Photolithography

- Process by which patterns are formed on the surface of the wafer
- Needed for selective doping and formation of metal interconnects

3 main components
  - Photoresist - light sensitive polymer
  - Exposure system - irradiates photoresist through a mask
  - Developer - dissolves exposed photoresist

After the photoresist is patterned, the underlying material is etched using wet or dry techniques.

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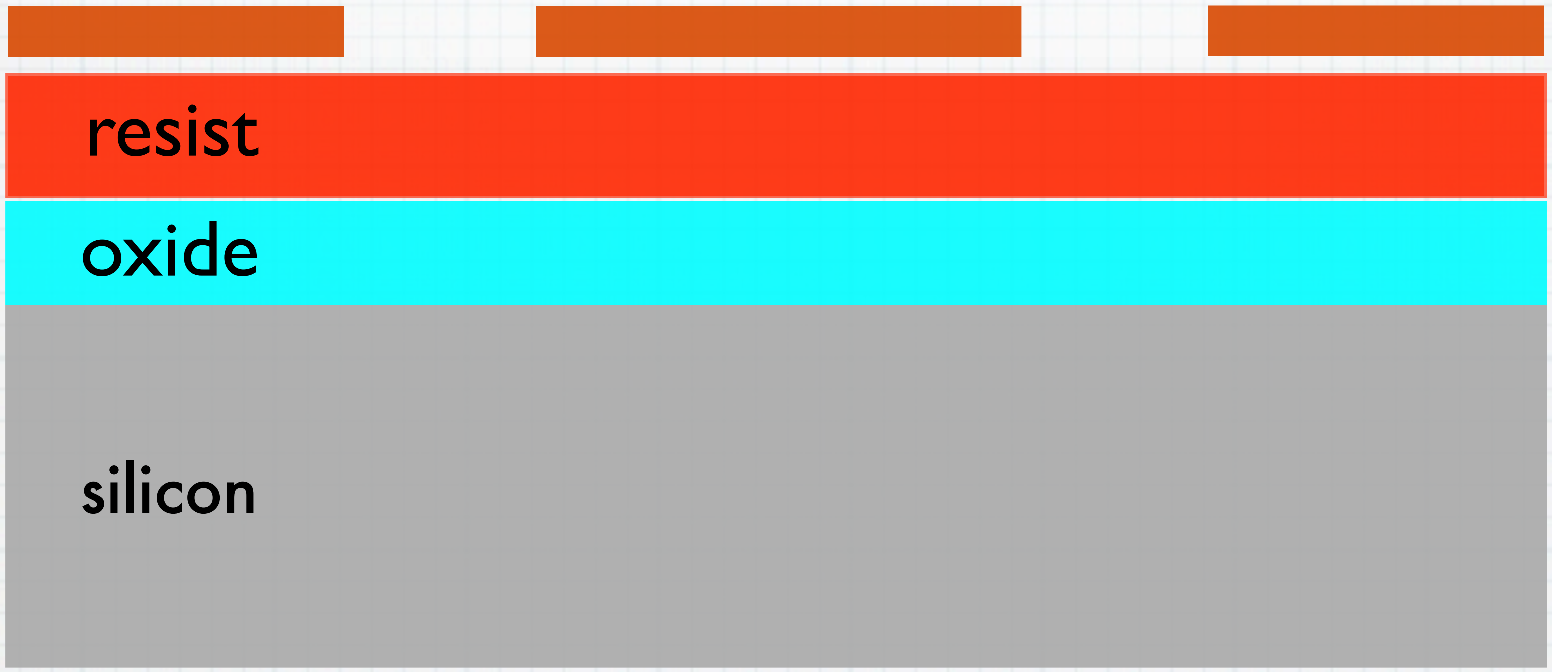
Spin on a layer of photoresist. Typically about 1 μm thick.



