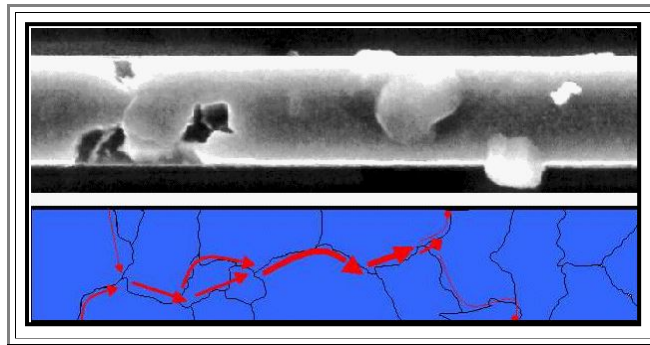


Electromigration

Advanced

- ▶ The picture below shows an **Al** circuit line of an **IC**; it is about **1 μm** across.
 - It has been "**stressed**" for some time by running a **DC** current through it at temperatures and current densities somewhat higher than what it would encounter in normal operation. The minus pole was on the left. The current density may have been in the **10⁵ A/cm²** region.
 - This is a hell of a current density - several orders of magnitude larger than what you would feel comfortable with in normal wires.
- ▶ The conductor line obviously has suffered from this treatment. In its left part - close to the minus pole - holes or pits have formed, and in its right part - close to the plus pole - we have extrusions or hillocks.
 - Obviously, substantial amounts of **Al** have migrated to the right: leaving back holes and generation hillocks. and
 - Considering that a huge number of electrons was driven from left to right by the current source, it almost looks as if those electrons have pushed some **Al**-atoms along.
- ▶ This is indeed what has happened. The phenomena of **electromigration** is, in general terms, a drift in the diffusion currents induced by the "**electron wind**".
 - Remember that there is always some self-diffusion, but without any driving forces, the net diffusion current in one direction is always cancelled by the exact opposite current in the other direction.
 - Exactly how those electrons push atoms about, is still a bit obscure, but the effect is clearly there, and appreciable in finite time spans if the current densities are extremely large.



- ▶ You thus would expect that electromigration scales with the [self-diffusion coefficient](#), and thus is more severe in materials with a low melting point.
 - Yes, but classical self-diffusion is a bulk property. In our poly-crystalline **Al**, we also have diffusion along grain boundaries, which is generally much faster than bulk diffusion.
 - A more detailed analysis of the picture above (which, incidentally, are from the thesis work of Dipl.-Ing. Wedemeyer in **1998**) that includes the grain boundaries clearly demonstrates that grain boundaries indeed provide the main pathway for the movement of the **Al** atoms.
 - ▶ At the holes, the cross-section of the **Al** wire is reduced, i.e. its local resistance **R** is larger, and the locally dissipated power $L = I^2 \cdot R$ at a constant current **I** goes up.
 - The wire heats up at the holes, electromigration becomes more severe, holes get bigger, and soon you have a complete interruption of the current path and thus the end of your **IC**.
 - ▶ We have a problem. As dimensions shrink by a factor of κ , the cross-sectional area of the **Al** lines tends to shrink by κ^2 , but the current only goes down linearly with κ .
 - With shrinking dimensions current densities thus tend to go up, and electromigration in pure **Al** (or **Al** with some **Si** to prevent [spiking](#)) would have made integrated circuits with a life time of **10** years simply impossible in the **80**s of the last century.
 - You must do something. Avoiding grain boundaries roughly parallel to the wire helps, but how are going to do this? Well, there are some tricks which help to create the "bamboo structure" you want, but this would not be sufficient.
- So you do what you **always** do in this kind of situation: You add some dirt to your **Al** and hope for the best.
- ▶ Maybe, the right element "poisons" the grain boundaries, making grain boundary diffusion for **Al** atoms more difficult. Or maybe.....
 - Having a "theory" or just a hunch to work from helps; but not too much. Doing is what really helps. And yes, if you add about **0.5 %** of **Cu**, electromigration becomes less severe. This is also true for other elements, but **Cu** is what is mostly used.
 - However, if only a tiny fraction of that **Cu** ever diffuse into the **Si**, it will kill your device. Also, your etching process for **Al** may suddenly not work anymore. And your **Al** metallization now might be more sensitive to corrosion. And the adhesion of the next layer is now different. And....

- You get the drift: There will always be a lot of demanding work out there for highly qualified people like you!