EE 701: Introduction to MEMS

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Etching

- The process of chemically and/or physically removing material. There are two main types.
- Wet etching
  - Isotropic
  - Anisotropic
- Dry etching
  - Vapor etching
  - Plasma-assisted etching
    - Ion milling
    - Ashing
    - Reactive Ion Etching
      - Deep Reactive Ion Etching

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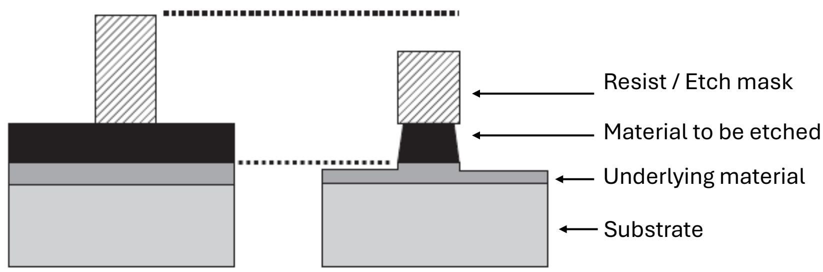
Etching

- In general, one is looking for etch selectivity (ratio of etch rates of material to be etched to other materials exposed to the etchant including the resist or etch mask). In other words, the material to be etched is etched much more rapidly than the etch mask and/or any other materials that are exposed to the etchant.
- In practice, etch selectivity is limited..



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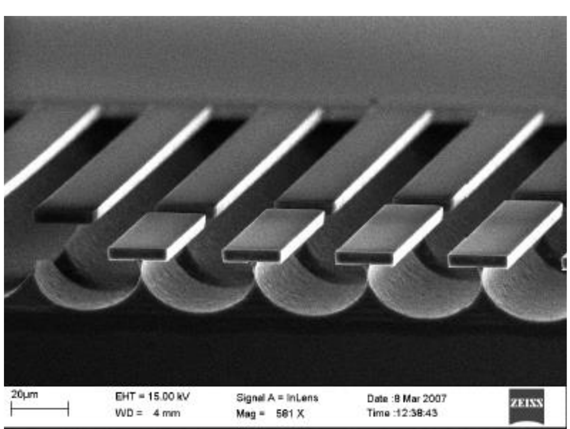
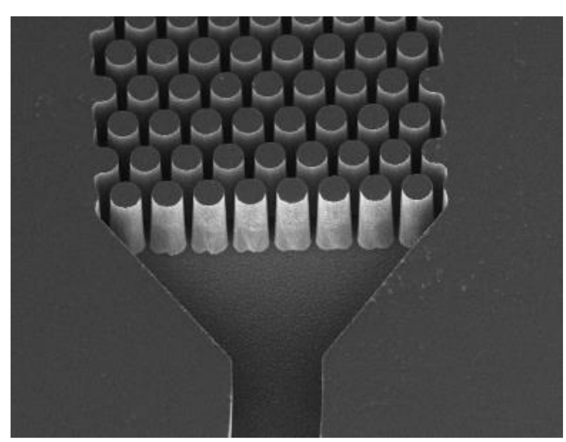
A comparison between isotropic and anisotropic etched features



Isotropic etching



Anisotropic etching

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Wet etching

- Wet etching involves the etching of material by a liquid chemical that attacks exposed material. It is often conducted in a tank or using a spray tool.
- The rate of etching and type of etched feature depend on several conditions including the chemicals employed, material to be etched, etched feature, etch time, choice of masking layer, control of etch process, etc.
- Most wet etching is isotropic. However, there are some etchants for single-crystal silicon that result in anisotropic etch features.
- Complications that can result include the impact of etch products, mass transport/heat transport limitations, evaporation of etchant, control of temperature in exothermic reactions, etc.