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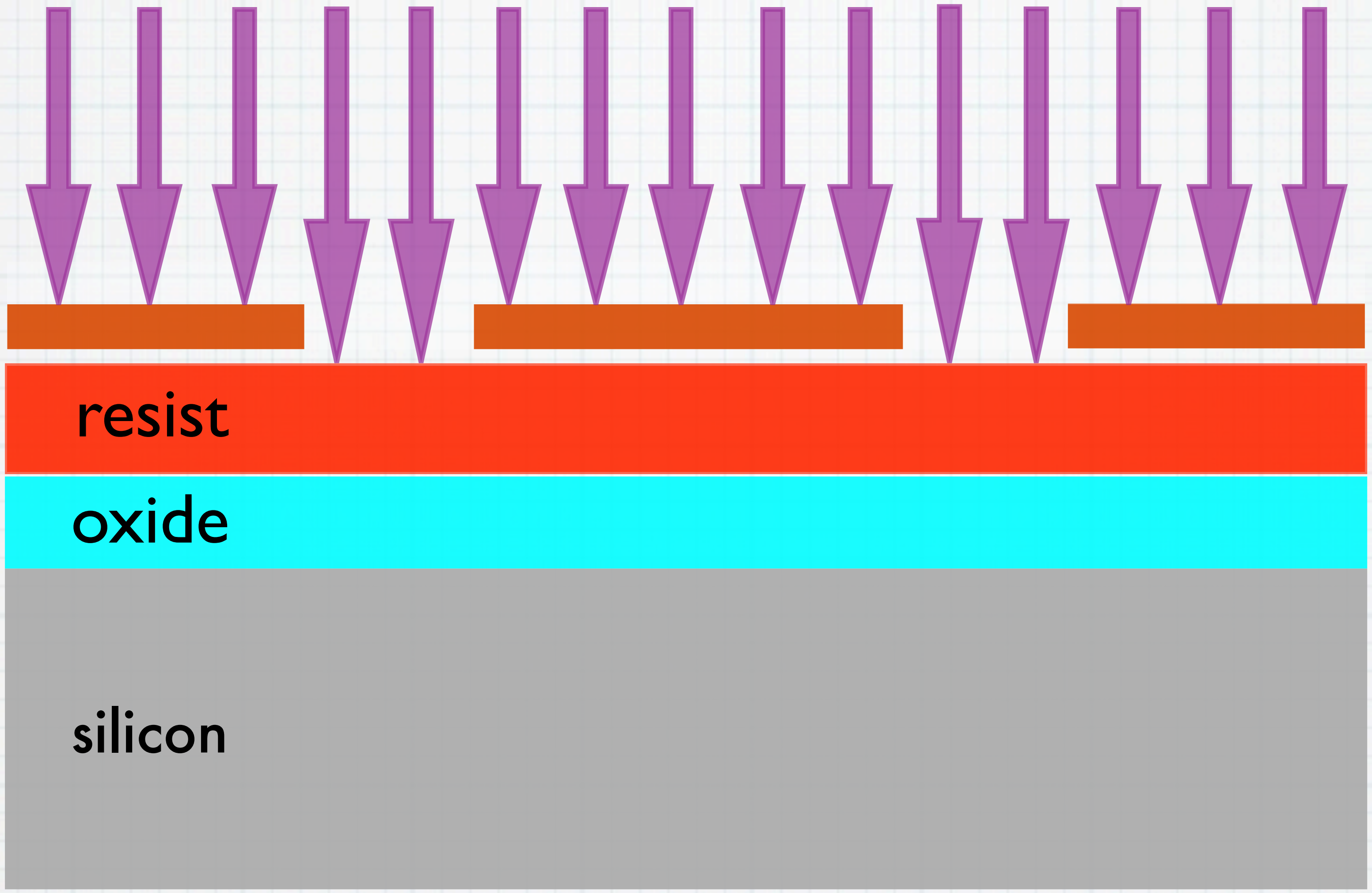
Bring a photomask into alignment with the wafer.



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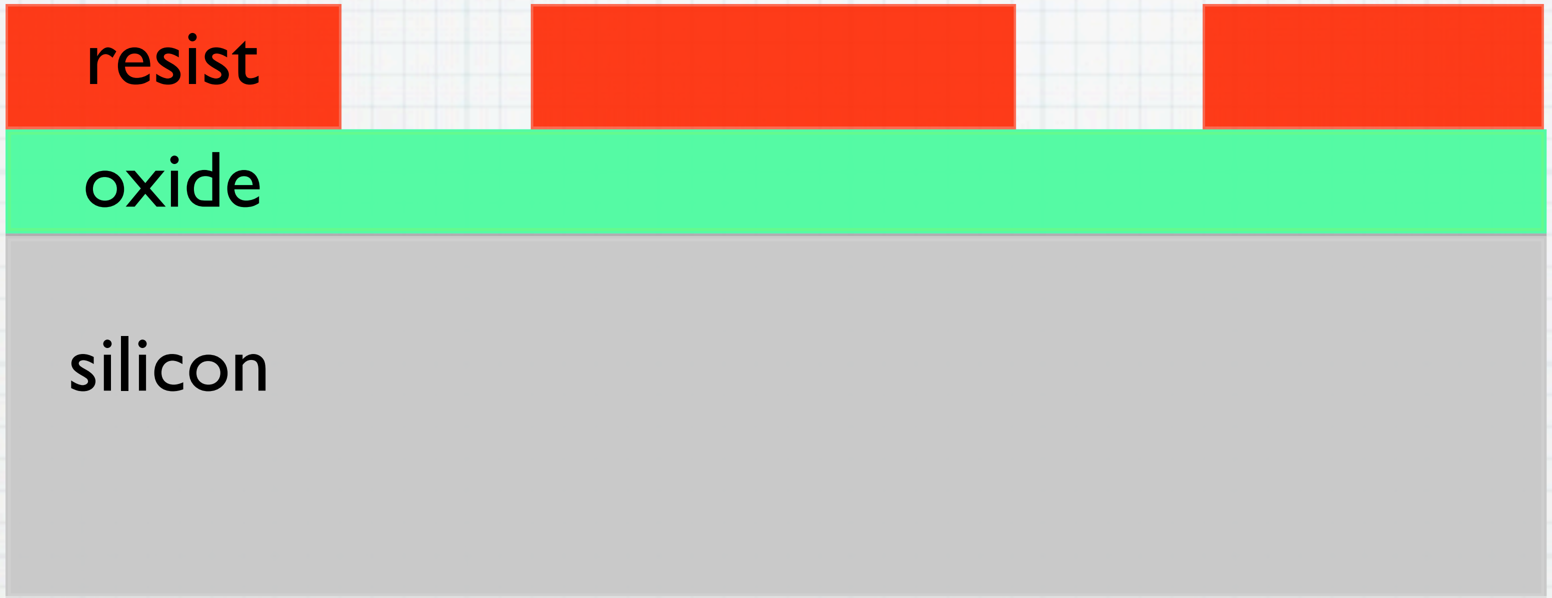
Spin on a layer of photoresist. Typically about 1 μm thick.

