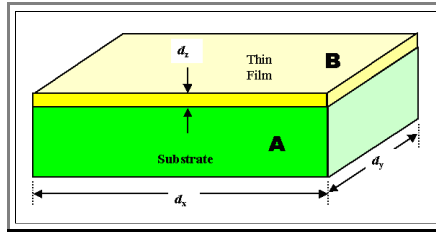


3.2 Mechanical Properties

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 $d_{x,y} \gg d_z$.

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 **NiSi₂** (thin) layers on a **Si** substrate where the interface roughness and the surface roughness is quite different.

- Two questions come to mind

- How do we define and measure roughness?
- How rough will it be in typical situations?

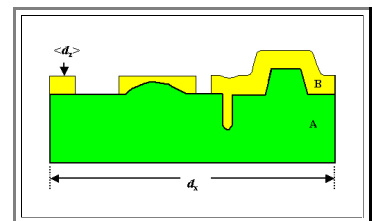
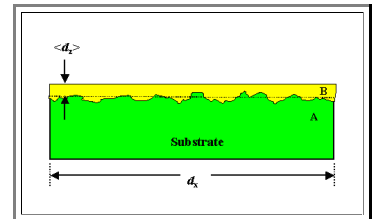
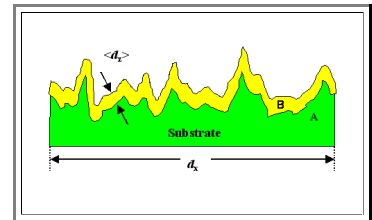
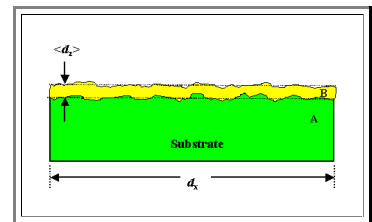
You know the answer to the first question from your [Lab classes](#):

- 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.