MEMS: Fabrication

Lecture 5:
Micromachining

Prasanna S. Gandhi
Assistant Professor,
Department of Mechanical Engineering,
Indian Institute of Technology, Bombay,
Recap: Last Class

- E-beam lithography
- X-ray lithography
- Ion beam lithography
- Oxidation
Today’s Class

- Clean room fundamentals
- Si wafer preparation
- Chemical etching process
- Anisotropic Etching
- Silicon micromachining
  - Surface micromachining
  - Bulk micromachining
  - How to produce devices
Clean Room Fundamentals

- Need
- Class of a clean environment
  - Class X clean room → not more than X particles (of size 0.5\(\mu\)m or larger) per cubic foot of air
- How this cleanliness is produced and maintained??
Clean Room Fundamentals

- Air conditioning plant
- HEPA filters air recirculation through these filters
Si-wafer preparation

- Czochralski process

- Cutting, CMP, cleaning
Primary and Secondary wafer flats are used to identify orientation and type.

(100) n-type
(111) n-type
(100) p-type
(111) p-type

Primary flat
{110} direction
Primary flat
Secondary flat
Primary flat
Secondary flat
Primary flat
Secondary flat
Chemical Etching

- Isotropic etching
  - Etchant: HNA mixture.
  - HNA can dissolve 550µm thick silicon wafer in about 20 min.
  - HNA mixture removes silicon equally in all directions.
  - SiO₂ etch: 10-30nm/min

Without agitation (5)

With agitation (20)
Chemical Etching

Without agitation (5)

- Isotropic etching
  - Undercut
  - Etch bias

- Materials & etchants*
Etch Stop Mechanisms

- Time etch stop
- Dopant B+ (heavy dope) as etch stop
  - Pg 45 Spoek
- Thin films
- Electrochemical etch stop
- Anisotropic Etching planes
Chemical Etching

Choice of etchant:

- Etch rate
- Topology of the surface to be etched
- Etch selectivity of mask material and other materials
- Toxicity
- Ease of handling
Chemical Etching

- Anisotropic bulk etching
  - Etchant: KOH, EDP (ethylen diamine pyrocatechol), TMAH (Tetra methyl ammonium hydroxide)
  - $<111>$ direction has lower etching rates than $<100>$
  - Can produce grooves, slanted/vertical walls
Chemical Etching

- Silicon crystal geometry*
- Examples of use of the crystal geometry in etching
- Fundes regarding etch shapes under different conditions*
Anisotropic Etching

KOH, EDP and TMAH
- EDP etches oxide 100 times slower than KOH,
- KOH, TMAH dangerous to eye
- KOH less dangerous than EDP & TMAH
- Etch curves*: 5hrs to etch 300µm thick wafer
- H2 bubbles during KOH etching of Si
- EDP ages quickly in contact with oxygen producing red brown color, vapor is harmful
- HF dip is necessary for EDP: native oxide problem
A square $<110>$-oriented mask feature results in a pyramidal pit.
Convex corners where \{111\} planes meet are not stable. They are rapidly undercut. This permits creation of suspended structures.
Any mask-layer feature, if etched long enough, will result in a rectangular V-groove pit beneath a rectangular that is tangent to the mask features, with edges oriented along <110> directions.
The effect of misalignment is to enlarge the etched region. This figure shows the effect of a 5° misalignment for a rectangular feature.
Illustrating the lift-off method for patterning evaporated metals
The use of a modified lift-off process to create sharp tips.
Conclusions

- Chemical etching
  - Isotropic
  - Anisotropic
- Bulk and Surface micromachining
- Etch stop mechanisms
- Liftoff process
Next class

- Plasma based processes
  - Plasma etching
  - RIE
- Sputtering
- PE CVD
Wafer Cleaning Process

- Need
- CMP - Chemical mechanical polishing
- RCA cleaning
Chemical Vapor Deposition (CVD)

- Chemical reaction in vacuum chamber
- High temperatures (>300°C)
- Polysilicon, SiO₂, Si₃N₄, tungsten, titanium, copper etc. can be deposited
- Low pressure CVD (LPCVD)
- Plasma Enhanced CVD: low temperatures
- Pressure, temp, gas flow
For small time $t$, and

$$x = \frac{B}{A} (t + \tau)$$

for large time $t$, where $\chi$ is the thickness of the oxide layer in the silicon substrate in micrometers at time $t$, in hours. $A$ and $B$ are constants, and the parameter $\tau$ can be obtained by:

$$\tau = \frac{\left( d_0^2 + 2Dd_0 \right)}{k_s} \frac{k_s}{2DN_0}$$
where

- **D** = diffusivity of oxide in silicon, e.g.,
  - \( D = 4.4 \times 10^{-16} \text{cm}^2/\text{s at 900}^\circ \text{C} \)

- **\( d_0 \)** = initial oxide layer \((\sim 200 \text{ in dry oxidation, } = 0 \text{ for wet oxidation})\)

- **\( k_s \)** = surface reaction rate constant

- **\( N_o \)** = concentration of oxygen molecules in the carrier gas
  - \( = 5.2 \times 10^{16} \text{molecules/cm}^3 \text{ in dry } \text{O}_2 \text{ at } 1000^\circ \text{C and 1atm} \)
  - \( = 3000 \times 10^{16} \text{ molecules/cm}^3 \text{ in water vapor at the same temperature and pressure} \)

- **\( N_1 \)** = number of oxidizing species in the oxide
  - \( = 2.2 \times 10^{22} \text{ SiO}_2 \text{ molecules/cm}^3 \text{ in dry O}_2 \)
  - \( = 4.4 \times 10^{22} \text{ SiO}_2 \text{ molecules/cm}^3 \text{ in water vapor} \)