



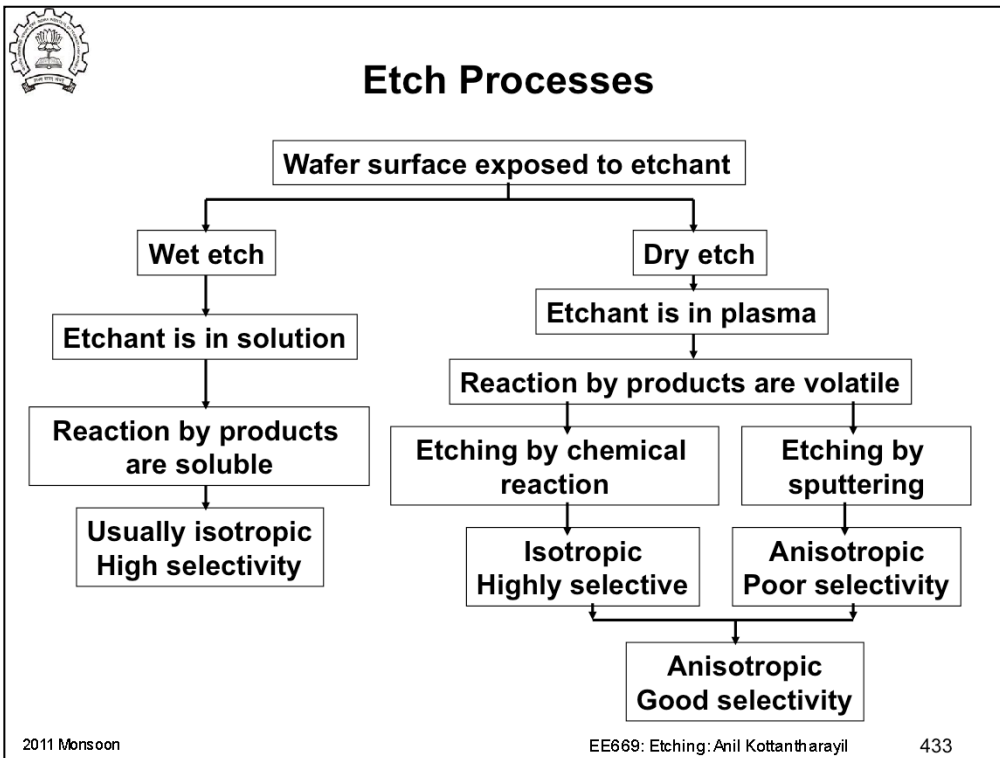
EE669: VLSI Technology

Etching

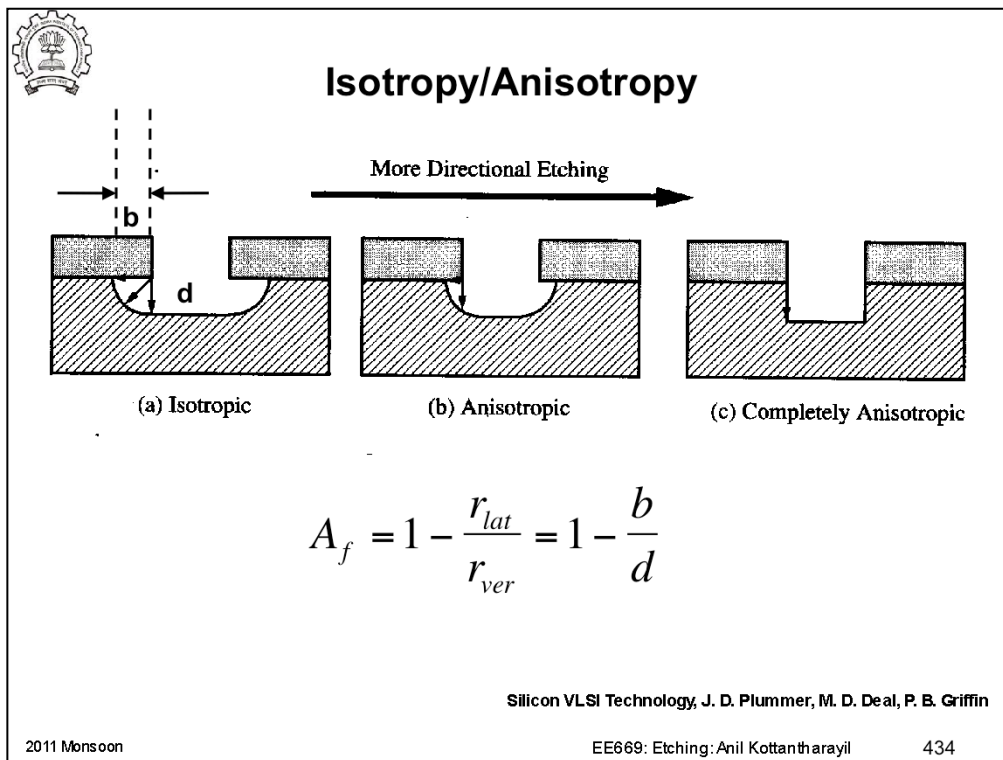
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Associate Professor,
Department of EE, IIT Bombay