Bring a photomask into alignment with the wafer.

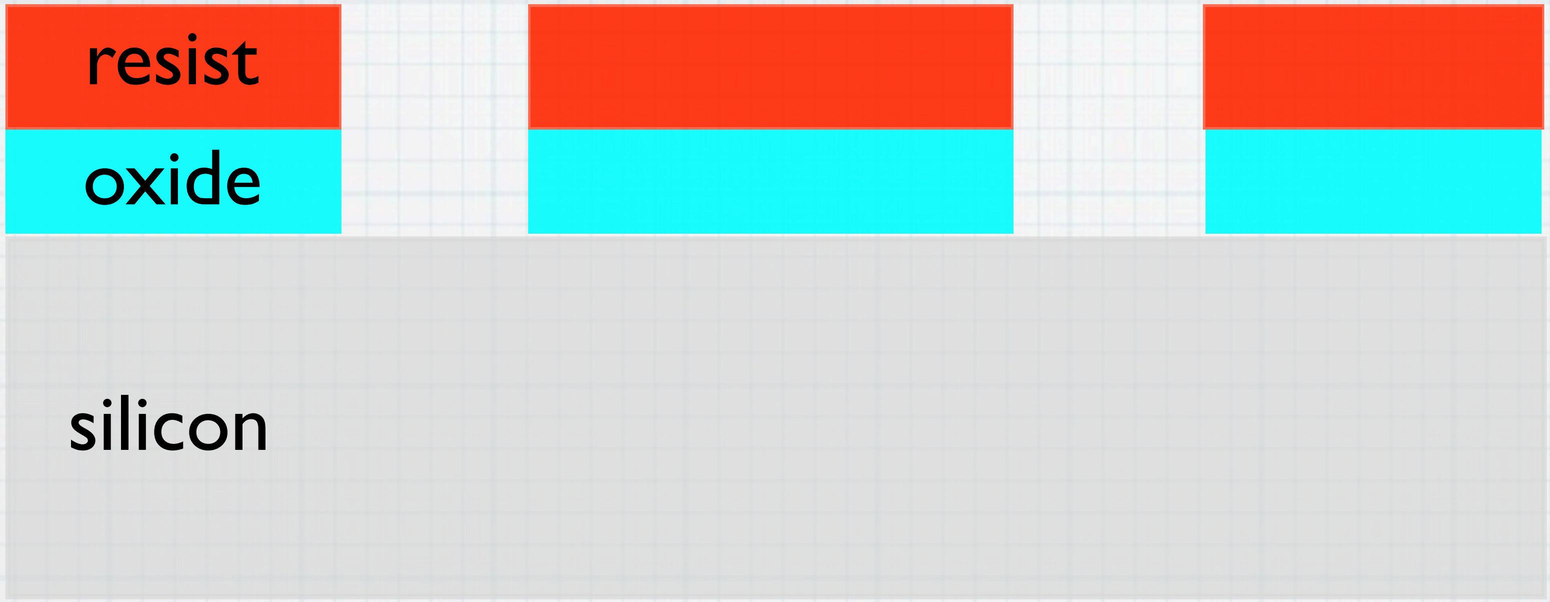
Expose photoresist with UV light through openings in photomask.

The polymer molecules in the exposed regions of photoresist are altered by the absorption of the UV photons. The altered photoresist is more soluble in a developing solution.



Immersing everything into the developer removes the exposed resist. The developer does not affect the masked photoresist (as long as the wafer is not left in the developer too long.) The developer does not affect the silicon or the oxide.

The photoresist serves as a masking layer for etching into the oxide. An acid etch is used to remove the oxide in the exposed regions, transferring the pattern to the oxide layer.



Finally, the photoresist is washed away using a simple solvent, like acetone (finger-nail polish remover). The wafer, with the patterned oxide, is ready to go on to the next step in the process.

Etching

Etching is the process by which patterns are transferred into the oxide (or metal layer, as we'll see later, or even the silicon itself, in some cases).

The simplest approach is use a chemical solution that breaks down the layer to be removed. Generally, the solutions that etch best are acidic liquids. Since the wafer is being immersed in a liquid solution, this type of process is called "wet chemical" etch. (We'll discuss a "dry" etching technique later.)

There has been extensive work to identify and characterize wet chemical etches for a variety of materials.

SiO_2

The chemical reation is

$$SiO_2 + 6HF \rightarrow H_2SiF_6 + 2H_20$$

Since the H_2SiF_6 is a gas soluble in water, the by-products are dissolved. As the reaction progresses, the oxide is slowly dissolved away into the liquid.

For other materials, the etch process (which, of course, use different etch solutions) may involve first oxidizing the material, and then removing the oxide. (Many etches involve H_2O_2 in their formulations.)

