Gettering

Gettering is a process by which unwanted impurities are removed by providing an alternative location (a "getter") where they prefer to reside (their energy is lower).

Gettering originated in vaccuum tubes, where Ti was used to getter trace remnant gases.

Similarly in Si ICs we may want to get rid of unwanted trace elements.

For integrated circuits, the primary unwanted impurities are metals, which:

- Increase recombination.
  - Increase junction leakage.
  - Reduce life-times (reduces solar cell efficiency, DRAM efficiency).
  - Reduce β in BJT's.
- Segregate to interfaces resulting in interface states.
  - Noise.
  - Threshold voltage shifts by trapping charges.
  - Degraded Si/SiO_2 interface.
- Precipitate.
  - Alternative conducting paths.

It is desirable, therefore to remove metals from the active device regions to either the backside or to the bulk of the wafer.

Sources of unwanted impurities include:

- Initial melt
- Chemicals (cleaning/etching solutions, photoresist)
- Handling (wafer tracks, tweezers, boxes, particles etc.)
- Process chambers (stainless steel, quartz)

The first requirement of successful gettering is providing a region away from the active device regions to which metals will segregate in a strongly preferential fashion.

Possible extrinsic getters include:

Damage: Rather than being a distortion within the crystal lattice, the metal may prefer to be in a damaged region, where it may be satisfying some dangling bonds, or simply causing less distortion, thereby reducing total free energy.

- Mechanical Damage: Roughening with abrasive or scribing with diamond scribe.
- Laser Damage: Cleaner. Generates amorphous or polysilicon region.
- Ion Implantation (Ar ions): Generates an amorphous layer and high density of Ar inhibits recrystallization.

Film Deposition: Preferential segregation and grain boundaries.

- Polysilicon Films: Grain boundaries provide gettering sites.
- Deposited Nitride Film: Not as effective but has been used.

Heavy Doping: Preferential segregation to heavily doped regions due to Fermi level effects, pairing, decoration of precipitates.

- Phosphorus: N-type doping most effective.

Outdiffusion: Reaction of metals to form volatile compounds.

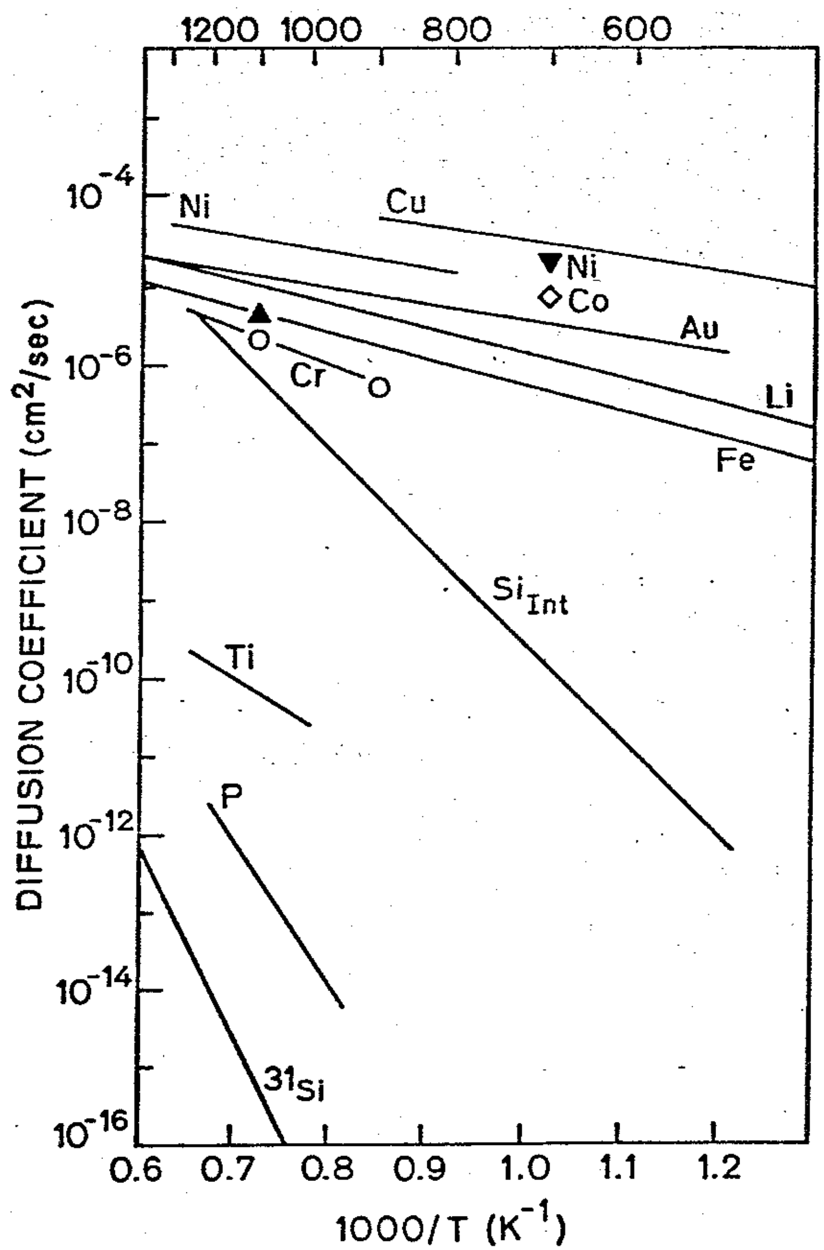
- HCl: Used in inert or oxidizing ambient.