VLSI chips are made by a sequence of additive and subtractive techniques. We had seen several additive processes like oxidation, thin film deposition and ion implantation. Many of these processes cannot be done selectively in some areas. There are exceptions to this though. When a film cannot be selectively deposited or formed on the wafer surface, it is possible to selectively remove them through masked etch processes.

In addition to removal of material from unwanted regions, etch processes (especially wet chemical etch processes) can also be used for contamination removal and surface preparation in VLSI processing. Example: wafer surfaces have to be prepared before ALD deposition so that the surface is terminated with the right kind of species as we had seen in the module on thin film deposition.



This slide shows various possibilities in which etching can be done. We would look at the terminology in greater detail.



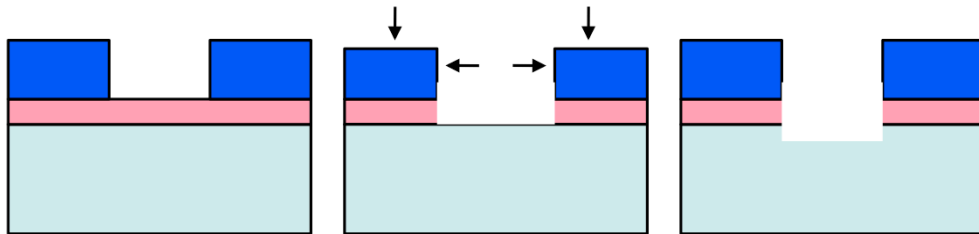
When a material is being etched through a mask, the etching can happen vertically in the opening in the mask as well as laterally under the mask as shown. In a fully directional etch, the lateral etch rate would be zero.

B is called the etch bias.

When etching happens in all directions in equal measure, we have isotropic etching. When the etching happens only vertically, the etching is called anisotropic.



Etch Selectivity



$$S = \frac{r_1}{r_2}$$

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Etch Processes: Wet etch

Etch rate and selectivity:

- **Concentration**
- **Temperature**
- **Stirring of solution**

Williams et al., *IEEE Journal of MEMS*, Dec. 1996 & Dec. 2003

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The etch rate and selectivity depends on the concentration, temperature and stirring conditions.

Some of the factors that we need to consider in some detail are the following:

As the chemical reaction happens, we may reasonably assume that the liquid next to the surface would be depleted of reactants. The surface is being etched. So some chemical reaction is happening and the reaction products should be either soluble or gases. The reaction products have to be removed from the surface.

Stirring of etching solutions helps to enhance etch rates and improve uniformity as the products of reactions would be taken away more efficiently with stirring. Stirring the solution avoids redeposition of particles lifted from the wafer surface and also result in rapid replenishment of the reactants at the wafer surface.



SiO₂ etch using HF solutions

- Overall reaction
 - $\text{SiO}_2 + 6\text{HF} \rightarrow \text{H}_2\text{SiF}_6 + 2\text{H}_2\text{O}$
- Various concentrations used: 49%, 10%, 2%, ...
- Etch rate and selectivity depends on the concentration
- Selective to Si
- Selective to Si₃N₄ at low concentration and if Si₃N₄ contains low H and O
- BHF (HF: NH₄F = 1:5) for etching SiO₂ selective to photo resist and Si

Williams et al., IEEE Journal of MEMS, Dec. 1996 & Dec. 2003

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Detailed etch processes and rates under typical conditions are documented in:

1. Kirt R. Williams and Richard S. Muller, Etch Rates for Micromachining Processing, IEEE JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 5, NO. 4, pp. 256-269, DECEMBER 1996
2. Kirt R. Williams, Kishan Gupta, and Matthew Wasilik, Etch Rates for Micromachining Processing – Part II, IEEE JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 12, NO. 6, pp DECEMBER 2003

The overall chemical reaction proposed is shown.

