3.5.2 Mechanisms of Electrical Breakdown

What are the atomic mechanisms by which breakdown occurs or dielectrics fail? This is a question not easily answered because there is no general mechanism expressible in formulas. Most prominent are the following disaster scenarios:

Thermal breakdown

- A tiny little current that you can't even measure is flowing *locally* through "weak" parts of the dielectric. With increasing field strength this current increases, producing heat *locally*, which leads to the generation of point defects. Ionic conductivity sets in, more heat is produced *locally*, the temperature goes up even more.... - *boooom*!
- This is probably the most common mechanism in run-of-the-mill materials which are usually not too perfect.

Avalanche breakdown

- Even the most perfect insulator contains a few free electron. Either because there is still a non-zero probability for electrons in the conduction band, even for large band gaps, or because defects generate some carriers, or because irradiation (natural radioactivity may be enough) produces some.
- In large electrical field these carriers are accelerated; if the field strength is above a certain limit, they may pick up so much energy that they can rip off electrons from the atoms of the materials. A chain reaction then leads to a swift ***avalanche** effect*; the current rises exponentially ... *boom*!

Local discharge

- In small cavities (always present in sintered ceramic dielectrics) the field strength is even higher than the average field (ϵ is small)- a microscopic arc discharge may be initiated. Electrons and ions from the discharge bombard the inner surface and erode it. The cavity grows, the current in the arc rises, the temperature rises ... - *boooom*!

Electrolytic breakdown

- Not as esoteric as it sounds! Local electrolytical (i.e involving moving ions) current paths transport some conducting material from the electrodes into the interior of the dielectric. Humidity (especially if it is acidic) may help. In time a filigree conducting path reaches into the interior, reducing the local thickness and thus increasing the field strength. The current goes up....*booom*!
- This is a very irreproducible mechanism because it depends on many details, especially the local environmental conditions. It may slowly built up over years before it suddenly runs away and ends in sudden break-through.

Do the incredibly good dielectrics in integrated circuits fail eventually? After all, they are worked at very high field strength, but the field never increases much beyond its nominal value.

- The answer is that they *do* fail. The mechanisms are far from being clear and it is one of the more demanding tasks in the field to predict the life-time of a dielectric in a chip. Empirically, however, an interesting relation has been found:
- The dielectric will fail after a certain amount of charge has been passed through it - very roughly about **1 As**. This allows to test the chip dielectrics: A very small current is forced through the dielectric; the voltage necessary to do that is monitored. If the voltage rapidly goes down after about **1 As** of total charge has been passed, the dielectric is **OK**. Now its life time can be predicted: Since every time the voltage is on, a tiny little current flows, the life time can be roughly predicted from the leakage current and the average frequency of voltage switching. About **10 a** should be obtained.