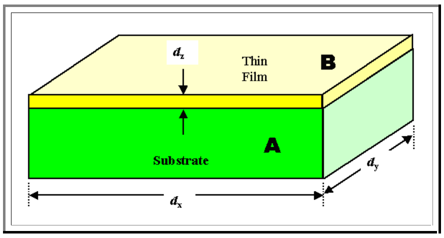
3.2 Mechanical Properties

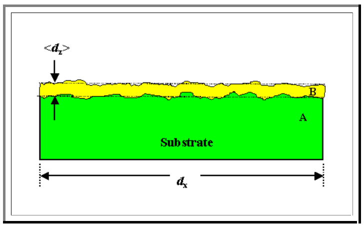
3.2.1 Geometry and Topology

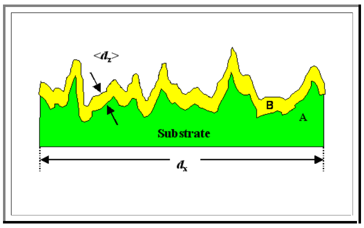
At this stage, when you think about a "thin film" you probably have this picture in mind:

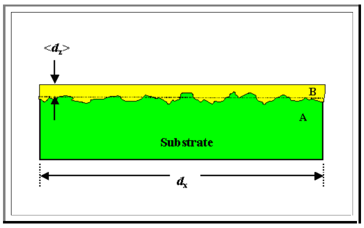


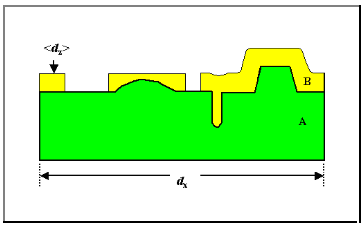
- Some solid Material **B**, with thickness d_z supposed to be "thin", on top of some substrate **A** having a lateral extension $d_{x,y} >> d_z$.

That is fine, but now let's look at some thin films with a more involved **geometry** or **topology** as the case might be:









In the first picture we have a more realistic situation, The surface of the substrate **A**, onto which we deposit our thin film **B** is **rough**. This is certainly realistic, because complete absence of roughness would mean atomically flat, which is not impossible but hard to imagine in a real world.

- Note that the roughness of the interface and the roughness of the thin layer surface may be correlated (as drawn), but this must not necessarily be so. The link provides an example for $\mathbf{NiSi_2}$ (thin) layers on a **Si** substrate where the interface roughness and the surface roughness is quite different.
- Two questions come to mind

1. How do we define and measure roughness?
2. How rough will it be in typical situations?

You know the answer to the first question from your Lab classes:

- Measure the deviations z_i at regular intervals i from an ideally flat average surface (dotted line in the drawing; note that you may have two surfaces or interfaces with different roughness) and take the "**root mean square**" (***RMS***) for the **roughness *R***, i.e.

$$R = \left(\frac{1}{N} \sum_{i=1}^{N} z_i^2 \right)^{1/2}$$

- Usually you can't do that, so you measure from an arbitrary ideal surface *somewhere,*. Then simply subtract the *average*, i.e. use $(z_i - \langle z_i \rangle)^2$ in the sum. Simplified, we might also use an **average roughness R_a** according to

$$R_a = \frac{1}{N} \sum_{i=1}^{N} |z_i|$$

- What kind of roughness do we find (or want) in typical situations? There is a clear and simple answer: It depends! We will look at that whenever we encounter it in semiconductor technology.
- By the way, the **RMS** of the roughness may be much larger than the thickness of the thin film. The second picture shows just that - and it would be a good illustration for certain solar cells where d_z would even be considerably smaller!

The third picture shows a case where there is some interface roughness, but the surface is quite smooth.

- Well - why not? Realistically, however, the surface is quite smooth because you made it so - by a special process called "chemical mechanical polishing" (***CMP***).
- Actually, what we see here in a highly stylized form is the *key process* for integrated circuits after, let's say, **1995**. If you look at the picture of the IBM chip shown before, you could see exactly that: A thin layer of oxide was deposited on a rough substrate (with **Cu** wires on it), but the surface at the oxide is perfectly flat.

The last picture show some aspects of thin films in semiconductor technology.

- Our thin film may be flat on top but accommodating "roughness" in the substrate (on the left), *conformally* following the substrate (and then completely cover "little" holes; on the right), and it may be structured, i.e. having defined "holes".

All in all, just defining, describing and measuring "geometry" and "topology" (and ignoring exactly what the difference is between those two terms) can be a demanding task.

- However, we will not waste time and brainpower to delve into this topic more deeply but will tackle it whenever it comes up in semiconductor technology.