Important Note: Getter has to be stable over the entire process.

For example, if ion-implantation damage anneals out during subsequent processing, the previously gettered metals are re-released. (Reason for use of Ar rather than Si implantation.)

The second requirement for gettering is that the target impurities must be able to diffuse from active device regions to getter (often this means through full wafer thickness).

The diffusion coefficients of metals in Si is generally orders of magnitude higher than B or P etc. (dopants), but there is a large range.



Slow diffusers are difficult to remove, but also less likely to arise from contamination late in process.

Experimental observation: gettering of slower-diffusing metals is much faster than expected by diffusion coefficient calculations.

To see why, we can look at gold as an example.

Gold can be either substitutional or interstitial. Vast majority of Au is substitutional, but diffusion is primarily via interstitial species.

$$C_{\mathrm{Au}_s} >> C_{\mathrm{Au}_i} \tag{1}$$

$$D_{\mathrm{Au}_s} << D_{\mathrm{Au}_i} \tag{2}$$

$$D_{\mathrm{Au}_s} C_{\mathrm{Au}_s} << D_{\mathrm{Au}_i} C_{\mathrm{Au}_i} \tag{3}$$

This is similar to phosphorus diffusion.

$$\mathrm{Au}_s \Leftrightarrow \mathrm{V} + \mathrm{Au}_i$$

$$\mathrm{Au}_s + \mathrm{I} \Leftrightarrow \mathrm{Au}_i$$

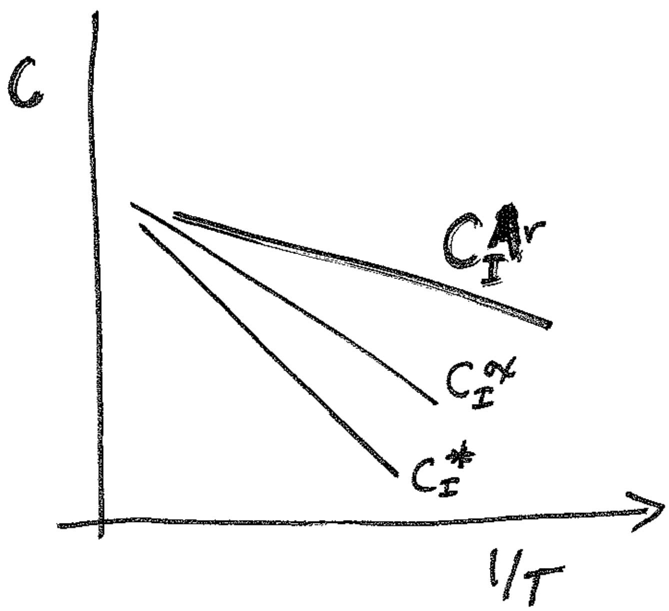
$$D_{\mathrm{Au}} \cong D_{\mathrm{Au}_i} \left(\frac{C_{\mathrm{Au}_i}}{C_{\mathrm{Au}}} \right) \tag{4}$$

If V$\Uparrow$ $\mathrm{Au}_i \Downarrow$, I$\Uparrow$ $\mathrm{Au}_i \Uparrow$

Thus if you inject interstitials during gettering, the effectiveness can be greatly improved for some metals.

