EE669: VLSI Technology

Chemical Vapor Deposition and Atomic Layer Deposition

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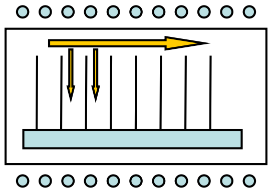
1

CVD Kinetics: Example (3)

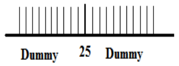


$$\boxed{t'_{film} = \frac{1}{\frac{1}{k_S}+\frac{1}{h_G}}\frac{C_G}{N}}$$

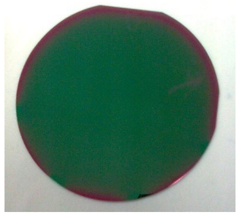
- Diffusion through the gap between closely stacked wafers
  - can be increased by reducing the pressure: LPCVD
- Depletion of reactants as the flow moves from the edges of the wafer to the centre ➔ within the wafer non uniformity
  - can be avoided by increasing the spacing between the wafers
  - can be avoided by retarding the reaction ➔ reduce temperature

2

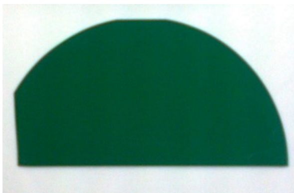
LPCVD: Undoped poly-Si



Process Parameters
- Temperature: 630°C
- SiH_4 flow: 80 sccm
- Gas Pressure: 0.3 Torr
- Deposition time: 20 mins.



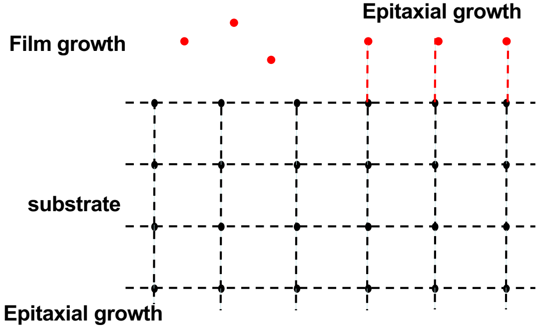
Process Parameters
- Temperature: 630°C
- SiH_4 flow: 80 sccm
- Gas Pressure: 0.15 Torr
- Deposition time: 20 mins.



Krishnakali, CEN

3

CVD epitaxy



- Epitaxial growth
  - The growing film follows the crystalline structure of the substrate
  - The added atoms occupy lattice sites on the surface
  - If substrate and film are of the same material => homo epitaxy, otherwise hetero epitaxy

4

CVD epitaxy of Si

- The surface should be very clean, no contaminants
  - SiO_2 on silicon surface should be removed *in-situ* prior to epitaxial growth

$$SiO_2 + 2H_2 \Rightarrow Si + 2H_2O \quad (> 900C)$$

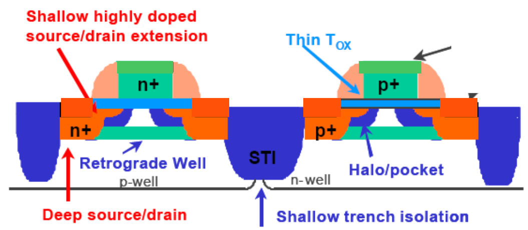
- It is important to give sufficient time for the deposited atoms to migrate on the surface and occupy lattice sites
- Growth rate and surface diffusivity are important parameters that need to be balanced: both increase with temperature
- Additional knob for reducing growth rate and possibly increasing surface diffusivity is to add H_2 to SiH_4 based epitaxy in VLSI integration

$$SiH_4 \rightleftharpoons Si + 2H_2$$

5

Si/SiGe selective epitaxy

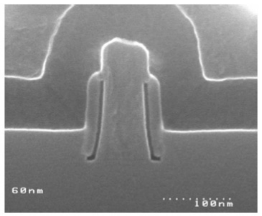
- Selective epitaxy is required in certain applications where the exposed wafer surface has oxide (field oxide) or nitride (spacer) at many locations and Si in other locations
- Si or SiGe should grow epitaxially on top of crystalline Si
- No Si or SiGe should grow on top of the oxide or nitride



6

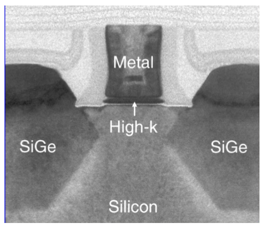
Si/SiGe selective epitaxy (2)

- Examples:
  - Elevated source/drain in thin film SOI technology
  - Embedded SiGe source/drain in pMOS for strain enhancement



A. M. Waite et al., ESSDERC 2003

SOI-MOSFET



K. Mistry et al., IEDM 2007

pMOSFET

7

Si/SiGe selective epitaxy (3)

- Si or SiGe would grow epitaxially on Si.
- Polycrystalline Si or SiGe would grow on the oxide and nitride
  - contains crystalline grains and the grain boundaries contain plenty of defects
- Introduce a chemical etchant to the reaction which would etch Si or SiGe (as required)
- Polycrystalline material may be etched faster than the crystalline material due to the presence of defects

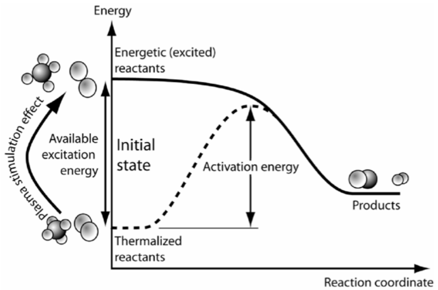
$$Si + 4HCl \rightleftharpoons SiCl_4 + 2H_2$$

