Lecture 16:

LPCVD

(Low Pressure Chemical Vapor Deposition)

Dong-Il “Dan” Cho

School of Electrical Engineering and Computer Science,
Seoul National University
Nano/Micro Systems & Controls Laboratory

Chemical Vapor Deposition

- Polysilicon
  - $SiH_4 \rightarrow Si + 2H_2$ (SiH_4 silane)
- Silicon dioxide
  - $SiH_4 + O_2 \rightarrow SiO_2 + 2H_2$
  - $SiCl_2H_2 + 2N_2O \rightarrow SiO_2 + 2N_2 + 2HCl$ ($SiCl_2H_2$ dichlorosilane DCS)
  - $Si(OC_2H_5)_4 \rightarrow SiO_2$ + byproducts ($Si(OC_2H_5)_4$ tetraethoxysilane TEOS)
- Silicon nitride
  - $3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12H_2$
  - $3SiCl_2H_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2$
- Metals
  - $WF_6 \rightarrow W + 3F_2$
  - $WF_6 + 3H_2 \rightarrow W + 6HF$

Low Pressure Chemical Vapor Deposition

- Low Pressure Chemical Vapor Deposition (LPCVD)
  - CVD processes at subatmospheric pressure (***below 10 Pa***)
  - Large numbers of wafers to be deposited ***simultaneously*** and ***uniformly***
  - Most modern CVD process are either ***LPCVD*** or ***UHCVD***.

Brief Review of CVD Process

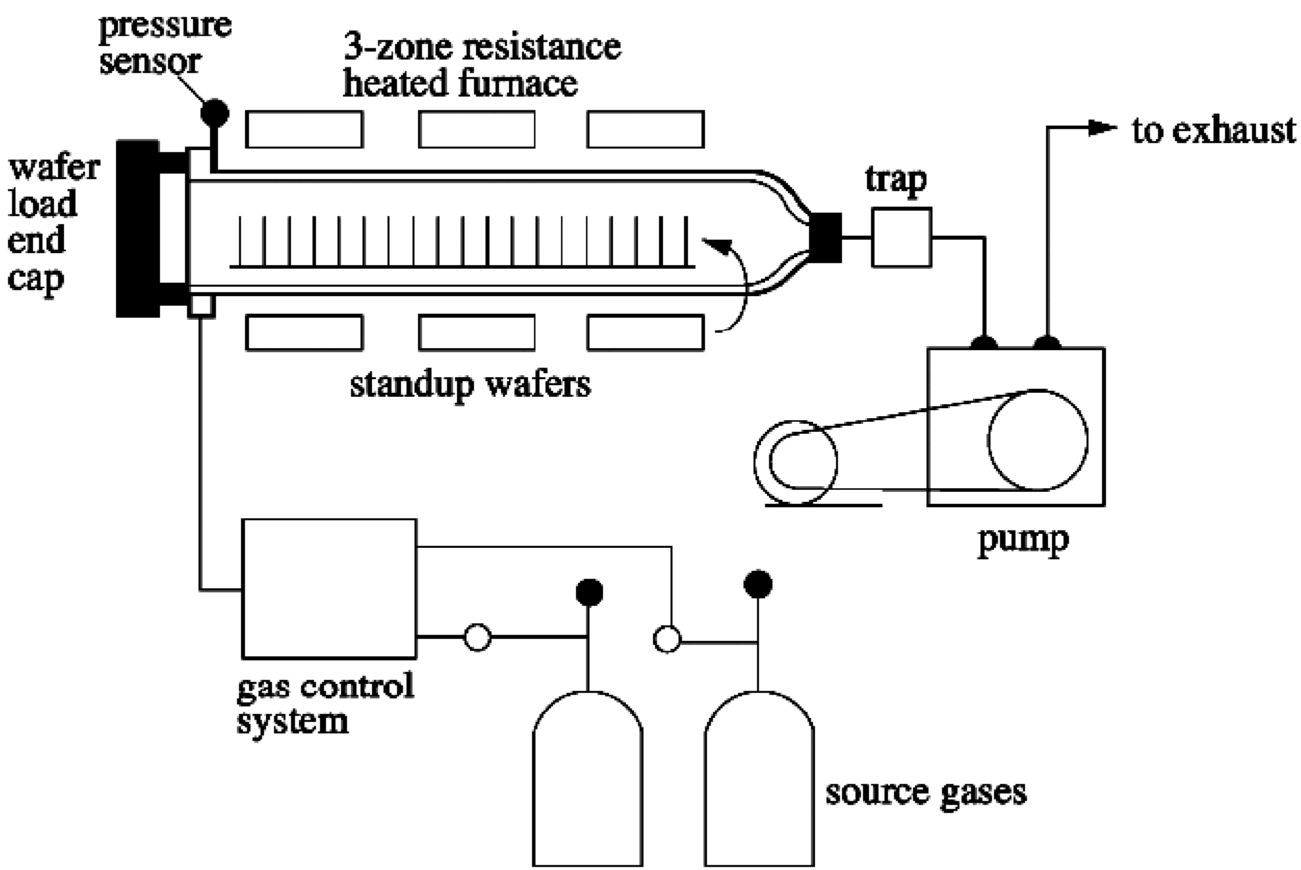
- Brief review of CVD process

Process	Advantages	Disadvantages	Applications	Remarks	Pressure / Temp.
APCVD	Simple, high dep. Rate, low temp.	Poor step coverage, particle contamination	Doped & undoped low-temp. oxides	Mass-transport controlled	100-10 kPa (≈ 0.1 ~ 1 atm) / 350-400 °C
LPCVD	Excellent purity & uniformity, conformable step coverage, large wafer capacity	High temp. & low dep. Rate	Doped & undoped high temp. oxides, silicon nitride, polysilicon, W, WSi_2	Surface-reaction controlled	100 Pa (≈ 10^{-3} atm) / 550-600 °C
PECVD	Lower substrate temp.; fast, good adhesion; good step coverage; low pinhole density	Chemical (e.g., hydrogen) & particulate contamination	Low-temp. insulators over metals, passivation (nitride)		2-5 Torr (≈ 2.6×10^{-3} ~ 6.6×10^{-3} atm) / 300-400 °C

Refer the Appendix (the last page) for the pressure units.