Typically, the silicon dioxide etch is “buffered” by adding ammonium fluoride (NH_4F) to the solution. This provides additional fluorine ions, which tend to deplete during the etching process.   So a buffered HF solution will keep its “potency” much longer than a straight HF solution

The buffered etched solutions are know as BHF, or more commonly, as “buffered oxide etch” (BOE).

The etch rate depends on the density of the oxide film (more on this later). Etch rates in the NSF lab tend to be around 60 nm/min (0.06 μm/min). But this is just an estimate, and the each etch should be calibrated in some fashion.

To determine when the oxide layer is completely removed, you can do careful rate calibrations of the particular etch solution that you are using and then simply go by time.

An alternative approach is to use an interesting difference between the surfaces of SiO_2 and Si.

SiO_2 is hydroscopic, meaning that water will stick to the surface. So if you immerse an SiO_2-coated water into an etch solution and then remove it, there will be a layer of liquid adhering to it.

Crystalline Si, on the other hand, is hydrophobic, meaning that the surface can't be wetted. So a Si wafer, on being removed from a liquid solution, will appear to be completely dry.

So by using a test wafer during the etch, and watching for the change in surface wetting characteristics, you can determine when and oxide layer has been removed.

Selectivity

Selectivity is the etch rate ratio between to materials. $S = r_1/r_2$. In order to use a good etch mask, the mask material material much be etched much more slowly than the material that you intend to etch. Also, it is desirable to have good selectivity between the film being etched and the underlying substrate. The silicon/silicon dioxide/photoresist combination is nearly ideal. The selectively ratio between SiO_2 and photoresist in HF is extremely high, as is the ratio between SiO_2 and Si. Other combinations may not work as well.

