3.2 Epitaxy

Outline

3.2.1 Introduction

Epitaxy is the growth of single crystalline films upon the surface of a single crystal substrate.

	Homoepitaxy	**Heteroepitaxy**
	identical	different
	chemical composition of substrate and deposited film	
Examples:	Si/Si	Ge/Si Si/Al_2O_3 (Silicon on Saphire) GaAlAs/GaAs (HEMT, HFET)

Applications: Bipolar: - Definition of transistor regions by vertical doping
- SiGe structures heterojunction bipolar transistors (HBT)

CMOS: - Minimization of the vertical "latch-up" effect (switching of a parasitic p-n-p-n thyristor) by deposition of lightly doped epi-Si on heavily doped substrates
- Formation of strained Si on SiGe for higher electron mobility

Techniques: - **Vapor-phase epitaxy** (VPE, similar to CVD, dominating in Si processing)
special case: Molecular Beam Epitaxy (MBE)

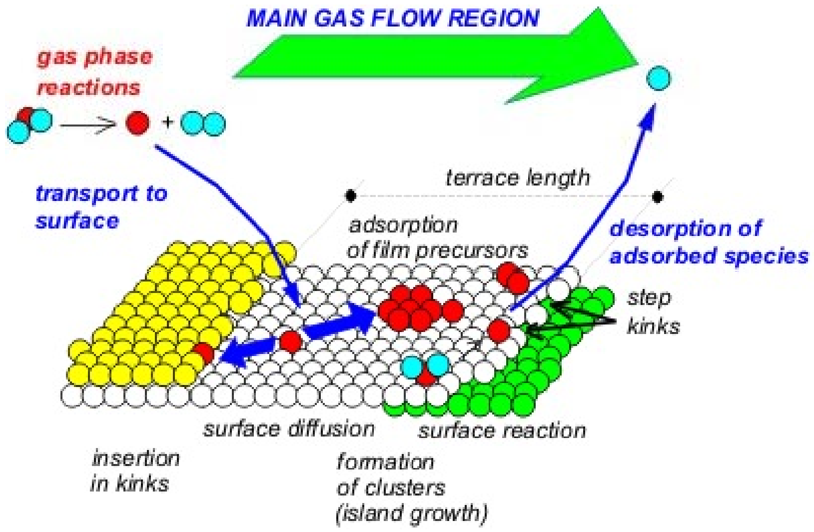
- Liquid-phase epitaxy (LPE, III-V compounds)

- Solid-phase epitaxy (SPE, annealing of amorphous layers)

3.2.2 Process of Silicon Epitaxy

- Thermally activated CVD process
- Cold-wall reactors (quartz, stainless steel)
- Atmospheric or reduced pressure conditions
- Highly demanding requirements with regard to thickness uniformity and defects

Deposition Kinetics



Basic steps:

- Transport of gaseous species toward the growing surface in a non-isothermal flow field;
- Surface processes, such as absorption of precursors and surface diffusion of adatoms over the terrace, and their incorporation into step kinks or island clusters;
- Desorption of reactants and by-products from the deposition surface;
- Transport of these species back into bulk gas phase.

Deposition characteristics of silicon precursors:

Silicon Source	Deposition Temperature (°C)	Growth Rate (µm/min)	Remarks
$SiCl_4$	1150 - 1250	0.4 - 1.5	Very high temperature, used in old processes
$SiHCl_3$ (TCS)	1110 - 1150	0.4 - 2.0	High temperature, popular source
SiH_2Cl_2 (DCS)	1020 - 1120	0.4 - 3.0	Reasonable temperature, used for selective epi growth
SiH_4	650 - 900	0.2 - 0.3	Used in SOS and Si-Ge epi, gas phase nucleation --> low p
Si_2H_6	400 - 600	< 0.1	Very low temperature

Dopants: AsH_3, PH_3 B_2H_6

Carrier: H_2

Purge: N_2

Chamber etch: HCl

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Deposition chemistry:

Elementary steps

$SiCl_4 + H_2$	$\rightleftharpoons$	$SiHCl_3 + HCl$
$SiHCl_3 + H_2$	$\rightleftharpoons$	$SiH_2Cl_2 + HCl$
SiH_2Cl_2	$\rightleftharpoons$	$SiCl_2 + H_2$
$SiHCl_3$	$\rightleftharpoons$	$SiCl_2 + HCl$
$SiCl_2 + H_2$	$\rightleftharpoons$	Si $+ 2\,HCl$