Schematic of Low Pressure CVD

- Schematic of Low Pressure CVD

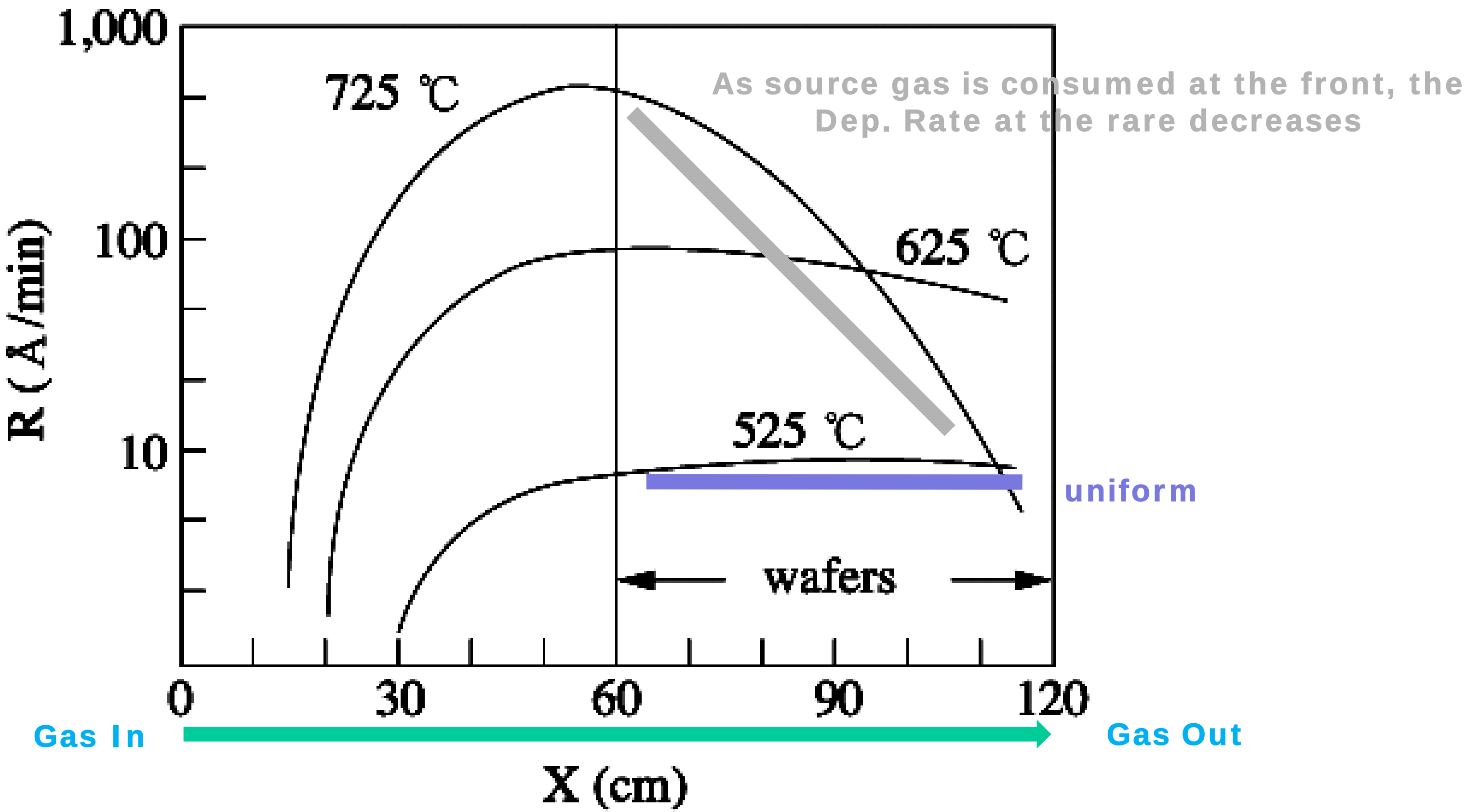


Low Pressure CVD System Feature

- Low Pressure CVD system feature
  - Dep. rate is dominated by temperature.
  - Few torr pressure decrease increases diffusion 1000 times
    - ⇒ Uniformity dramatically increases.
  - Deposited on the reactor wall
    - ⇒ Periodically the cleaning of the reactor wall is needed.
  - Good uniformity on the single wafer, Low uniformity among wafers
    - ⇒ The process condition establishment is needed for the uniformity among wafers.

Low Pressure CVD (1)

- Poly Si Dep. rate vs. Distance from gas inlet
  - As Temp. increases, Dep. rate also increases.