Etch rate of the oxide vary with the doping, density and stoichiometry. For example a thermal CVD or PECVD SiO₂ generally etch faster than a thermal oxide.

Even though nitride may not be etched as fast as oxide, this again depends on the composition. Thermal CVD nitride etches slow in HF and PECVD nitride may etch faster depending on the density, oxygen and hydrogen content in the film. Typical selectivity of the SiO₂ etch to Si₃N₄ are in the range of 20 to 100.

Buffered HF (BHF) is a mixture of HF and NH₄F. Typical mixture is 1 part by weight of 49% weight percent HF and 5 parts by weight of 40 weight percent NH₄F. So the solution would contain 33% percent by weight of NH₄F and 8.3% percent by weight of HF. One advantage of BHF is that it does not attack photo resist. However HF attacks resist.

The BHF reaction is expected to be along the lines shown at the bottom. It is assumed that the NH₄F reacts to form NO₂ which subsequently oxidizes the silicon and the oxide is then etched by HF.



Isotropic Silicon Etch

- HF:HNO₃:CH₃COOH
 - Typical mixing ratio is 1:60:6
- The overall reaction
$$18\text{HF} + 4\text{HNO}_3 + 3\text{Si} \rightarrow 3\text{H}_2\text{SiF}_6(\text{aq}) + 4\text{NO}(\text{g}) + 8\text{H}_2\text{O}$$
- CH₃COOH is used for uniform etching with smooth surfaces (c-Si)
- NH₄F can be used instead of HF for a longer lasting solution
- Selective to Si₃N₄ and SiO₂

Williams et al., ~~IEEE~~ Journal of MEMS, Dec. 1996 & Dec. 2003

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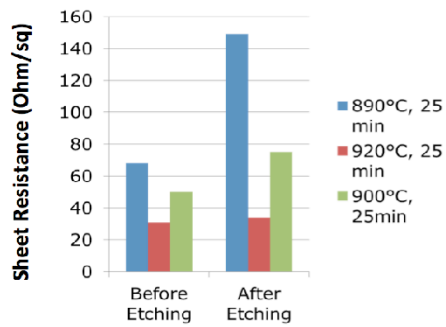
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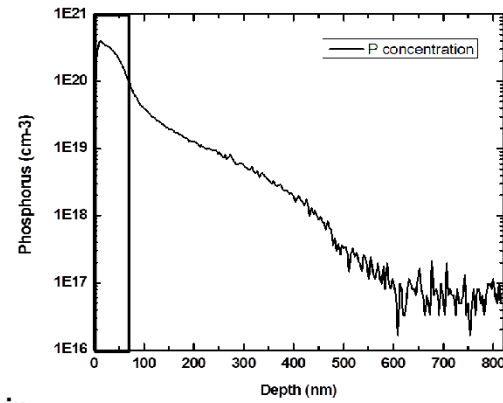


Isotropic Silicon Etch for Dead Layer after Phosphorous Diffusion

Phosphorous diffused in Si using a solid source



Dead layer etching in
HF:HNO₃:CH₃COOH
1:60:6

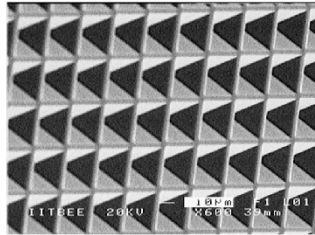


Gaudhaman Jeevanandam, NCPRE

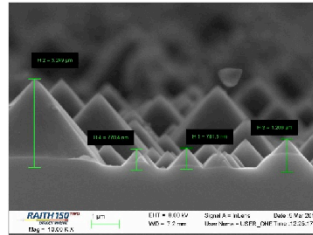


Anisotropic Si etch: KOH or NaOH or $\text{N}(\text{CH}_3)_4\text{OH}$

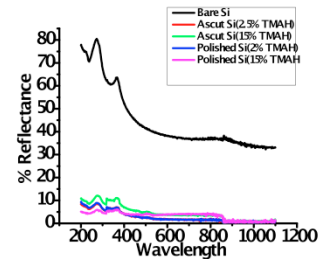
KOH etch selectivities $\rightarrow (110):(100):(111)$ of 400:200:1



Inverted pyramids, 25 μm X 25 μm squares
with 5 μm gap. TMAH
2.5%



Random texturization, 2.5
% TMAH, 85 – 90 C,
3.3 μm .



