6.5.3 Plasma Etching

- **Plasma etching**, also known as **dry etching** (in contrast to *wet* etching) is the universal tool for structure etching since about **1985**. In contrast to all other techniques around chip manufacture, which existed in some form or other *before* the advent of microelectronics, plasma etching was practically unknown before **1980** and outside the microelectronic community.
  - What is Plasma etching? In the most simple way of looking at it, you just replace a liquid etchant by a plasma. The basic set-up is not unlike sputtering, where you not only deposit a layer, but *etch the target* at the same time.
  - So what you have to do is to somehow produce a plasma of the right kind between some electrode and the wafer to be etched. If all parameters are right, your wafer might get etched the way you want it to happen.
- If we naively compare chemical etching and plasma etching for the same materials to be etched - lets take **SiO_2** - we note major differences:

Chemical etching of **SiO_2**	*Plasma etching* of **SiO_2**
Etchant: **$HF + H_2O$** (for etching **SiO_2**.	*Gases:* **$CF_4 + H_2$** (or almost any other gas containing **F**).
Species in solution:: **F^-**, **HF^-**, **$H^+SiO_4^{2-}$**, **SiF_4**, **O_2** - whatever chemical reactions and dissociation produces.	*Species in plasma and on wafer:* **CF_x^+ ($x \leq 3$)**, and all kinds of unstable species not existent in wet chemistry. Carbon based polymers, produced in the plasma which may be deposited on parts of the wafer.
Basic processes: **SiO_2** dissolves	Etching of **SiO_2**, formation of polymers, deposition of polymers (and other stuff) and etching of the deposited stuff, occurs simultaneously
Driving force for reactions: Only "chemistry", i.e. reaction enthalpies or chemical potentials of the possible reactions; essentially equilibrium thermodynamics	*Driving force for reactions:* "Chemistry", i.e. reaction enthalpies or chemical potentials of the possible reactions, including the ones never observed for wet chemistry, near equilibrium, *and* non-equilibrium physical processes", i.e. mechanical ablation of atoms by ions with high energies.
Energy for kinetics: Thermal energy only, i.e. in the **1 eV** range	*Energy for kinetics:* Thermal energy, but also kinetic energy of ions obtained in an electrical field. High energies (several **eV** to hundreds of **eV**) are possible.
Anisotropy: None; except some possible **{hkl}** dependence of the etch rate in crystals.	*Anisotropy:* Two major mechanisms **1.** Ions may have a preferred direction of incidence on the wafer. **2.** Sidewalls may become protected through preferred deposition of e.g. polymers Completely isotropic etching is also possible
Selectivity: Often extremely good	*Selectivity:* Good for the chemical component, rather bad for the physical component of the etching mechanism. Total effect is open to optimization.

- If that looks complicated, if not utterly confusing - that's because it is (and you thought just chemistry by itself is bad enough).
  - Plasma etching still has a strong black art component, even so a lot of sound knowledge has been accumulated during the last **20** years.
  - It exists in countless variants, even for just *one* material.
  - The many degrees of freedom (all kind of gases, pressure and gas flux, plasma production, energy spread of the ions, ...), or more prosaically, the many buttons that you can turn, make process development tedious on the one hand, but allow optimization on the other hand.
- The two perhaps most essential parameters are: **1.** the relative strength of chemical to physical etching, and **2.** the deposition of polymers or other layers on the wafer, preferably on the sidewalls for protection against lateral etching.

  - The physical part provides the absolutely necessary anisotropy, but lacks selectivity
  - The chemical part provides selectivity.
- Polymer deposition, while tricky, is often the key to optimized processes. In our example of **SiO_2** etching, a general finding is:
  - **Si** and **SiO_2** is etched in this process, but with different etch rates that can be optimized
  - The (chemical) etching reaction is always triggered by an energetic ion hitting the substrate (this provides for good anisotropy).
  - The tendency to polymer formation scales with the ratio of **F/H** in the plasma. The etching rate increases with increasing **F** concentration; the polymerization rate with increasing **H** concentration.
  - Best selectivity is obtained in the border region between etching and polymer formation. This will lead to polymer formation (and then protecting the surface) with **Si**, while **SiO_2** is still etched. The weaker tendency to polymer formation while etching **SiO_2** is due to the oxygen being liberated during **SiO_2** etching which oxidizes carbon to **CO_2** and thus partially removes the necessary atoms for polymerization
- Enough about plasma etching. You get the idea.
  - A taste treat of what it really implies can be found in an advanced module.