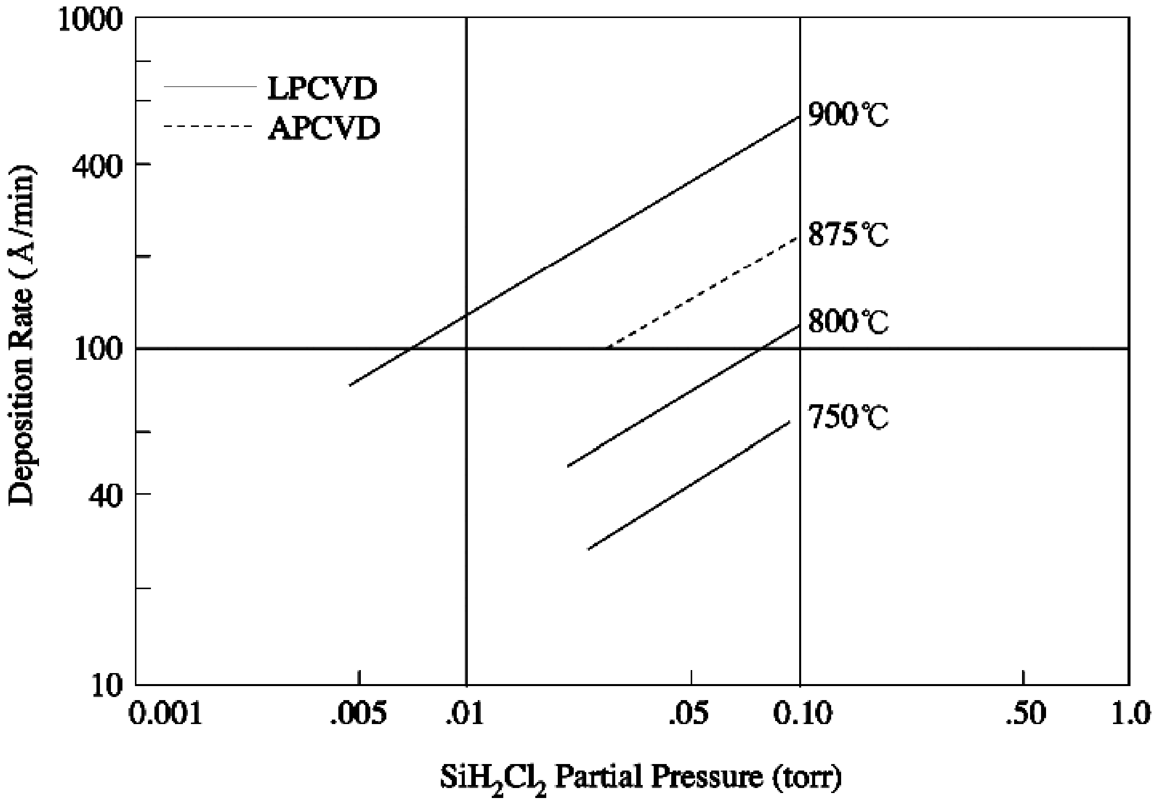


Low Pressure CVD (2)

- CVD Dep. rate key parameter
  - $R = A \exp(-E_a / kT) P_a P_b P_c \ldots P_n$
    - R: Dep. rate
    - A: Constant
    - E_a: Activated energy
    - $P_a, P_b, P_c, \ldots P_n$: Partial pressure

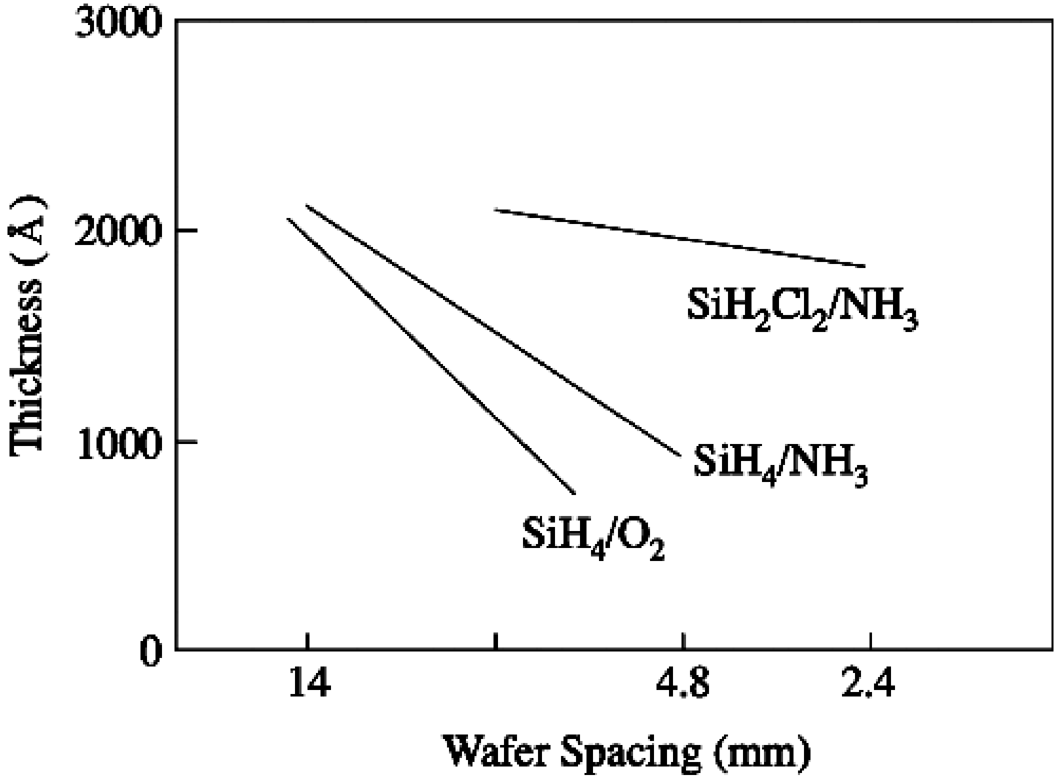
Low Pressure CVD (3)

- Si_3N_4 Dep. rate vs. Partial pressure of $SiCl_2H_2$
  - As partial pressure increases, dep. rate also increases.