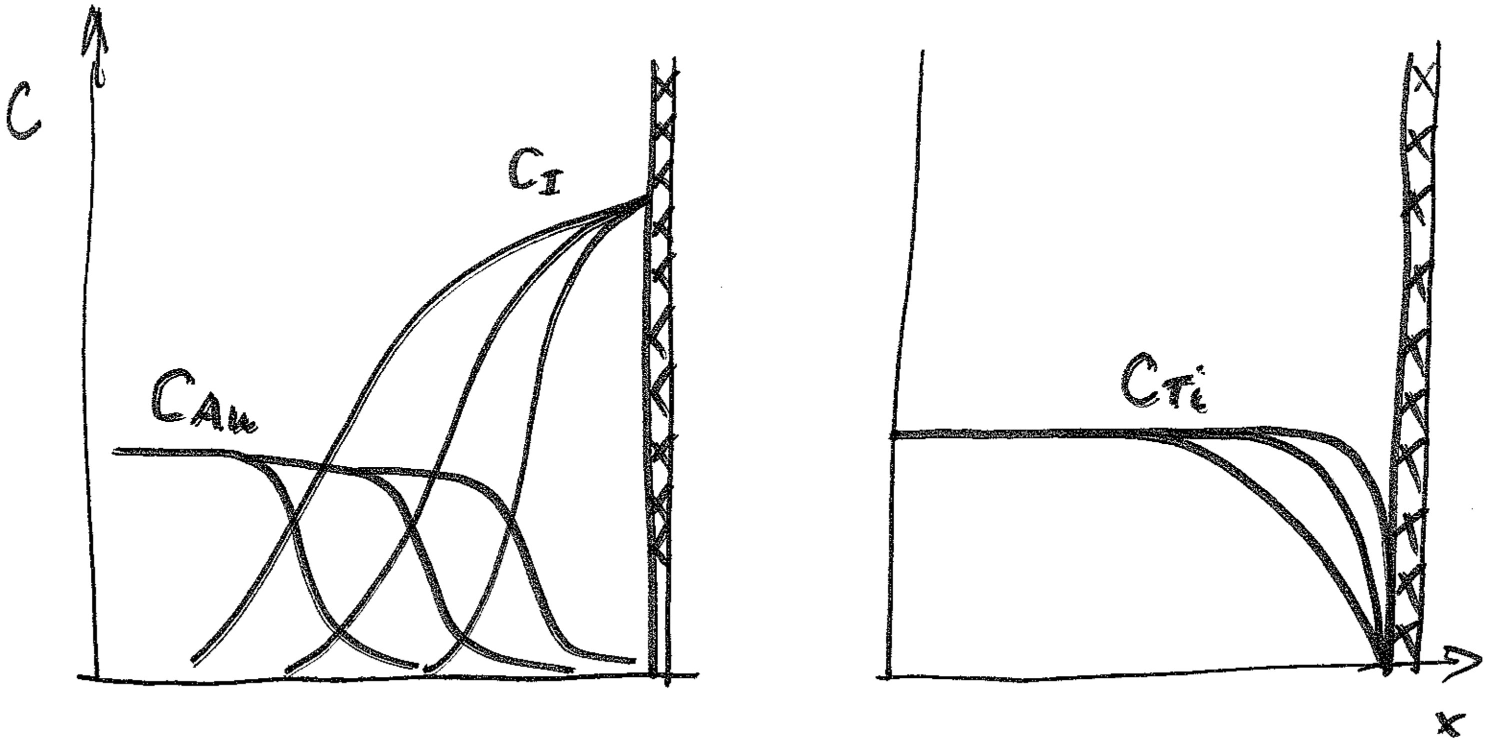
For example, oxidation imcreases Au diffusivity (since it's due to Au_i diffusion which is higher than $\mathrm{D}_{\mathrm{Au}_s}$).

Some gettering procedures generate interstitials much more effectively than oxidation (particularly at low temperatures): Ar implantation, P diffusion



Some interstitial metals, such as Au and Pt, diffuse much more rapidly than silicon interstitials.

Thus diffusion is limited by diffusion of self-interstitials, not interstitial impurities.



Other metals (like Ti) are primarily interstitial, but diffuse slowly even as interstitials. Thus they are unaffected by interstitial injection.

Interstitial injection provides a mechanism for enhancing metal diffusion at low temperatures.

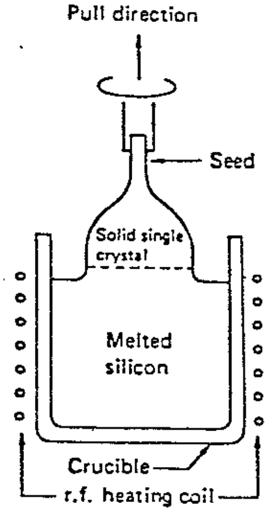
High temperature getters (no I injection):

- Film deposition
- Mechanical damage

Low temperature getters: (I injection):

- Phosphorus diffusion
- Argon implantation

Intrinsic Gettering



During crystal growth, large concentrations of O and C are inorporated into silicon boule.

The concentrations of O and C can approach the solubilities of O and C at the melting point of silicon.