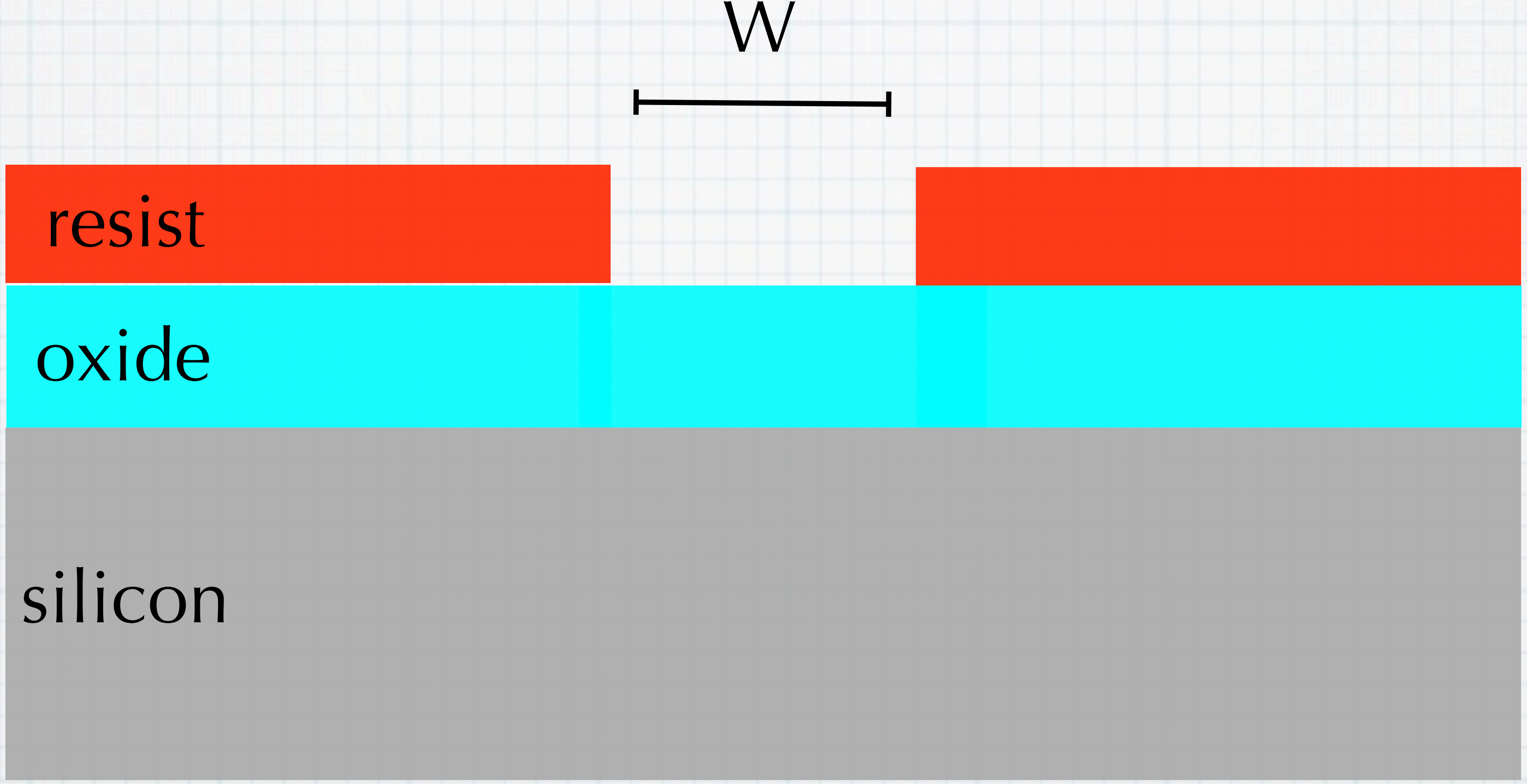
Directionality

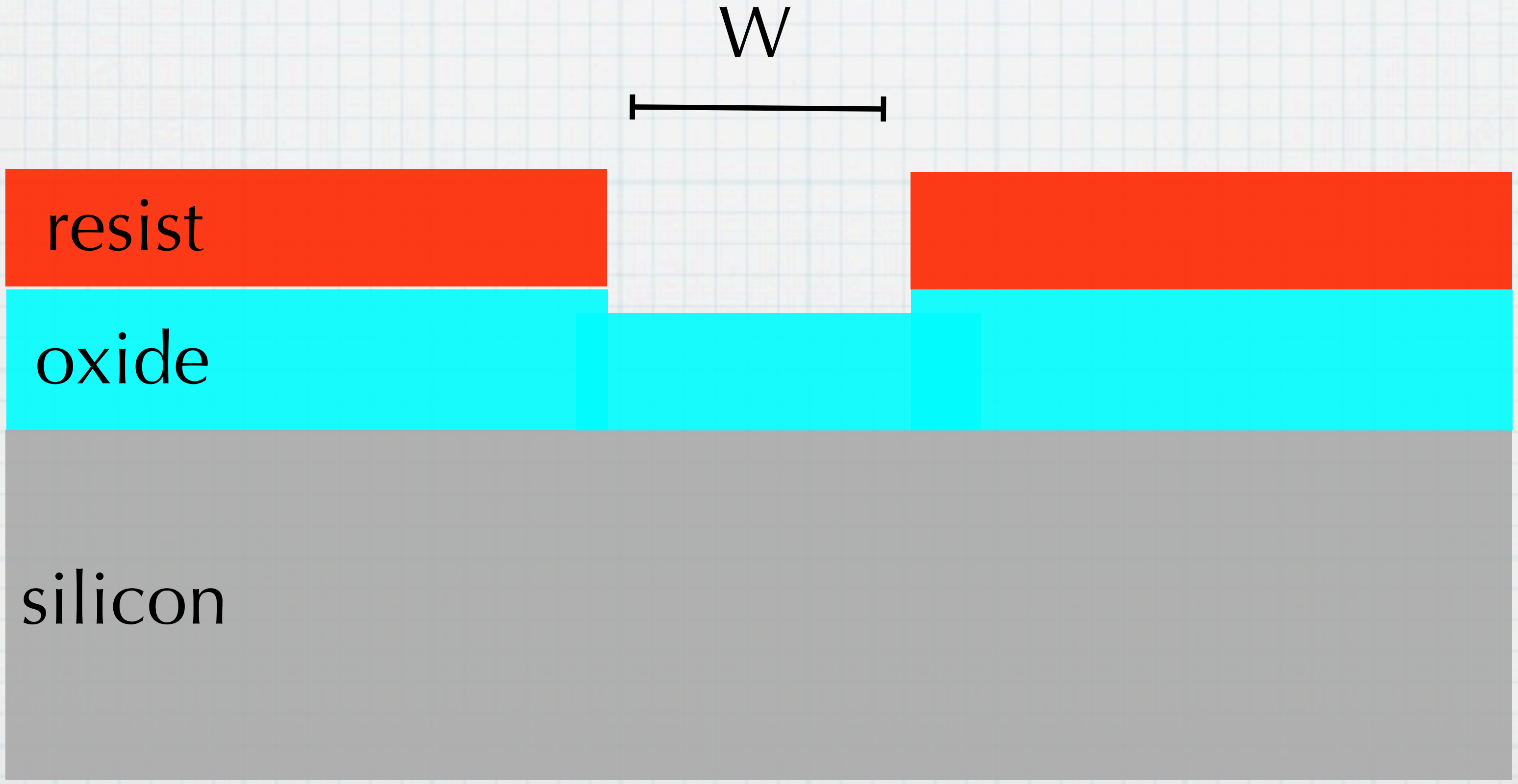
Many wet etches are isotropic, meaning that the etch the same in all directions. In the case of SiO_2, this isn't surprising because the motion of the molecules in the liquid solution is random and the SiO_2 is amorphous. There are no preferred directions.

However, some etches are anisotropic, meaning that they etch in faster some directions than in others. This can lead to some peculiar and interesting etched patterns. For example, a solution of KOH in water is very aniostropic when etching crystalline silicon. The dry etches that we will study later are also aniostropic.