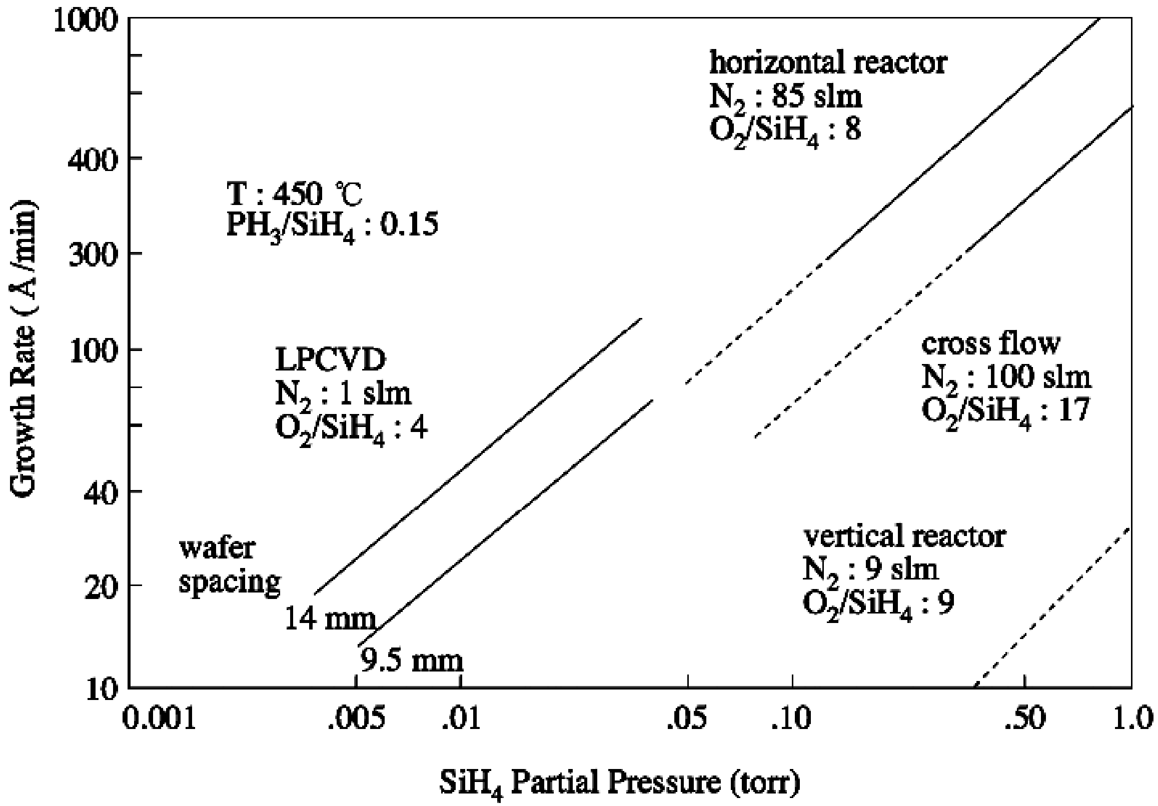
Low Pressure CVD (4)

- Poly Si Dep. thickness in the center of wafer vs. Wafer spacing
  - Quartz boats structure can influence uniformity.



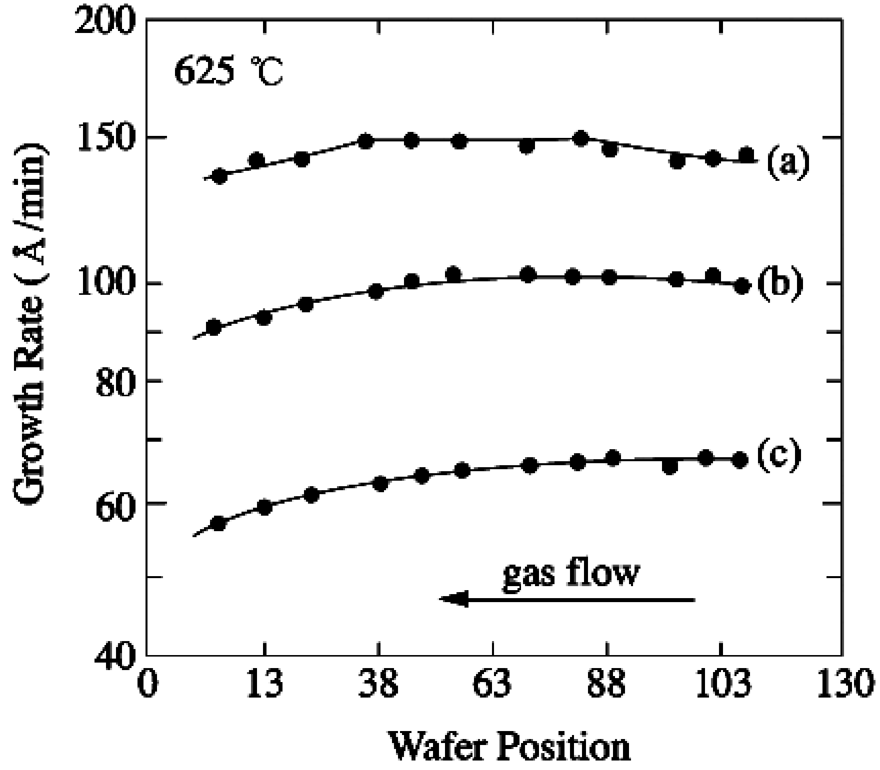
Low Pressure CVD (5)

