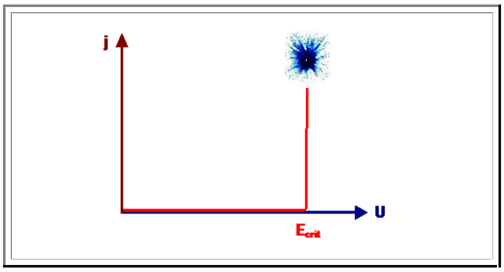
3.5 Electrical Breakdown and Failure

3.5.1 Observation of Electrical Breakdown and Failure

As you know, the **first law of Materials science** is "Everything can be broken". Dielectrics are no exception to this rule. If you increase the voltage applied to a capacitor, eventually you will produce a big bang and a lot of smoke - the dielectric material inside the capacitor will have experienced "**electrical breakdown**" or electrical break-through, an irreversible and practically always destructive sudden flow of current.

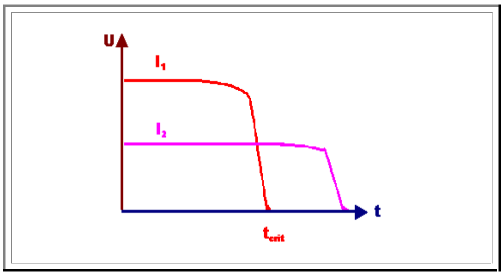
- The critical parameter is the field strength ***E*** in the dielectric. If it is too large, breakdown occurs. The (***DC***) current vs. field strength characteristic of a dielectric therefore may look look this:



- After reaching $\boldsymbol{E}_{\mathbf{crit}}$, a sudden flow of current may, within very short times (**10^{-8} s**) completely destroys the dielectric to a smoking hot mass of undefinable structure.
- Unfortunately, $\boldsymbol{E}_{\mathbf{crit}}$ is *not* a well defined material property, it depends on many parameters, the most notable (besides the basic material itself) being the production process, the thickness, the temperature, the internal structure (defects and the like), the age, the environment where it is used (especially humidity) and the time it experienced field stress.

In the cases where time plays an essential role, the expression "**failure**" is used. Here we have a dielectric being used at nominal field strength well below its breakdown field-strength for some time (usually many years) when it more or less suddenly "goes up in smoke". Obviously the breakdown field strength decreases with operating time - we observe a failure of the material.

- In this case the breakdown may not be explosive; but a leakage current may develop which grows over time until a sudden increase leads to total failure of the dielectric.
- The effect can be most easily tested or simulated, by impressing a constant (*very small*) current in the dielectric and monitoring the voltage needed as a function of time. Remember that by definition you cannot have a large current flowing through an insulator = dielectric; but "ein bißchen was geht immer" - a tiny little current is always possible if you have enough voltage at your disposal. A typical voltage-time curve may then look like this:



- The voltage needed to press your tiny test current through the dielectric starts to decrease rapidly after some time - hours, days, weeks, ..., and this is a clear indication that you dielectric becomes increasingly leaky, and will go up in smoke soon.
- A typical result is that breakdown of a "good" dielectric occurs after - very roughly - **1 C** of charge has been passed.

The following table gives a rough idea of critical field strengths for certain dielectric materials

Material	Critical Field Strength [kV/cm]
Oil	200
Glass, ceramics	200...400
Mica	200...700
Oiled paper	1800
Polymers	50...900
SiO_2 in **ICs**	> 10 000

- The last examples serves to remind you that **field strength** is something *totally different from voltage*! Lets look at typical data from an integrated memory circuit, a so- called ***DRAM*** , short for **Dynamic Random Access Memory**. It contains a capacitor as the central storage device (no charge **= 1**; charge **= 0**). This capacitor has the following typical values:
  - *Capacity* ≈ **30 fF** (femtofarad)
    Dielectric: ***ONO***, short for three layers composed of Oxide (**SiO_2**), Nitride (**Si_3N_4**) and Oxide again - together about **8 nm** thick!
    Voltage: **5 V**, and consequently
    Field strength **$E = 5/8$ V/nm ≈ $6 \cdot 10^6$ V/cm**.
  - This is *far above the critical field strength* for practically all *bulk* materials! We see very graphically that high field strength and voltage have nothing to do with each other. We also see for the first time that materials in the form of a *thin film* may have properties quite different from their bulk behavior - fortunately they are usually much "better".
- Last, lets just note in passing, that electrical breakdown is *not* limited to insulators proper. Devices made from "*bad* " conductors - i.e. semiconductors or ionic conductors - may contain regions completely depleted of mobile carriers - space charge regions at junctions are one example.
  - These insulating regions can only take so much field strength before they break down, and this may severely limit their usage in products

Questionaire
Multiple Choice questions to 3.5.1