Reflectance of
random textured
wafers.

Sandeep S. S., NCPRE

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$\text{N}(\text{CH}_3)_4\text{OH}$ is tetra methyl ammonium hydroxide (TMAH).

These hydroxides etch the (100) and (110) planes of Si faster than (111) planes.



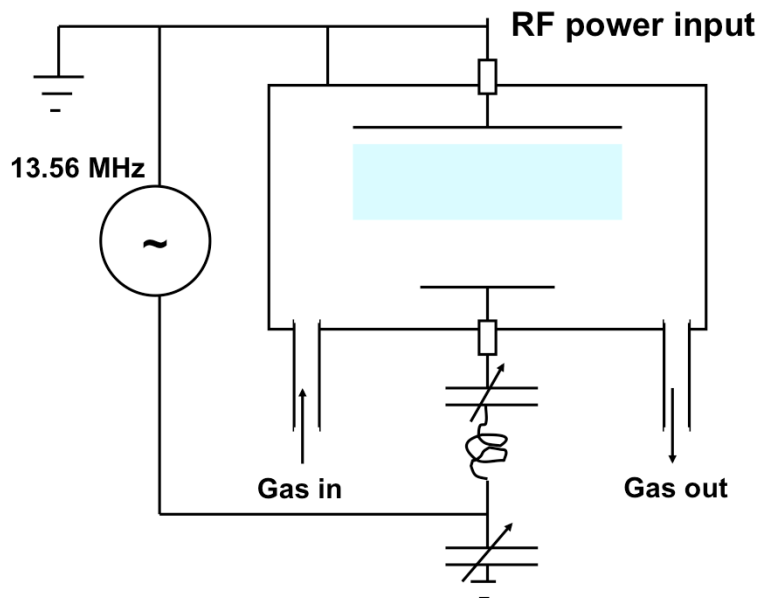
Self Study

All wet etch processes described in

1. Kirt R. Williams and Richard S. Muller, Etch Rates for Micromachining Processing, IEEE JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 5, NO. 4, pp. 256-269, DECEMBER 1996
2. Kirt R. Williams, Kishan Gupta, and Matthew Wasilik, Etch Rates for Micromachining Processing – Part II, IEEE JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 12, NO. 6, pp DECEMBER 2003



Dry Etch or Reactive Ion Etch



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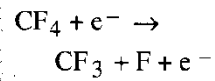
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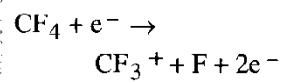


Dry Etch or Reactive Ion Etch: Si etch

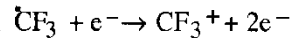
Dissociation:



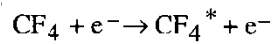
Dissociative ionization:



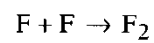
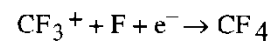
Ionization:



Excitation:



Recombination:



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Types of Etch

Classification

- **Chemical etch:**
 - caused by chemical reaction of the free radicals like F, CF₃, ... with materials on the wafer surface
 - isotropic, highly selective
- **Physical etch:**
 - caused by bombardment of high energy ions on the wafer surface
 - anisotropic, not selective
- **Ion enhanced etch:**
 - ions and free radicals acting together
 - anisotropic and selective



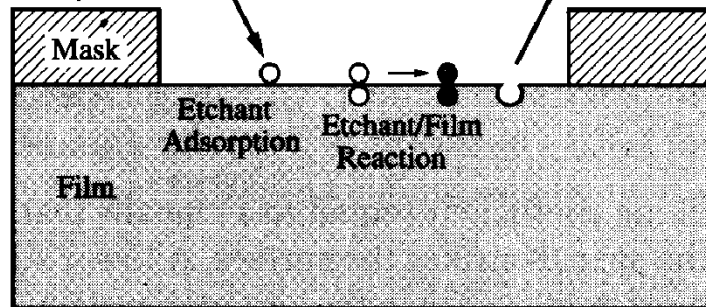
Chemical Etch Process

Etchant (Free Radical) Creation



Etchant
Transfer

Byproduct
Removal



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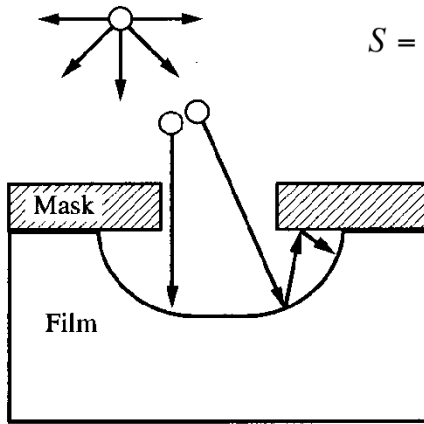
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Chemical versus Physical etch