- Doped SiO_2 Dep. rate vs. Partial pressure of SiH_4



Low Pressure CVD (6)

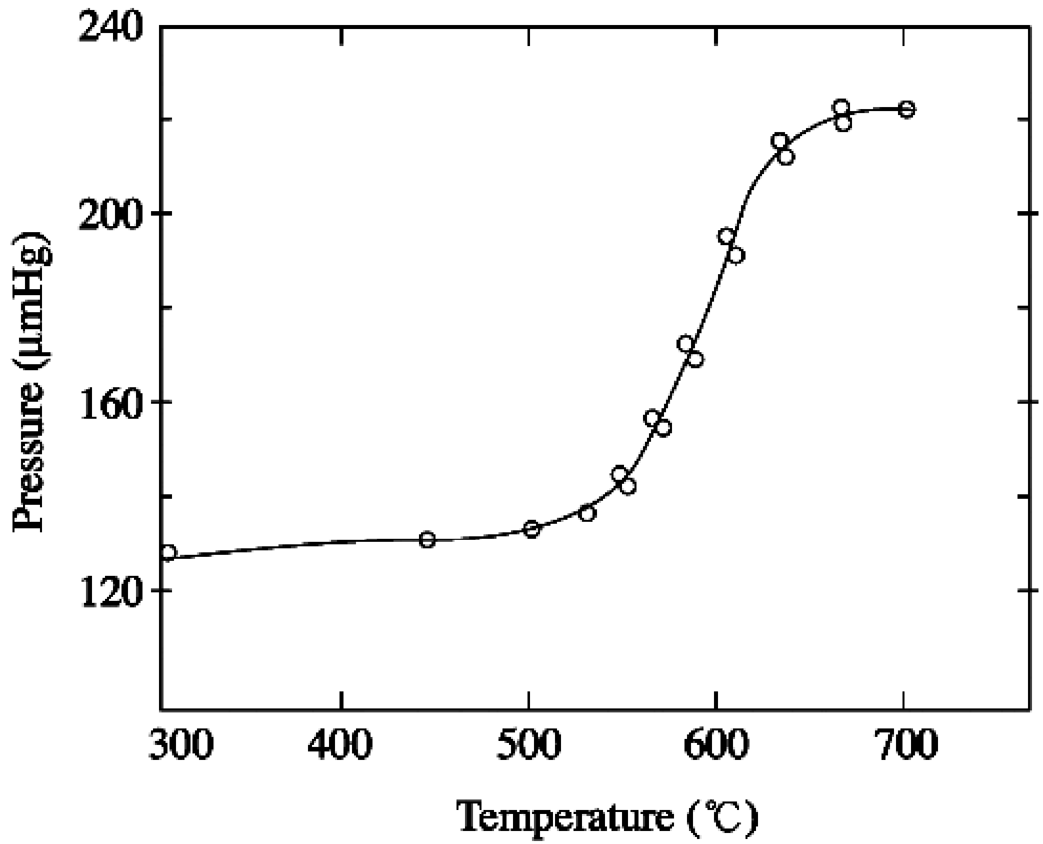
- Poly Si Dep. rate vs. Wafer position
  - As a wafer is nearer to the gas inlet, the Dep. Rate is faster.



(a) 100 cc/min, 344 ㎛Hg (b) 56 cc/min, 226 ㎛Hg (c) 29 cc/min, 138 ㎛Hg

Low Pressure CVD (7)

- Partial pressure vs. Temperature at SiH_4 53 cc/min

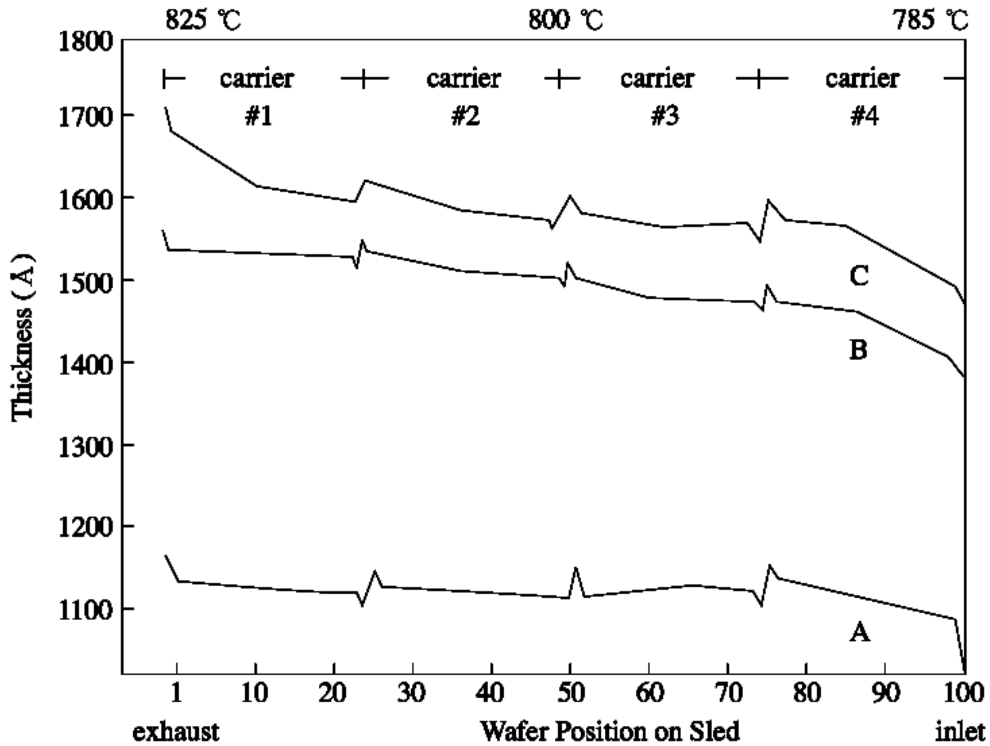


Low Pressure CVD (8)