- A sufficient process window in terms of pressure, gas flows and temperature may be found for selective epitaxial growth

8

Plasma Enhanced CVD (PECVD)

- Energy is required for the CVD reactions to happen
- In PECVD the energy is supplied through the plasma
  - The substrate temperature can be significantly lower than in thermal CVD systems (see lecture 16)

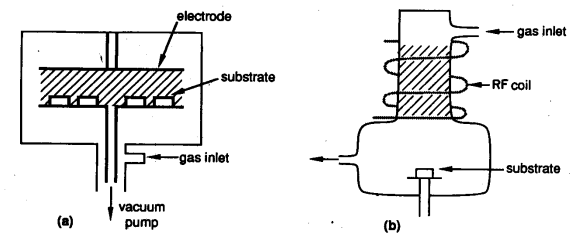


Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

Plasma Enhanced CVD (2)

- Species in excited state in a plasma can react at much lower temperature than ground state molecules
  - ➢ Lower temperature of deposition. E.g.: PECVD Si_3N_4 can be deposited at a substrate temperature of even 30C, whereas thermal CVD requires ~ 750C (see lecture 19 slides)
  - ➢ Hence compatible with metal layers used for interconnects
- Ions in the plasma may be used for sputtering, leading to a combination of deposition and physical etch
  - ➢ Used for gap filling applications like shallow trench isolation and pre-metal dielectric gap fills
  - ➢ Etching can be used for cleaning the wafer before deposition and for chamber cleaning between depositions
- Variety of species not available in a thermal reactor may be present
  - Larger variety of reaction pathways
  - E.g. Si_3N_4 can be deposited by reacting SiH_4 and N_2 in PECVD. Thermal CVD nitride requires NH_3.

Reactor Configurations

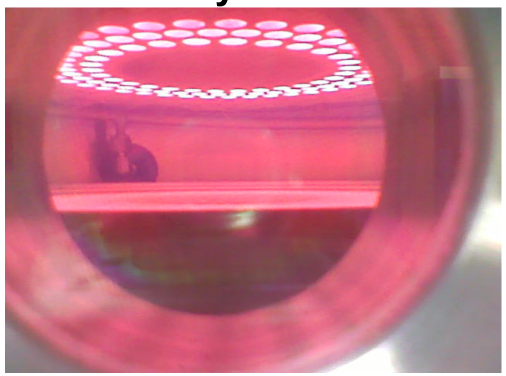


Capacitively coupled plasma
Electron density ~ 10^{10} to 10^{12} cm^{-3}

Inductively coupled plasma
Electron density ~ 10^{15} cm^{-3}
(remote plasma)

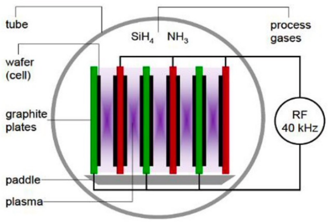
Hess and Graves, Chapter 7 in Chemical Vapor Deposition Principles and Applications, edited by Hitchman and Jensen, Academic Press, 1993

Glow Discharge in ICP-CVD System



S. Paluri, CEN

PECVD: Batch Processing

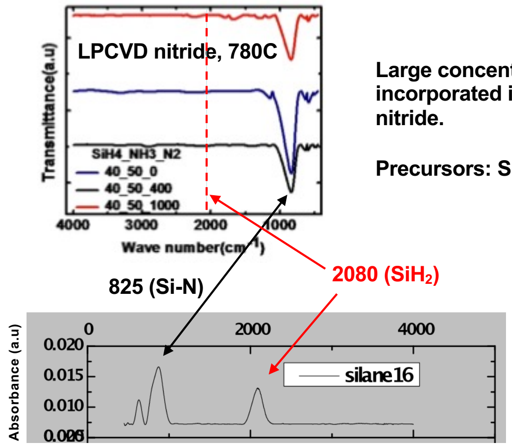


Rabindra Satpathy and Venkateswarulu Pamuru, Solar PV Power, Elsevier 2020

PECVD Applications

- Low temperature of deposition
  - Si_3N_4, a-Si films deposited by PECVD may contain more hydrogen than LPCVD films
    - Passivation layers in crystalline Si solar cells
    - Stress control => mobility enhancement in CMOS FETs
  - Low thermal budget => preferred thin film deposition scheme for backend of line (after making silicide contacts) VLSI processing
- Possibility to combine reactive ion etching and deposition
  - Isolation layers in VLSI technology => Gap fill

PECVD Applications (1)



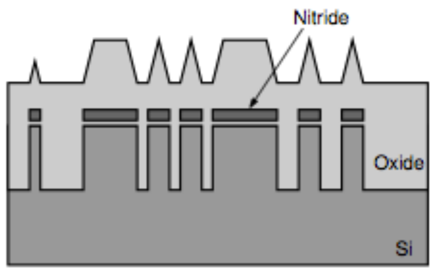
Large concentration of "H" incorporated in the PECVD nitride.

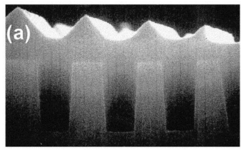
Precursors: SiH_4 + NH_3 in both cases.

PECVD 250C

FTIR data: Suresh Ch. & Dr. Trupti, CEN

PECVD Applications (2) – gap fill





Kahng et al., ICCAD 2006

C. O. Jung et al., Thin Solid films, v. 341, 1999, pp. 112-119

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