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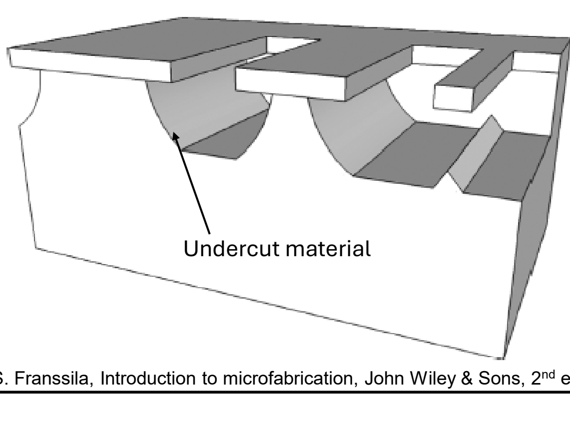
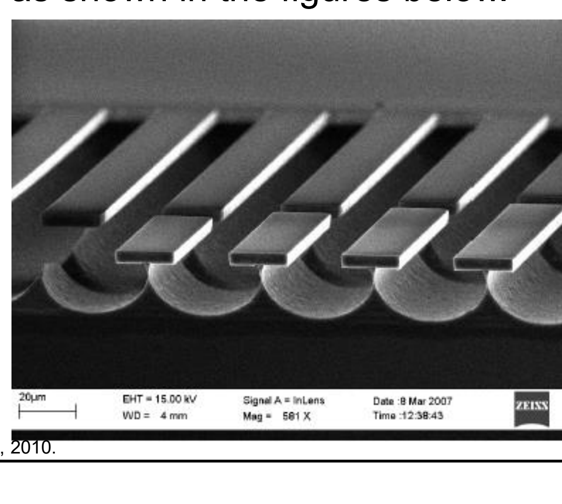
Isotropic wet etching

- An undercut results when the etchant removes material under the etch mask. This creates features as shown in the figures below.





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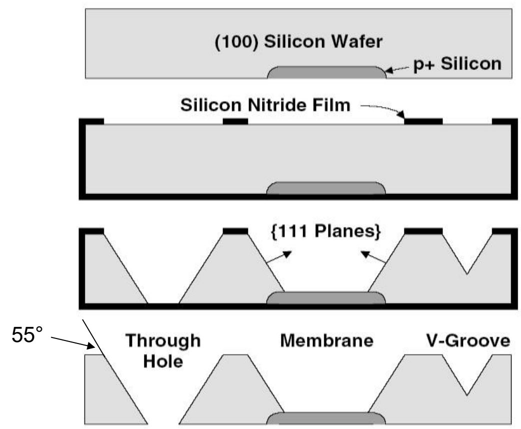
Anisotropic Si etching (KOH)

- Utilises the fact that (111) plane is more closely packed than (100) plane.
- Use <100> silicon with mask features perpendicular to crystal orientation
- Etch solution KOH:H_2O (80°C)
- Si <100> etch rate 84μm/hr
- Si <111> etch rate 0.21μm/hr
- Si3N4 etch stop or doped layer etch stop for membrane formation.
- SiO2 provides some etch selectivity but not as good as Si3N4.



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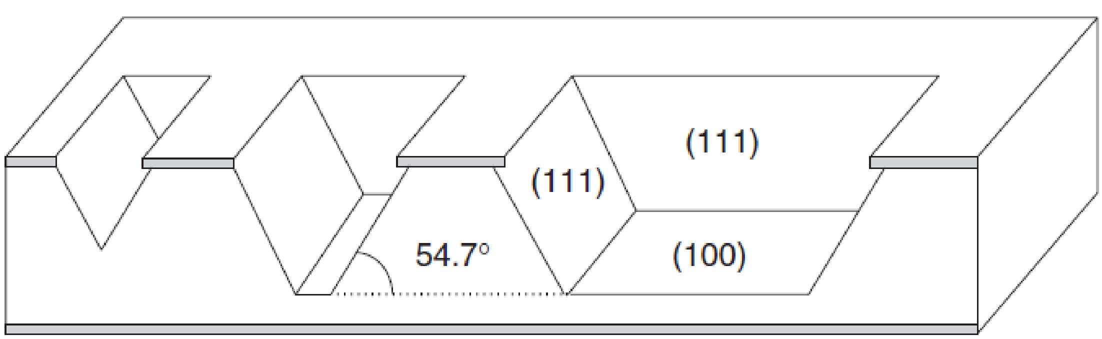
Anisotropic etching using KOH for silicon



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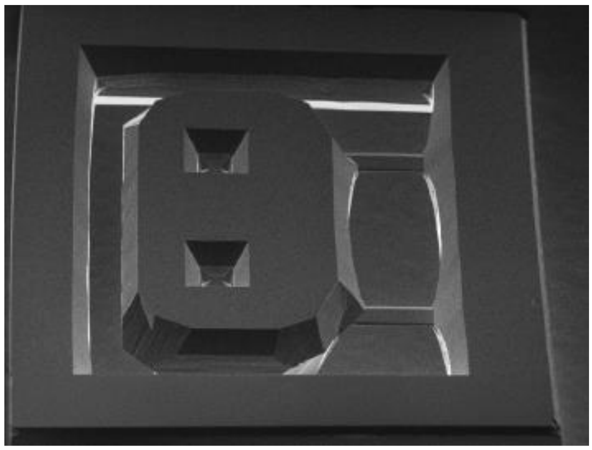
Example of a MEMS device using KOH etching