- SiN_x
  - Uniformity among wafers
    - 100 wafers = 25 wafers / boat x 4 boats
    - Boat pitch: 5 cm
    - Measurement wafer: 20 wafers

Low Pressure CVD (9)

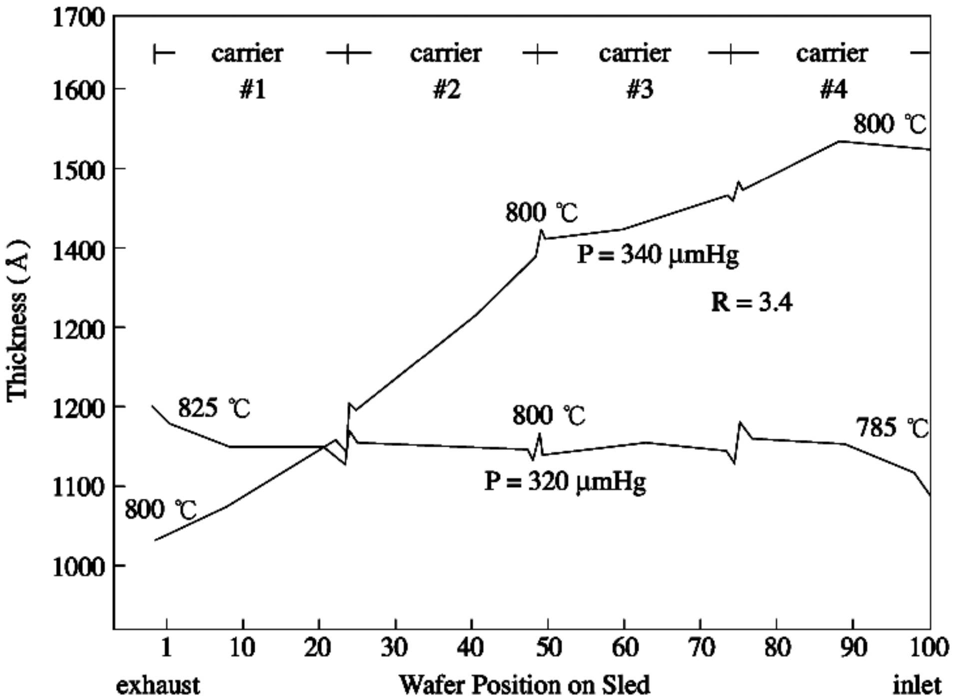
- Si_3N_4 dep. thickness vs. R (= SiH_2Cl_2 / NH_3)
  - As R increases, Si_3N_4 dep. thickness increases.



At 320 μmHg, R = SiH_2Cl_2 / NH_3 (a) R = 3.4, (b) R = 2.4, (c) R = 1.4

Low Pressure CVD (10)

- Si_3N_4 dep. thickness vs. wafer position with Temp. variation
  - For the good uniformity among wafers, Temp. variation needed inside the tube.



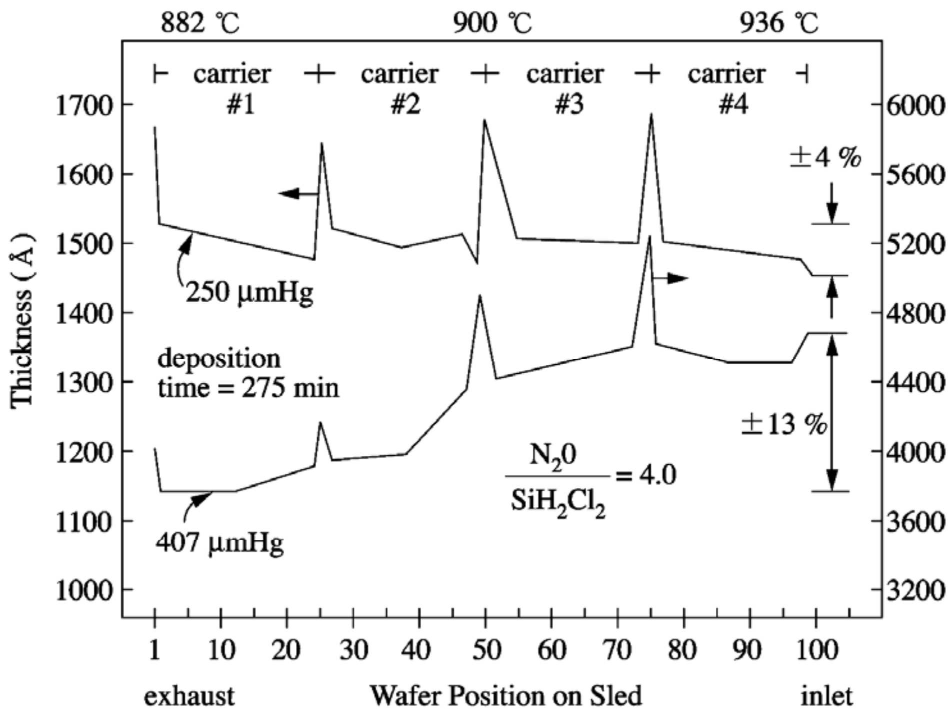
Low Pressure CVD (11)