Undercutting

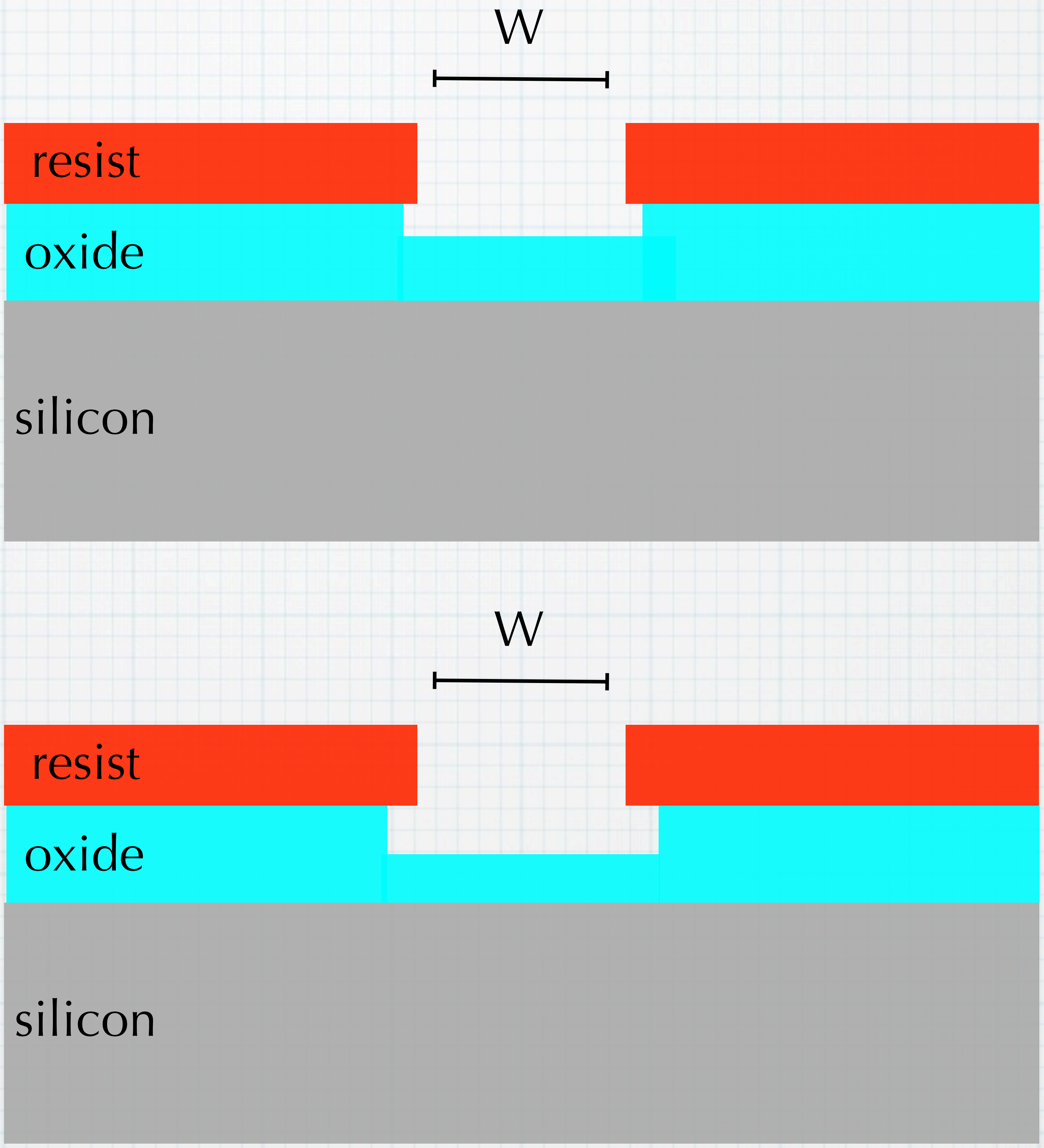
Isotropic etching has one serious drawback. Generally, we are etching thin films, and we are mostly concerned with etching "downward". The isotropic etch will also etch "sideways" in addition to downward.