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A listing of etchants for resist masked and unmasked etching

Table 11.1 Wet etchants for photoresist masked etching (mostly room temperature)

SiO_2	NH_4F:HF (7:1),[a] 35 °C
SiO_2	NH_4F: CH_3COOH:$C_2H_6O_2$ (ethylene glycol): H_2O (14:32:4:50)
Poly-Si	HF:HNO_3:H_2O (6:10:40)
Al	H_3PO_4:HNO_3:H_2O (80:4:16), water can be changed to acetic acid
Mo	H_3PO_4:HNO_3:H_2O (80:4:16)
W, TiW	H_2O_2:H_2O (1:1)
Cr	$Ce(NH_4)NO_3$:HNO_3:H_2O (1:1:1)
Cu	HNO_3:H_2O (1:1)
Ni	HNO_3:CH_3COOH:H_2SO_4 (5:5:2)
Ti	HF:H_2O_2 (1:1)
Au	KI:I_2:H_2O, KCN:H_2O
Pt, Au	HNO_3:HCl (1:3), "aqua regia," H_2O dilution may be used

[a] Called BHF, for buffered HF, and also known as BOE, for buffered oxide etchant.

Table 11.2 Wet etchants for unmasked etching

SiO_2	DHF, dilute HF (1%), for removing native oxide (about 10 nm/min)
SiO_2, PSG	HF (49%) sacrificial layer removal (>1 µm/min)
Si_3N_4	HF (49%) layer removal (4 nm/min)
Si_3N_4	H_3PO_4 (concentrated, 180 °C)
Si	HF:HNO_3:H_2O (6:10:40) (thinning etch, up to 20 µm/min)
Cu	HCl

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Dry etching

- Etching is achieved by chemically reactive vapors or plasma-assisted etching.
- Chemically reactive vapors such as XeF_2 exhibit a high etch selectivity for silicon. There is virtually no etching of silicon dioxide, metals or other materials.
- Vapor etching can be used for dry release of microstructures without yield issues arising from wet etchants (discussed later).

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Reactive ion etching

- Ion milling: Low-pressure glow discharge plasma produces ion species that is directed towards a substrate and physically sputters material from the substrate. There is little selectivity achieved from the relative rate of sputtering different materials.
- Focused ion beam milling: Focusing optics is used to direct the ion beam to specific regions on the wafer. This is typically used only to etch very small directed regions on the wafer.
- Ashing: Removal of photoresist from a wafer in a reactive oxygen plasma where the polymer is converted to carbon dioxide and water which is then extracted.

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Reactive ion etching

- Plasma etching is the etching of material by reactive gases excited by RF fields. It is typically done in a vacuum chamber. Ionized reactive species are directed towards the surface through the applied field(s).

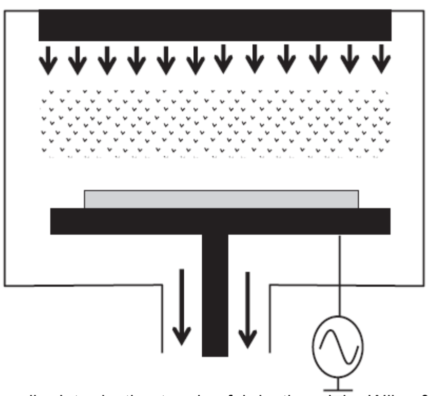

Table 11.3 Typical etch gases

Fluorine	Chlorine	Bromine	Stabilizers	Scavengers
CF_4	Cl_2	HBr	He	O_2
SF_6	BCl_3		Ar	
CHF_3	$SiCl_4$		N_2	
NF_3	$CHCl_3$			
C_2F_6				
C_4F_8				
XeF_2				

Silicon is readily etched by halogens (silicon dioxide and aluminum used as hard masks). Si3N4 by Fluorine.