- Film property

	Si_3N_4	CVD SiO_2		Thermal SiO_2
		Low temp.	High temp.	
Reflection Index	1.98	1.46	1.46	1.46
Relative Dielectric Constant	7.0	4.25	3.7	3.8
Density (g/cm^3)	2.8	2.1	2.25	2.25

Low Pressure CVD (12)

- Silicon Oxide Dep. thickness vs. Pressure
  - Gas: SiH_4, SiH_2Cl_2, CO_2, N_2O
  - As pressure decreases, Dep. thickness increases.



MEMS LPCVD in ISRC (1)

- MEMS LPCVD is in no service.
  - Out of sustain period

- New system is under installation.
  - Official installation schedule: Sep. ~ Nov. 2007
  - Still under installation
  - Technician: Ji-su Kim, 880-5454 (316), arf1224@snu.ac.kr
  - TA: Dae-il Kim, 880-5449, adward97@snu.ac.kr

MEMS LPCVD in ISRC (2)

- New system specification
  - Equip. model: E 1200 R&D Furnace
  - Equip. company: centrotherm, Germany
    http://www.centrotherm-ts.de
  - Wafer size: 4 ~ 6 inch
  - Deposition film
    - Low stress nitride (~ 1 ㎛)
    - Nitride
    - Poly-Si (~ 3 ㎛)
    - Amorphous-Si

MEMS LPCVD in ISRC (3)

- New system specification (cont'd)
  - Pump: EDWARDS IH600 (Dry)
  - Consumption power: 460 W, 150 A, 60 Hz
  - Max. Temp.: 900 °C
  - Controller system: CCC-RM (centrotherm, Germany)
  - Gas: DCS, NH_3, SiH_4
  - MFC
    - Poly Si
      - SiH_4 Max. 300 sccm
    - Nitride
      - DCS Front Max.: 200 sccm
      - DCS Rear Max.: 200 sccm
      - NH_3 Front Max.: 550 sccm
      - NH_3 Rear Max.:550 sccm

MEMS LPCVD in ISRC (4)

- Test run
  - Poly Si (1000 Å)
    - Process condition

Process Name	Poly Si		
Dep. Temp.	622 °C / 624 °C / 625 °C (Load / Center / Gate)	Dep. time	14 min.
Wafer	6 inch, 3 EA		
Gas	SiH_4 60 sccm		
Tube pressure	270 mTorr		

- Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)
L	1048	1013	1036	1041	1024	1.698
C	1050	1032	1037	1049	1032	0.865
G	1028	1014	1027	1033	1023	0.928

MEMS LPCVD in ISRC (5)

- Test run
  - Poly Si (30000 Å)
    - Process condition

Process Name	Poly Si		
Dep. Temp.	622 °C / 624 °C / 625 °C (Load / Center / Gate)	Dep. time	406 min.
Wafer	6 inch, 3 EA		
Gas	SiH_4 60 sccm		
Tube pressure	270 mTorr		

    - Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)
L	30031	30040	30051	30878	30855	1.39
C	30867	31749	30054	30120	30117	2.7
G	30058	30834	30066	30077	30060	1.27

MEMS LPCVD in ISRC (6)

- Test run
  - Amorphous Si (1000 Å)
    - Process condition

Process Name	Amorphous Si		
Dep. Temp.	549.5 °C / 555 °C / 555 °C (Load / Center / Gate)	Dep. time	54 min.
Wafer	6 inch, 3 EA		
Gas	SiH_4 60 sccm		
Tube pressure	250 mTorr		

- Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)
L	1034	1015	1025	1018	1027	0.927
C	1024	1007	1021	1017	1018	0.837
G	1023	1020	1022	1025	1032	0.585

MEMS LPCVD in ISRC (7)

- Test run
  - Amorphous Si (3000 Å)
    - Process condition

Process Name	Amorphous Si		
Dep. Temp.	549.5 °C / 555 °C / 555 °C (Load / Center / Gate)	Dep. time	162 min.
Wafer	6 inch, 3 EA		
Gas	SiH_4 60 sccm		
Tube pressure	150 mTorr		

    - Process result

Zone \ Point	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)
L	3145	3086	3121	3112	3121	0.947
C	3109	3071	3092	3072	3044	1.056
G	3118	3079	3100	3105	3105	0.629

MEMS LPCVD in ISRC (8)

- Test run
  - Low stress Nitride (1000 Å)
    - Process condition

Process Name	Low stress Nitride		
Dep. Temp.	825 °C / 828 °C / 825 °C (Load / Center / Gate)	Dep. time	30 min.
Wafer	4 inch, 3 EA		
Gas	DCS-L 21 sccm, DCS-R 30 sccm, NH_3-L 3.5 sccm, NH_3-L 5 sccm		
Tube pressure	150 mTorr		

    - Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)	Stress (Mpa)
L	1014	987	1028	1025	1033	2.7	40
C	981	981	996	994	989	0.759	70
G	1005	987	1015	1018	1003	1.5	72

MEMS LPCVD in ISRC (9)