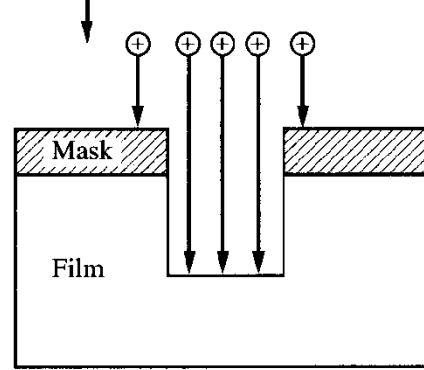
Reactive Neutral Species



Chemical etch

$$S = \frac{F_{reacted}}{F_{incident}}$$

Ionic Species



Physical etch

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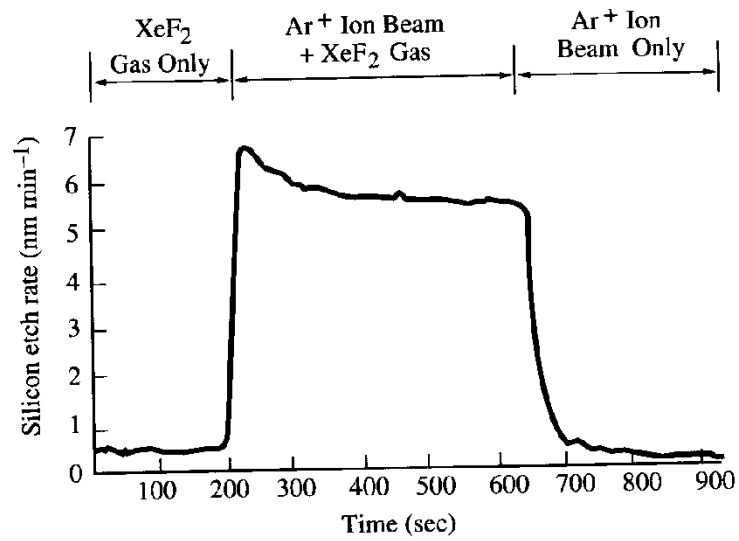
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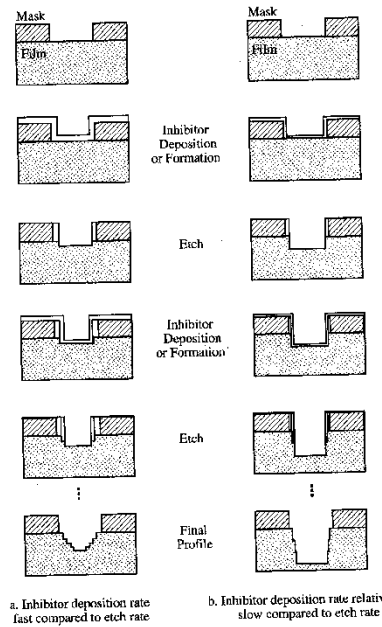
Ion Enhanced Etch



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Reactive Ion Etch: Role of Inhibitors





Self Study: All Dry Etch Processes Described in Plummer

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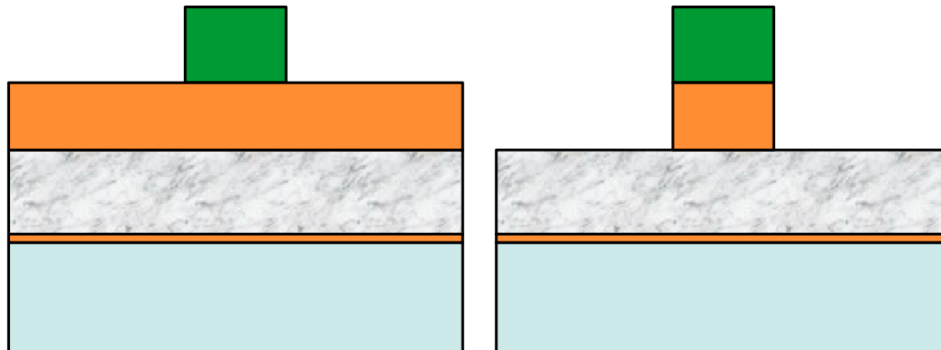
Case Study: Poly-Si Etch for Small Gate Length