Can reduce O and C incorporation by changing pull-rates or using magnetic fields (O in the ppm range).

When the temperature is reduced, the solubility is reduced and oxygen tends to precipitate out.

Oxygen precipitation has positive and negative aspects:

If there are oxygen precipitates in the active device regions, they can destroy devices.

Oxygen precipitates in bulk provide sites for gettering of metals (decorate precipitates and associated stacking faults).

Presence of oxygen also makes silicon more robust (less brittle) which is particularly important for larger wafer sizes.

The goal then is to keep the oxygen precipitates, but limit them to the bulk while removing them from active device regions.

Therefore, steps followed are:

1. **Out-diffusion.** High T ($\sim$ 1100°C) Ar ambient. O depleted near surfaces. Form denuded zone.

2. **Nucleation.** Low T (650 - 750°C) Large supersaturation so many small nuclei form, but grow very slowly.

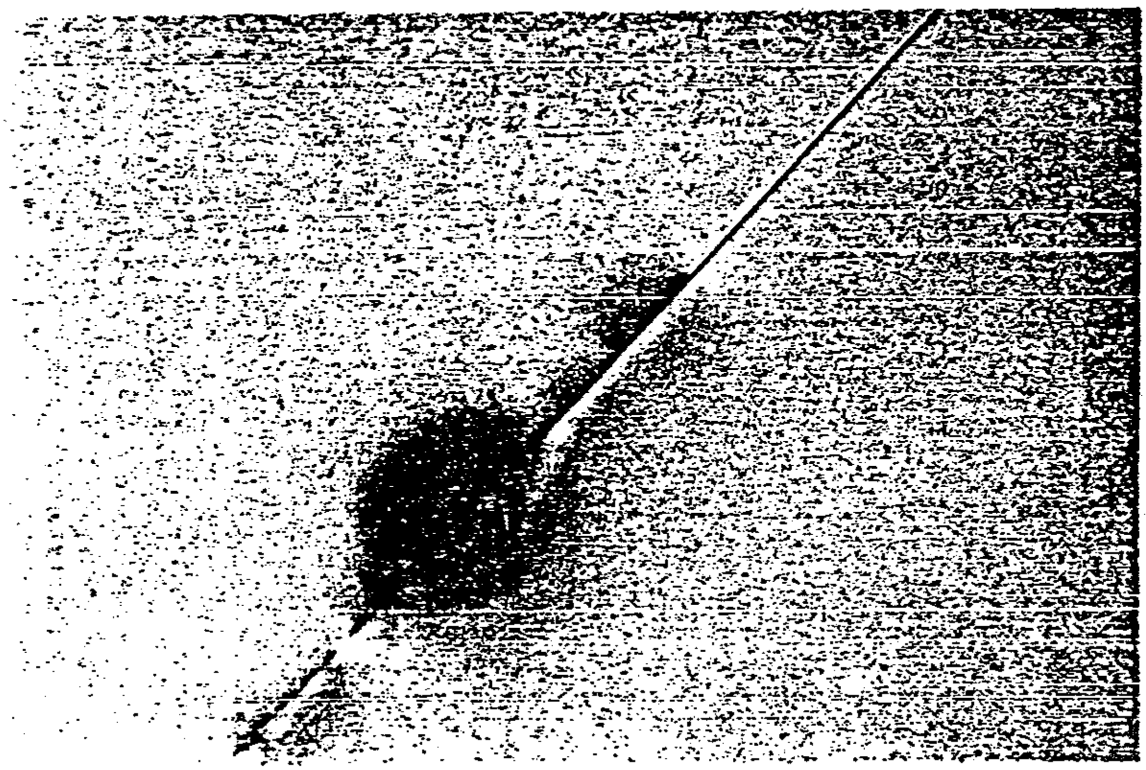
3. **Precipitate growth.** High T (1000 - 1100°C) Existing precipitates grow relatively rapidly (faster O diffusion).

The oxygen precipitation is like internal oxidation, with factor of 2.2 expansion. Thus oxygen precipitation injects interstitials, assisting metal diffusion.

$$2\mathrm{Si} + \mathrm{O}_2 \longrightarrow \mathrm{SiO}_2 + \mathrm{I} \tag{5}$$

Interstitial injection enhances diffusion and helps metals diffuse to gettering sites.

Interstitial supersaturation also results in growth of stacking faults at precipitates, which increase effectiveness of precipitates as gettering sites.



Since C is smaller than silicon, incorporation of C into precipitates can provide some free volume, enhancing precipitation.

An advantage of intrinsic getters is that they are closer to active device regions than backside.

Also, they are distributed and so have very large total capture cross-section.