EE 527 MICROFABRICATION

Lecture 23

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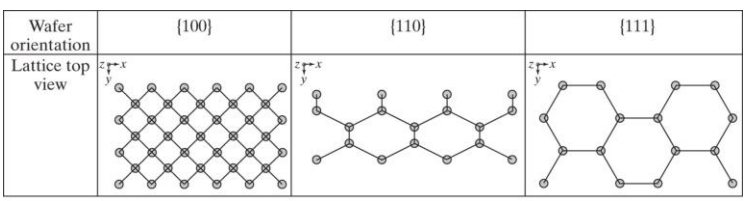
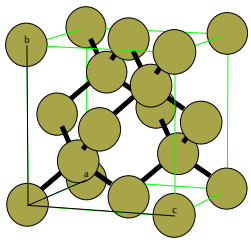
SILICON CRYSTAL STRUCTURE

- Silicon atoms in a crystal lattice are regularly arranged in a lattice structure.
- Material properties, such as Young's modulus of elasticity, mobility, and piezoresistivity) and chemical etch rates of silicon bulk are orientation dependent.



SILICON CRYSTAL STRUCTURE



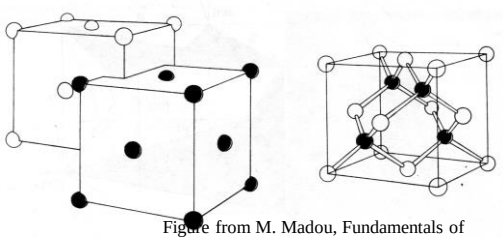
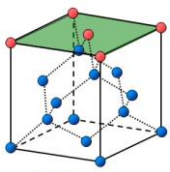
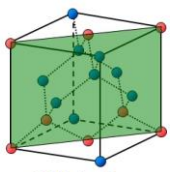


Figure from M. Madou, Fundamentals of Microfabrication, CRC 1997

Diamond structure:
a = b = c = 5.43095 A at 300 K
α = β = γ = 90°



(001) Surface



(110) Surface

CRYSTAL PLANES AND ORIENTATIONS

- Miller indices: *hkl*
- The following steps are used to determine the three directional indices,
  - A vector of convenient length is positioned such that it passes through the origin of the coordinate system.
  - The length of the vector projection on each of the three axes is determined.
  - These three numbers are multiplied or divided by a common factor to reduce them to the smallest integer values.
  - The three indices, not separated by commas, are enclosed in square bracket: [hkl]

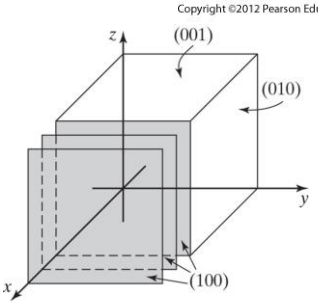
CRYSTAL PLANES AND ORIENTATIONS

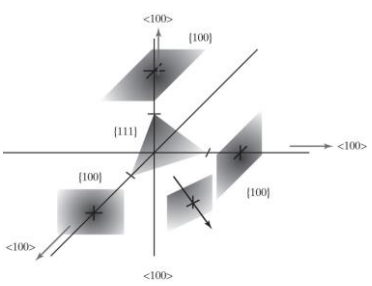
- Miller indices: *hkl*
- The three integers describing a plane as following,
  - Find the intercepts of the plane with the crystal axes and express these intercepts as integral multiples of the basis vectors
  - Take the reciprocal of the three integers and reduce these to the smallest set of integers h, k, l.
  - Label the plane using parentheses (hkl)

CRYSTAL PLANES AND ORIENTATIONS

TABLE 3.1 Summary of notation for planes, directions, and their families.