Reversible reactions

Negative growth (etching by HCl) possible at T < 900°C & T > 1400°C

Overall reactions

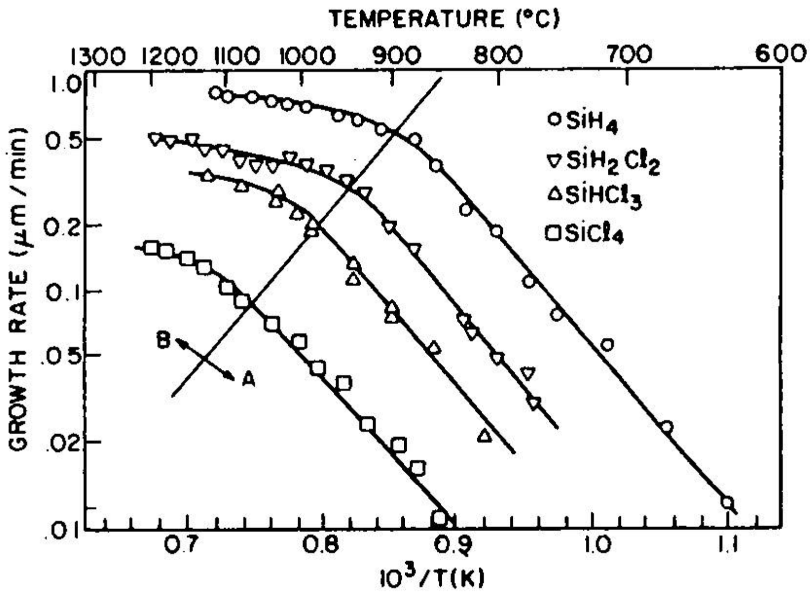
$SiCl_4 + 2\,H_2 \rightleftharpoons Si + 4\,HCl$

$SiH_4 \longrightarrow Si + 2\,H_2$

$SiH_2Cl_2 \rightleftharpoons Si + 2\,HCl$

A - reaction limited growth

B - mass-transport limited growth



F.C.Eversteyn, Philips Res. Rep. 19(1974)45

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$SiCl_4/H_2$ Process flow:

- Evacuation
- Heating of the susceptor up to process temperature (~1200 °C)
- Removal of the native oxide by purging in H_2
- Etch back of the Si surface in $SiCl_4/H_2$ ambient
- Epitaxial deposition (changed $SiCl_4/H_2$ ratio)
- Cooling down

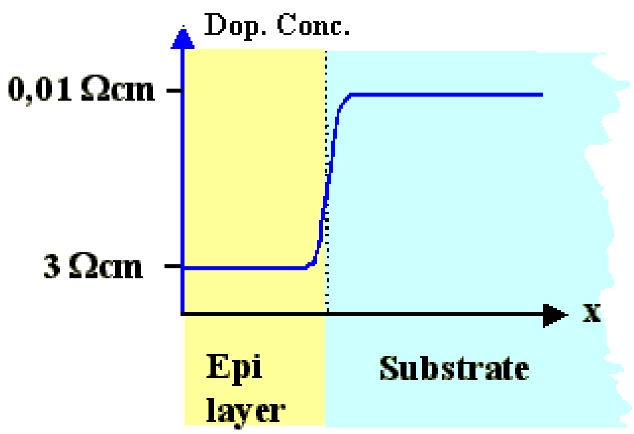
Doping:

Dopants supplied by gaseous precursors:

- AsH_3, PH_3, B_2H_6
  (diluted in H_2 to 20 ... 100 ppm)

- AsH_3, PH_3 reduce deposition rate
  (blockage of bonds)

- B_2H_6 increases deposition rate
  (support of H desorption)



Undesired Doping: Autodoping and Outdiffusion

- **Outdiffusion from substrate (transport inside wafer) (A):**
  Undesired effect occurring at high temperature: dopant atoms diffuse from the material featuring high doping level to the material featuring low doping level; common in high temperature epitaxial deposition where it prevents sharp change in dopant concentration between epi layer and the substrate
- **Autodoping (transport via gas phase) (B):**
  Dopant atoms evaporating from semiconductor surface region during high temperature treatments can be reintroduced into semiconductor causing undesired variations in dopant concentration at the surface; highly undesired effect; of particular concern in high-temperature epitaxial deposition processes.
- **Prevention:**
  - Reduce temperature by using suitable Si precursors {A+B}
  - Use As instead of P (diffusivity) {A+B}
  - Increase gas phase diffusivity by reduced pressure (As, P) {B}
  - Avoid HCl etching at high temperature {A+B}
  - Backside passivation (back-surface oxide seal) {B}

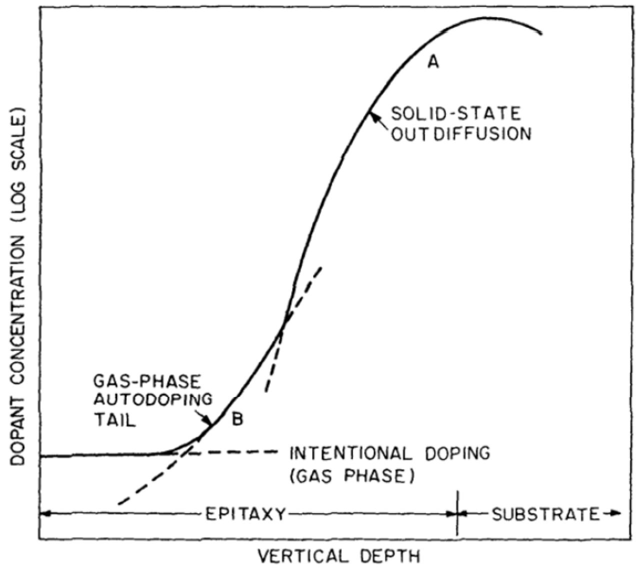


Fig.: Generalized doping profile of an epitaxial layer detailing the various regions of autodoping.