Resist trim: Isotropic etching of the resist to reduce the feature size in resist



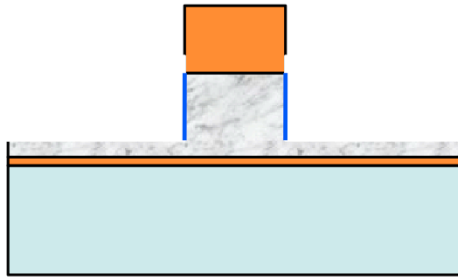
Case Study: Poly-Si Etch for Small Gate Length



**Hard mask etch and in-situ resist strip:
Transfer the pattern to hard mask**



Case Study: Poly-Si Etch for Small Gate Length



Poly-Si etch, step 1: Straight 90° profile, highly anisotropic etch, side walls protected by inhibitors



Poly-Si etch, step 2: More isotropic etch, highly selective

Step 3: Oxide HM etch in HF



Case Study: Poly-Si Etch for Small Gate Length

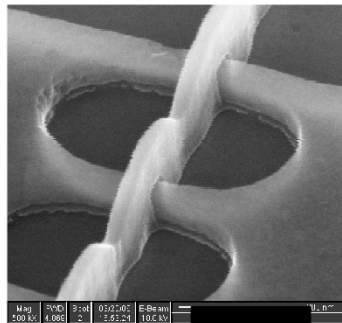
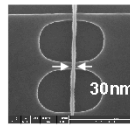
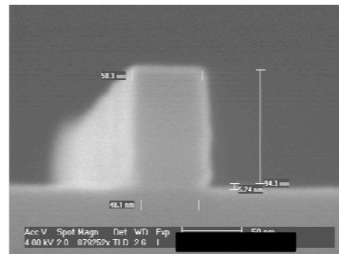


Image courtesy: IMEC

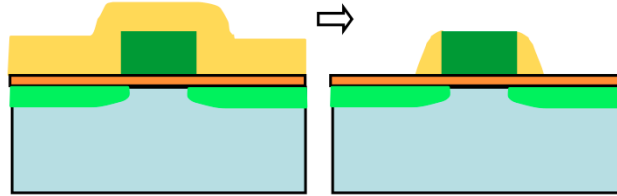
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Case Study: Spacer Etch



- Typical spacer used in VLSI: Si_3N_4
- Poor etch selectivity between Si_3N_4 and Si
- So a SiO_2 liner is used between the nitride and Si
- Anisotropic etching of Nitride → same thickness etched everywhere in the vertical direction

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Case Study: Spacer Etch

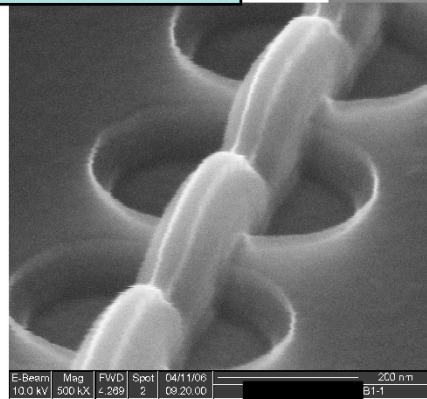
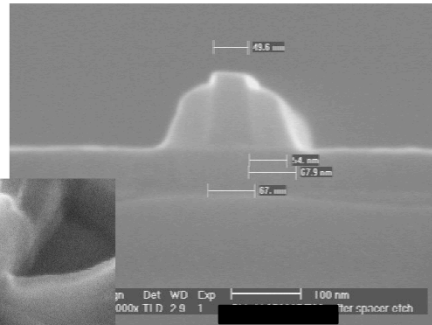
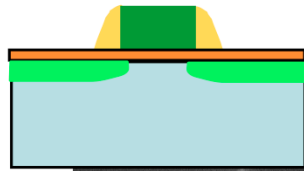


Image courtesy: IMEC