	Single element notation	Family notation
Directions	[hkl]	<hkl>
Planes	(hkl)	{hkl}

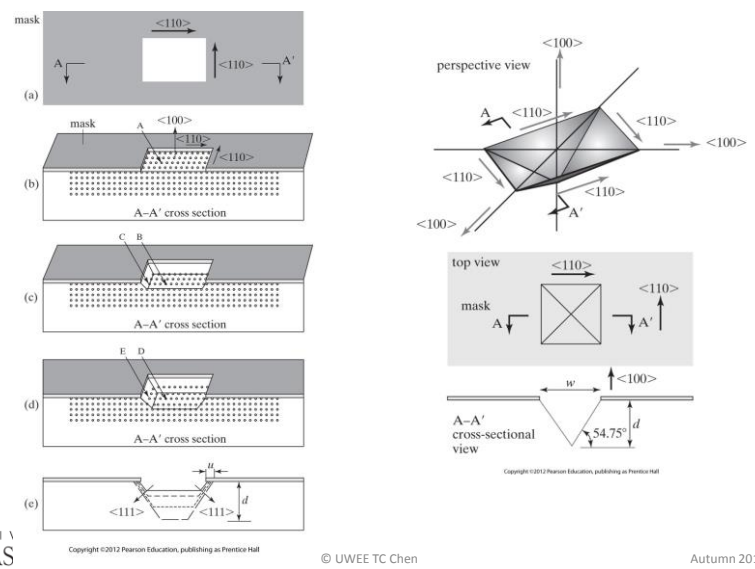




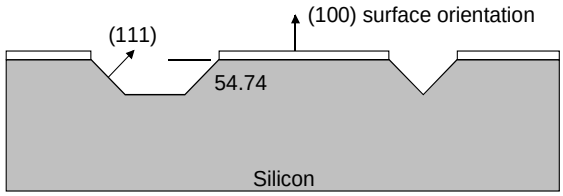
ANISOTROPIC ETCHING OF SILICON - 1

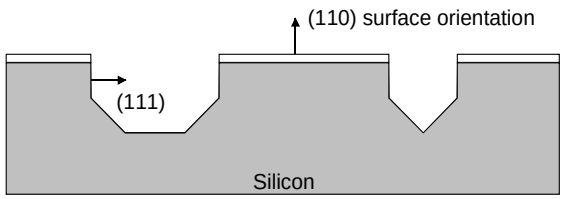
- Differing hybridized (sp^3) orbital orientation on different crystal planes causes drastic differences in etch rate.
- Typically, etch rates are: (110) > (100) >>> (111).
- The (111) family of crystallographic planes are normally the "stop" planes for anisotropic etching.
- There are 8 (111) planes along the ± x ± y ± z unit vectors.
- Intersections of these planes with planar bottoms produce the standard anisotropic etching structures for (100) Si wafers:
  - V-grooves
  - pyramidal pits
  - pyramidal cavities

ANISOTROPIC WET ETCHING



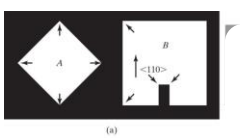
ANISOTROPIC ETCHING OF SILICON - 2





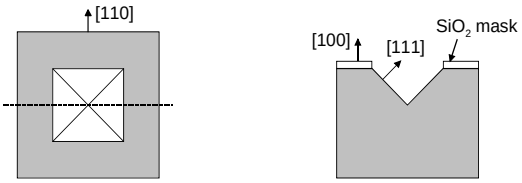
RULES OF ANISOTROPIC ETCHING

- Eliminate the restriction that the edges of a window must be a noninterrupted straight line.
- Next, eliminate the restriction that the edges must be parallel to <110> directions.
- Convex corner:
  - solid angles of masked region less than 180°.
  - Corners tend to be undercut.
- Concave corner:
  - solid angles of masked region greater than 180°.
  - Corners tend to be stopped at <111>.