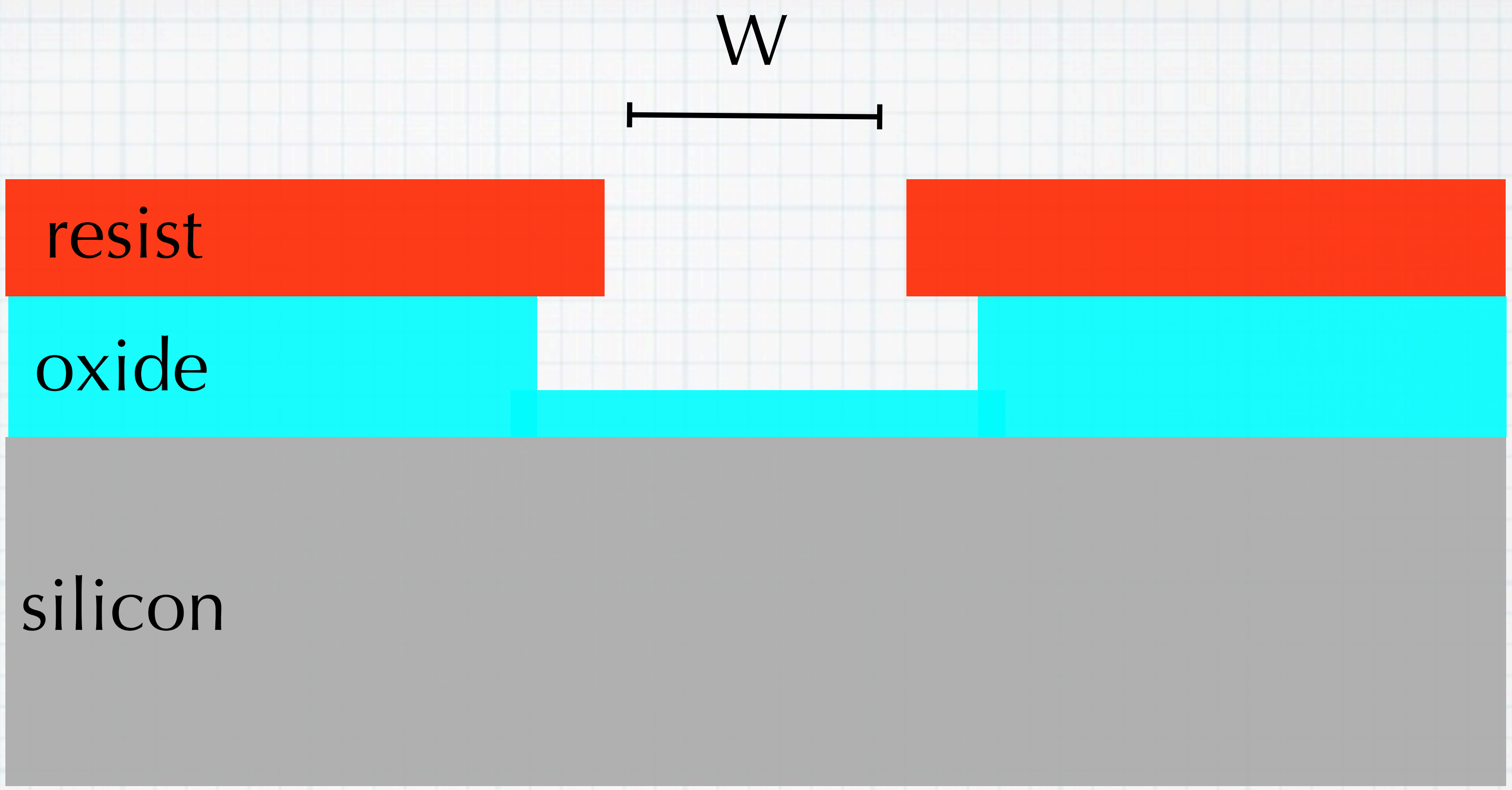




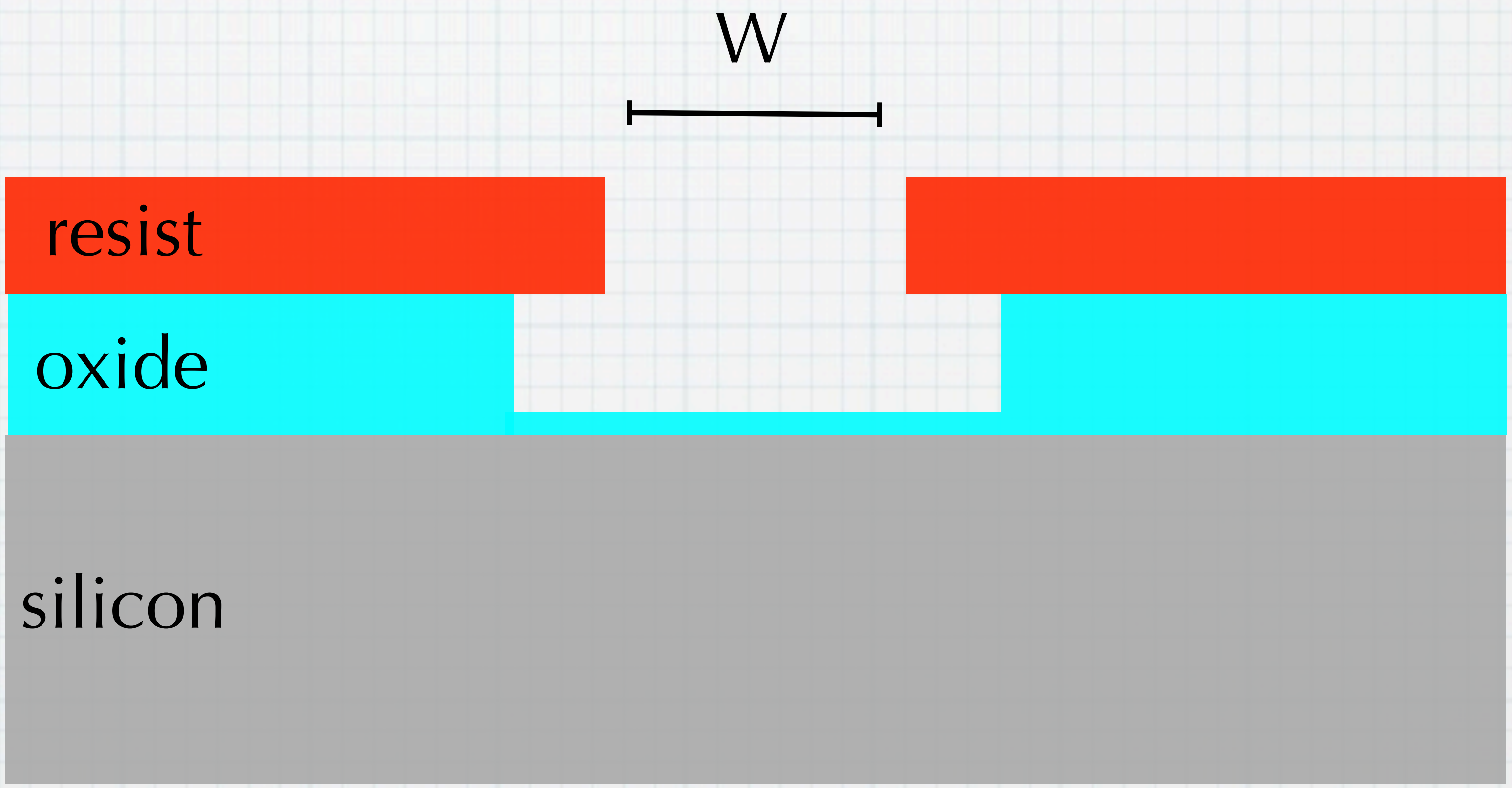
Initially,
all etching
is down

Once sidewalls form, etching will go sideways, too.



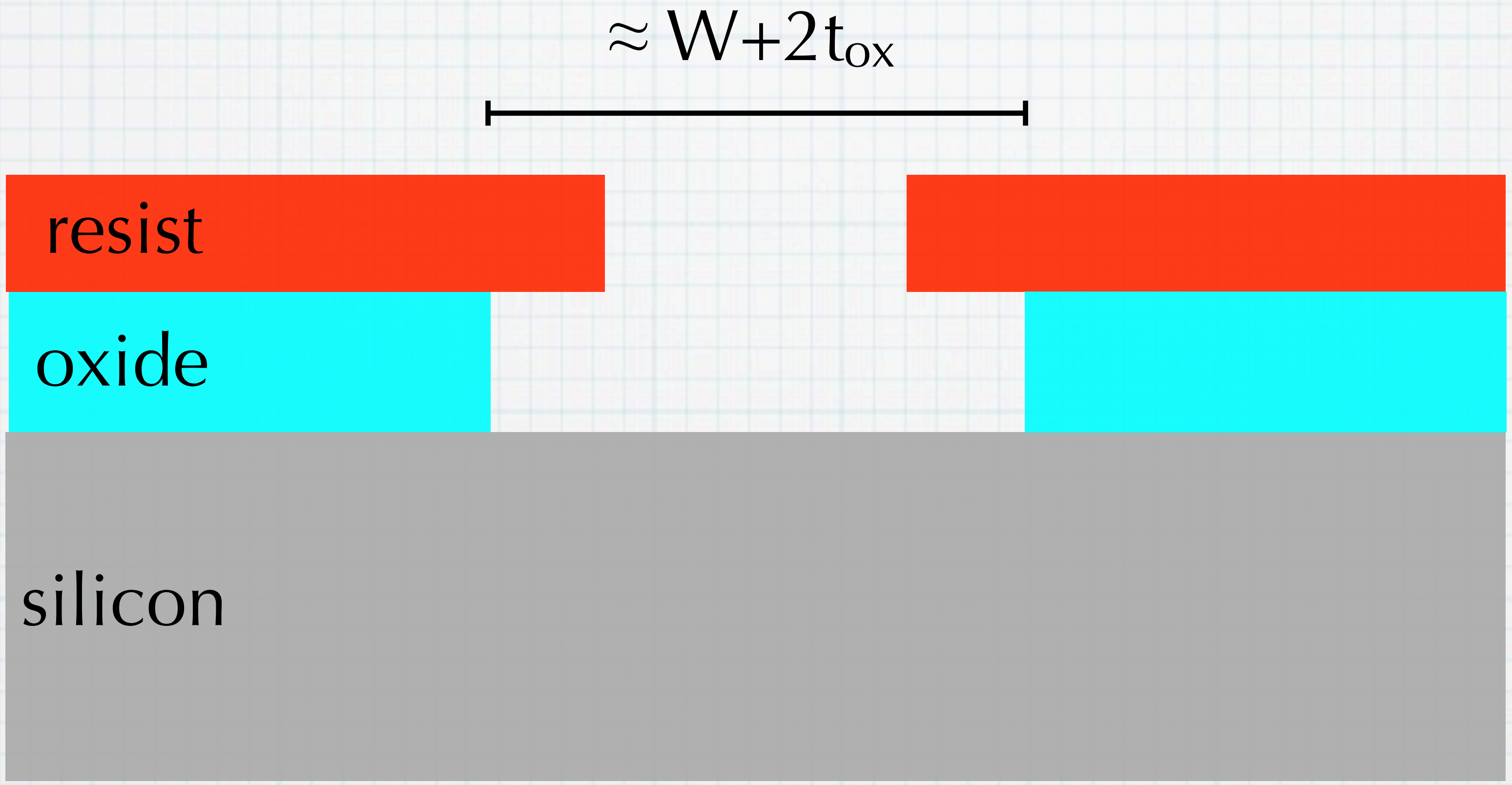


Undercutting gets bigger as the etch progresses



Once the downward etch is completed, the opening in the SiO_2 may be significantly bigger than planned.

For small devices (which need small openings), this is a huge problem. To avoid undercutting, alternative aniostropic etches have been developed.



Also, if the etch were allowed to continue, the sideways etching would continue until eventually all of the SiO_2 would be etched away. So it is important to stop the etch once the substrate has been reached.