- Test run
  - Low stress Nitride (10000 Å)
    - Process condition

Process Name	Low stress Nitride		
Dep. Temp.	825 °C / 828 °C / 825 °C (Load / Center / Gate)	Dep. time	322 min.
Wafer	4 inch, 3 EA		
Gas	DCS-L 21 sccm, DCS-R 30 sccm, NH_3-L 3.5 sccm, NH_3-L 5 sccm		
Tube pressure	150 mTorr		

- Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)	Stress (Mpa)
L	10551	10457	10890	10796	10744	2	46
C	10619	10366	10650	10632	10639	1.3	32
G	10690	10515	10872	10845	10734	1.6	47

MEMS LPCVD in ISRC (10)

- Test run
  - Nitride (1000 Å)
    - Process condition

Process Name	Low stress Nitride		
Dep. Temp.	770 °C / 773 °C / 770 °C (Load / Center / Gate)	Dep. time	48 min.
Wafer	6 inch, 3 EA		
Gas	DCS-L 6.6 sccm, DCS-R 7 sccm, NH_3-L 39.6 sccm, NH_3-L 42 sccm		
Tube pressure	150 mTorr		

- Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)
L	1000	968	996	996	991	1.6
C	995	998	997	991	990	0.4
G	1000	979	983	983	1005	2.2

MEMS LPCVD in ISRC (11)

- Test run
  - Nitride (3000 Å)
    - Process condition

Process Name	Low stress Nitride		
Dep. Temp.	770 °C / 773 °C / 770 °C (Load / Center / Gate)	Dep. time	153 min.
Wafer	6 inch, 3 EA		
Gas	DCS-L 6.6 sccm, DCS-R 7 sccm, NH_3-L 39.6 sccm, NH_3-L 42 sccm		
Tube pressure	150 mTorr		

- Process result

Point / Zone	Top (Å)	Center (Å)	Bottom (Å)	Right (Å)	Left (Å)	Uniform. (%)
L	2974	3069	3061	3043	3060	1.5
C	3032	3074	3033	3043	3049	0.6
G	2994	3124	3012	3066	3012	2.1

Reference

- J.M. Bustillo, R. T. Howe, and R. S. Muller, "Surface micromachining for microelectromechanical systems ," Proceedings of the IEEE, Vol. 86, No. 8, pp. 1552-1574, 1998
- Marc J. Madou, "Fundamentals of MICROFABICATION," 2nd edition
- S. Lee, C. Cho, J. Kim, S. Park, S. Yi, J. Kim, and D. Cho, "The Effects of Post-deposition Processes on Polysilicon Young's Modulus," IOP J. of Micromechanics and Microengineering, Vol. 8, No. 4, pp. 330-337, 1998
- S. Lee, C. Cho, J. Kim, S. Park, S. Yi, J. Kim, and D. Cho, "Mechanical Properties of Phosphorus-doped Polysilicon Films", Journal of the Korean Physical Society, Vol. 33, pp. 392-395, 1998
- S. Lee, and D. Cho. "The Effects of Texture on the Young's Modulus of Polysilicon", 1998 MRS Spring Meeting, 1998.
- K. Lee, and Y Kim, "Uniformity Improvement of Micromirror Array for Reliable Working Performance as an Optical Modulator in the Maskless Photolithography System," Journal of Semiconductor Technology and Science, Vol. 1, No. 2, 2001

Reference

- G. Li, and A. A. Tseng, “Low stress packaging of a micromachined accelerometer,” Electronics Packaging Manufacturing, IEEE Transactions on, Vol. 24, No. 1, pp. 18-25, 2001
- P. Melvas, E. Kalvesten, and G. Stemme, “A surface-micromachined resonant-beam pressure-sensing structure,” Microelectromechanical Systems, Journal of , Vol. 10, No. 4, pp. 498-502, 2001
- K. Meng-Hsiung, O. Solgaard, R. S. Muller, and K. Lau, ”Silicon-micromachined micromirrors with integrated high-precision actuators for external-cavity semiconductor lasers,” Photonics Technology Letters, IEEE, Vol. 8, No. 1, pp. 95-97, 1996
- P. J. French and P. M. Sarro, “Surface versus bulk micromachining:the contest for suitable applications”, IOP J. of Micromechanics and Microengineering, Vol. 8, pp. 45-53, 1998
- Gregory T. A. Kovacs, “Micromachined Trensducers Sourcebook,” 1st edition
- J. D. Lee, “Silicon Integrated Circuit microfabrication technology,” 2nd edition

Reference

- http://chiuserv.ac.nctu.edu.tw/~htchiu/cvd/home.html
- http://www.plasmas.org
- Brian Chapman, "Glow Discharge Processes: Sputtering and Plasma Etching", John Wiley & Sons, 1980.
- Lieberman, "Principles of plasma discharges and materials processing‟, John Wiley & Sons, 1994
- Tai-Ran Hsu, “MEMS & Microsystems Design and Maufacture”, McGraw-Hill, 2002
- Alfred Grill, “Cold Plasma in Materials Fabrication: From Fundamentals to Applications”, John Wiley & Sons, 1994

Appendix

- Pressure unit

Pressure Units

	pascal (Pa)	bar (bar)	technical atmosphere (at)	atmosphere (atm)	torr (Torr)	pound-force per square inch (psi)
1 Pa	≡ 1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	≡ 10^6 dyn/cm^2	1.0197	0.98692	750.06	14.504
1 at	98,066.5	0.980665	≡ 1 kgf/cm^2	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	≡ 1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	≡ 1 Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6,894.76	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	≡ 1 lbf/in^2

* 1 dyn = 10 micronewtons
1 kgf = 9.80665 N
1 lb = 1 pound
1 lbf = 4.4482216152605 N