ANISOTROPIC ETCHING OF SILICON - 3

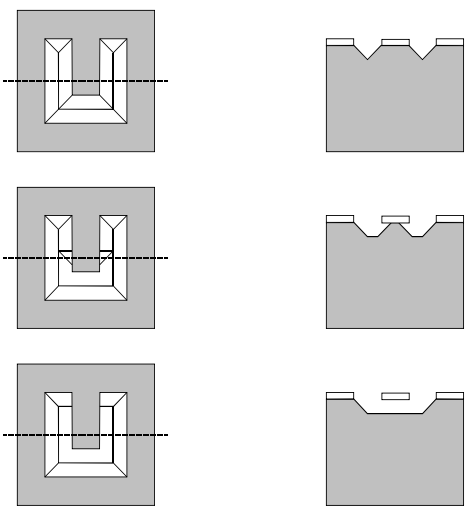
Symmetrical, anisotropically etched pyramidal pit:



Arbitrary mask features will become anisotropically etched to the [110]-aligned rectangle which contains them:

ANISOTROPIC ETCHING OF SILICON - 4

Progressive anisotropic etching of a cantilever



HYDROXIDE ETCHING OF SILICON

- Several hydroxides are useful:
  - KOH, NaOH, CeOH, RbOH, NH_4OH, TMAH: $(CH_3)_4NOH$
- Oxidation of silicon by hydroxyls to form a silicate:
  - $Si + 2OH^- + 4h^+ \rightarrow Si(OH)_2^{++}$
- Reduction of water:
  - $4H_2O \rightarrow 4OH^- + 2H_2 + 4h^+$
- Silicate further reacts with hydroxyls to form a water-soluble complex:
  - $Si(OH)_2^{++} + 4OH^- \rightarrow SiO_2(OH)_2^{2-} + 2H_2O$
- Overall redox reaction is:
  - $Si + 2OH^- + 4H_2O \rightarrow Si(OH)_2^{++} + 2H_2 + 4OH^-$

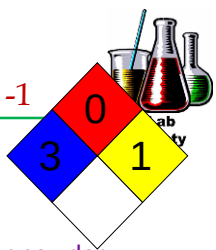
KOH ETCHING OF SILICON - 1

- Typical and most used of the hydroxide etches.
- A typical recipe is:
  - 250 g KOH
  - 200 g normal propanol (isopropanol has too low of a flash point)
  - 800 g H_2O
  - Use at 80°C with agitation
- Etch rates:
  - ~1 μm/min for (100) Si planes; stops at p^{++} layers
  - ~14 Angstroms/hr for Si_3N_4
  - ~20 Angstroms/min for SiO_2
- Anisotropy: (110):(100):(111) ~ 600:400:1
- Masking films: SiO_2, Si_3N_4, but not photoresist.

KOH ETCHING OF SILICON - 2

- Simple hardware:
  - Hot plate & stirrer.
  - Keep covered or use reflux condenser to keep propanol from evaporating.
- Presence of alkali metal (potassium, K) makes this completely incompatible with MOS or CMOS processing!
- Comparatively safe and non-toxic, aside from the high pH of the KOH solution.
  - It is still a very strong alkali solution which can cause burns!

POTASSIUM HYDROXIDE (KOH) -1



- NFPA704M code = 3-0-1; CAS # [1310-58-3]
- considered a slightly stronger base
- at room temp., KOH is a white solid, usually pellets or powder
- very hygroscopic
- standard reagent concentration is 97%

primary hazards:

- can cause extremely severe burns to the skin
  - treat with 1% acetic acid solution or common household vinegar
  - tissues have no natural defense to strong bases, so tissue damage can be greater than that of a strong acid

POTASSIUM HYDROXIDE (KOH) - 2

primary hazards:

- can cause extremely severe burns to the cornea
  - treat with 1% boric acid to neutralize after several minutes of irrigation with water
- nonflammable by itself, but can trigger the ignition of other materials
- very exothermic upon dissolving in H_2O
  - 10 kcal/mole
  - hot enough to ignite or melt some materials