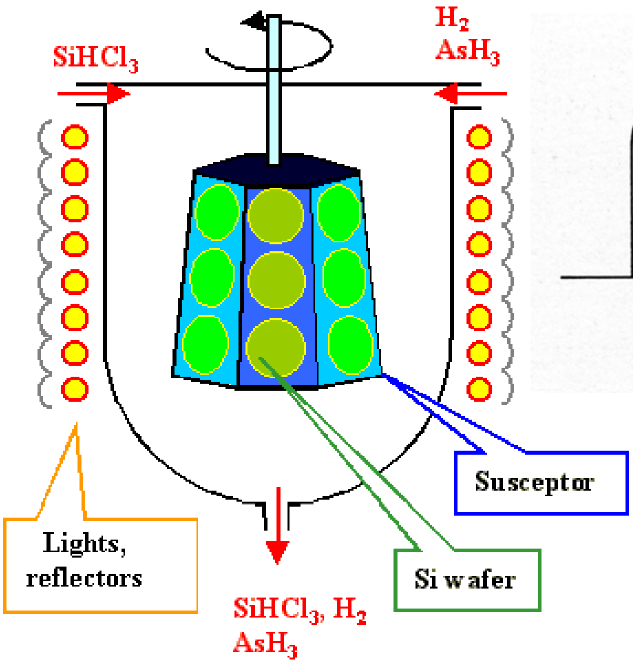
3.5.3 Equipment

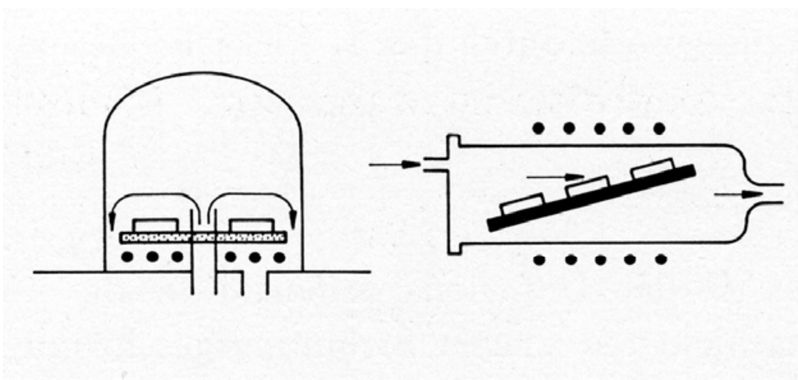
Reactor configurations

Barrel

Vertical

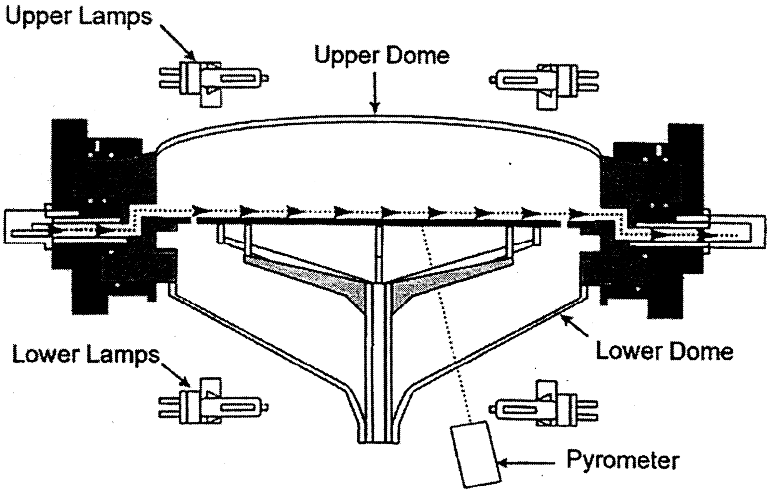
Horizontal





Heating: - IR radiative heating (quartz carrier can be used)
- Inductive heating (SiC covered graphite susceptors, chemically resistent, conducting)

Equipment: Single wafer chambers in clustertools



HTF Centura (Applied Materials)

Applied Centura Epi RP

Process flow (example):

1. Step: 1100 C, 60 s, H_2 30 sccm, 60 Torr,
2. Step: 1050 C, $SiCl_2H_2$

Deposition rate: 0.7 µm/min