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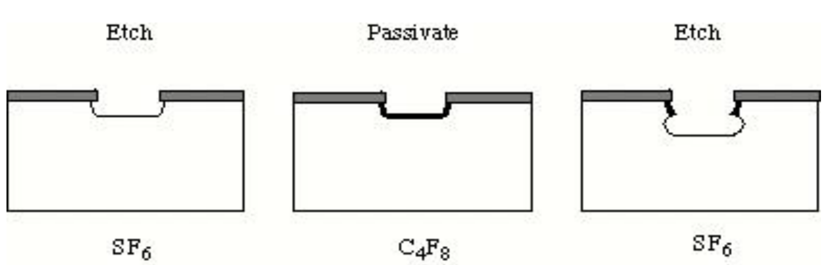
DRIE: the Bosch process

- Alternating cycles of passivation with a teflon-like polymer (deposition from a C_4F_8 plasma) and RIE etching of silicon with SF_6



Slide courtesy: S. Senturia, MIT

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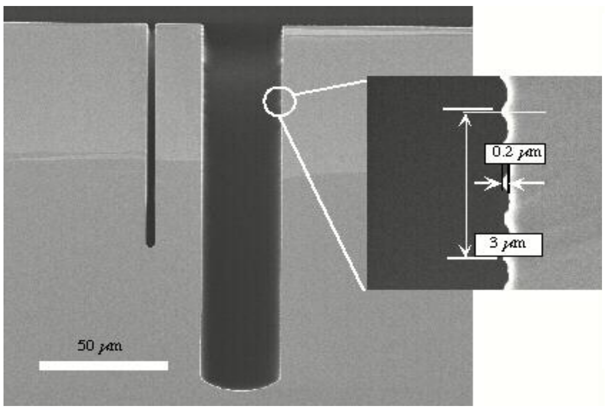
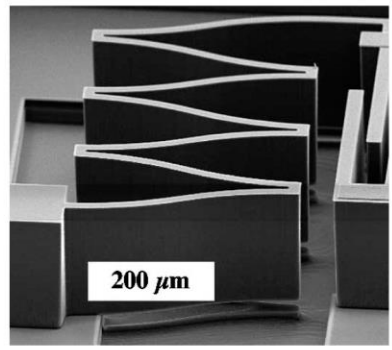
DRIE cross-sections

- Features of different width etch at different rates





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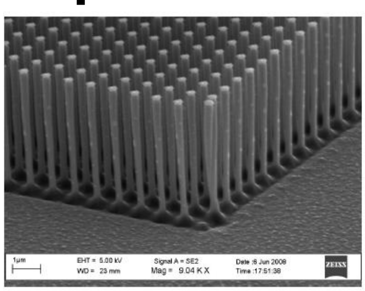
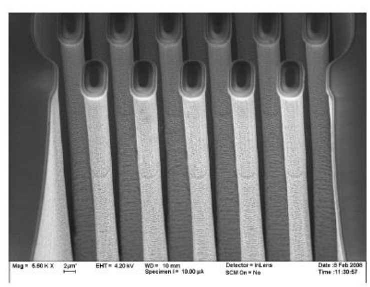
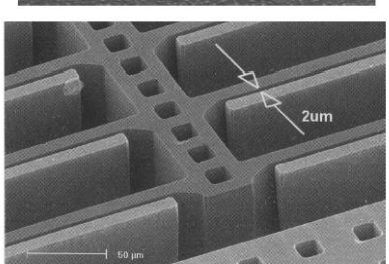
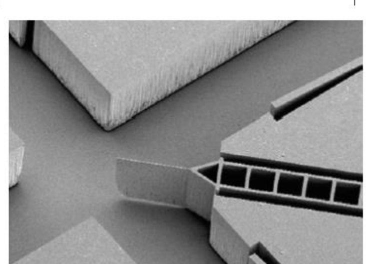
Examples of DRIE etched devices









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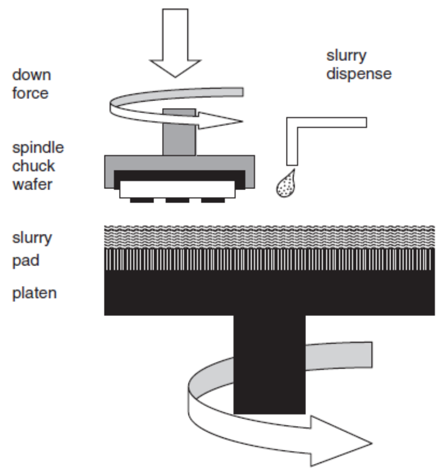
Chemical-Mechanical Polishing

- Wafer is pressed against a rotating platen containing an abrasive slurry with chemicals in the slurry that help dissolve the material removed by abrasive action by abrasive particulates (10-300nm).
- Used to create flat surfaces before lithography or deposition.
- A variety of metals (Cu, W), oxides (SiO2), semiconductors can be polished back using this method.



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