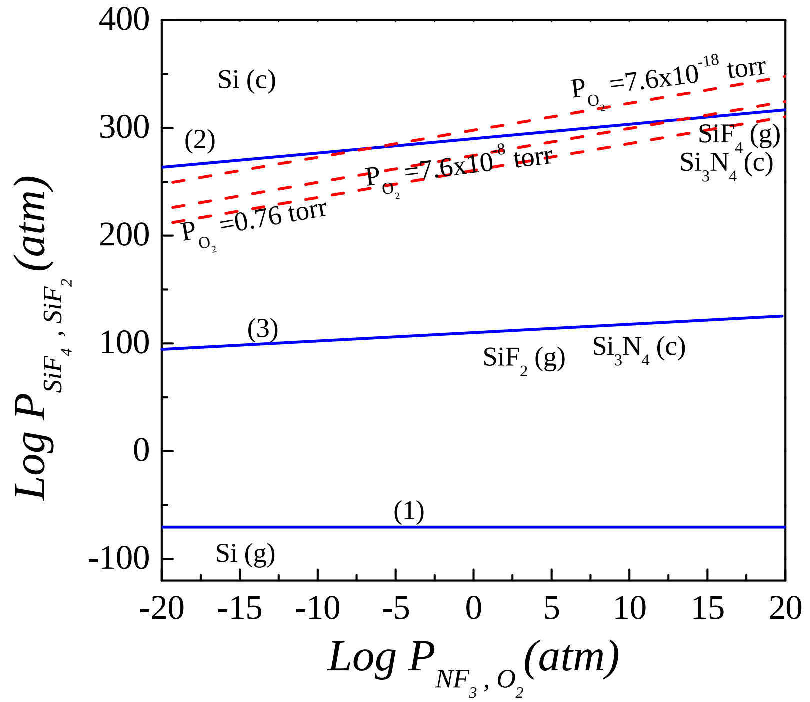
$NF_{3(g)}$

	Reactions	G(eV)	log(K)
1	$Si(c) \rightarrow Si(g)$	4.2	-70.5
2	$4NF_3(g) + 6Si(c) \rightarrow Si_3N_4(c) + 3SiF_4(g)$	-51.8	870.2
3	$4NF_3(g) + 9Si(c) \rightarrow Si_3N_4(c) + 6SiF_2(g)$	-40.1	673.97

$O_{2(g)}$

P_{O2}(torr)	Reaction 4	G(eV)	log(K)
0.76	$Si_3N_4(c) + 7O_2(g) + 15/2NF_3 \rightarrow 3SiF_4(g) + 4NO_2(g) + 3/2NO_2F(g) + 6NOF_3(g) + 6N_2(g)$	-37.1	623.4
7.6×10^{-8}			
7.6×10^{-18}			





Future Plans

Next Year Plans

- Identify potential low impact gases in target applications
- Perform thermodynamic calculations to assess potential impact and projected effectiveness
- Implement target chemistries and carry out plasma etching assessment

Long-Term Plans

- Formulate the models to predict emission from plasma processes
- Assess the effectiveness of the plasma chemistries compared to that of the PFC gases

Publications, Presentations, and Recognitions/Awards

- **Invited talk to AVS International Symposium, October 2012**
- **Presentation at the Plasma Processing Science Gordon Research Conference (GRC), July 2012**

Industrial Interactions and Technology Transfer

- **Video conference to Intel, January 31, 2012 (Karson Knutson, Doosik Kim)**
- **Conference call with Novellus, March 2012 (Ron Powell, Roey Shaviv, Juwen Gao)**
- **Student interview at IBM, February 29, 2012**
- **Student interview with Intel, March 2012**
- **Student will present at the Gordon Research Conference, July, 2012**

→ ***After studying the TSV by detailed thermodynamic analysis, the next step is to carry out kinetic measurements.***

→ ***Complex oxides? Magnetic materials? Noble metals?***

Reference

- c. Jansen, H., et al., The Black Silicon Method - a Universal Method for Determining the Parameter Setting of a Fluorine-Based Reactive Ion Etcher in Deep Silicon Trench Etching with Profile Control. Journal of Micromechanics and Microengineering, 1995. 5(2): p. 115-120.
- d. Mansano, R.D., P. Verdonck, and H.S. Maciel, Deep trench etching in silicon with fluorine containing plasmas. Applied Surface Science, 1996. 100: p. 583-586.
- e. Yeom, G.Y., Y. Ono, and T. Yamaguchi, Polysilicon Etchback Plasma Process Using Hbr, Cl2, and Sf6 Gas-Mixtures for Deep-Trench Isolation. Journal of the Electrochemical Society, 1992. 139(2): p. 575-579.
- f. Matsuo, P.J., et al., Role of N-2 addition on CF4/O-2 remote plasma chemical dry etching of polycrystalline silicon. Journal of Vacuum Science & Technology a-Vacuum Surfaces and Films, 1997. 15(4): p. 1801-1813.
- g. Syau, T., B.J. Baliga, and R.W. Hamaker, Reactive Ion Etching of Silicon Trenches Using Sf6/O-2 Gas-Mixtures. Journal of the Electrochemical Society, 1991. 138(10): p. 3076-3081.
- h. Demic, C.P., K.K. Chan, and J. Blum, Deep Trench Plasma-Etching of Single-Crystal Silicon Using Sf6/O2 Gas-Mixtures. Journal of Vacuum Science & Technology B, 1992. 10(3): p. 1105-1110.
- i. Yunkin, V.A., D. Fischer, and E. Voges, Highly Anisotropic Selective Reactive Ion Etching of Deep Trenches in Silicon. Microelectronic Engineering, 1994. 23(1-4): p. 373-376.
- j. Legtenberg, R., et al., Anisotropic Reactive Ion Etching of Silicon Using Sf6/O-2/Chf3 Gas Mixtures. Journal of the Electrochemical Society, 1995. 142(6): p. 2020-2028.
- k. Moss, S.J. and A. Ledwith, The chemistry of the semiconductor industry. 1987, Glasgow: Blackie. xiv, 426 p.
- l. Langan *et al.*, Method for plasma etching or cleaning with diluted NF.sub.3, US Patent 5413670, 1995.
- m. Wang, J.J., et al., High rate etching of SiC and SiCN in NF3 inductively coupled plasmas. Solid-State Electronics, 1998. 42(5): p. 743-747.
- n. Kim, B., et al., Use of a neural network to model SiC etching in a NF3 inductively coupled plasma. Modelling and Simulation in Materials Science and Engineering, 2005. 13(8): p. 1267-1277.