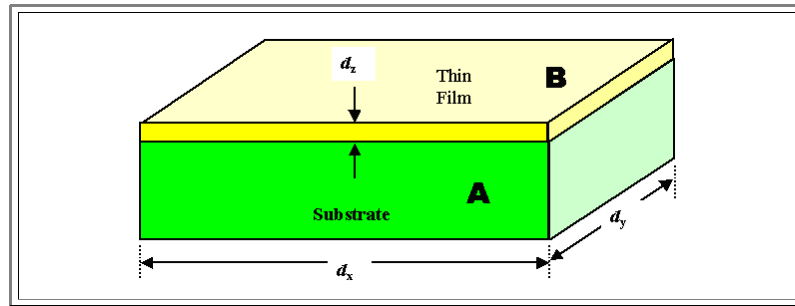### 3.2.2 Adhesion

Once more, what we want to have - idealized - is shown below. A thin film of a material **A** on top of material **B**. Of course, as we have seen, the interface (and thus the surface of material **B**) does not have to be perfectly flat but can be somewhat rough or even extemely rough.

But *now* we look at the quite important parameter of **adhesion**. What does that mean?

- It is obvious. Thin films **A** that do not *adhere* to their substrate **B** will not be of much use, since they will come off with little force.
- We have a first problem. Let's say you want a thin film of **Teflon** on top of your semiconductor, or whatever. Maybe not *you* personally, but lots of other people would just love to have that. Unfortunately, as we all know, nothing *sticks* to Teflon. In other words: The **sticking coefficient** of Teflon molecules (whatever exactly that will be) to any substrate is close to zero.
- There is indeed such a thing as a well-defined sticking coefficient of **B** on **A**, and we will come back to this.

Adhesion is thus a relatively clear thing, easy to conceive, and what we worry about now is how to define and measure it in some quantitative way. This is relatively easy, too - in principle.

- A direct measure of the amount of adhesion that we have for some interface is the work or energy we need to employ per **cm²** to remove **B** from **A**. This is nothing but the good old concept of surface and interface energies, applied to thin films, i.e. interfaces between two different materials. The questions now coming up are:

  - Can we calculate the interfacial energy between **A** and **B**?
  - Can we measure the interfacial energy between **A** and **B**?
  - Is it always the same, or does it depend on, e.g., the thickness d_Z or the detailed structure of the interface between **A** and **B**?

Let's look at the answers:

Can we calculate the interfacial energy between A and B?

- Not really. Or better put: That depends on many things. If we know the exact nature of the bonding between **A** and **B**, and if we can do all the calculations required, we will get relatively good results.
- But even without calculations, "theory" can give us a lot of important inputs. The interfacial properties, as far as adhesion is concerned, come just as much from the bonds and their binding potentials in the interface between **A** and **B**, as most of the mechanical properties of pure **A** or pure **B**. Essentially the same rules apply.

A few examples for this:

- If you deposit a metal **B** on top of a metal **A** and you know from the phase diagram that these metals are completely *miscible*, you know that you will have no adhesion problem. Complete miscibility, after all, necessitates that the bond strength between **A-A**, **B-B**, and **A-B** is not too different, so your **A-B** bonds in the interface should be just about as strong as those in **A** and **B**.
- The same kind of thinking will tell you that **Si** on **Ge**, for example, or any **III-V** semiconductor on top of any other covalently bonded group **IV**, or **III-V** semiconductor should give good adhesion.
- The same kind of thinking, however, will also teach you that if there is just *one* molecular layer of "dirt" in between **A** and **B**, you might be up shit's creek, as the saying goes, because you don't know how **A** and **B** bond to "dirt".
- Everyday experience also tells you that if there is not a continuous layer of dirt in between **A** and **B**, but just some dirt particles (called e.g. dust), you simply will not get **A-B** bonding either. And now you even realize that just a few particles of less then **1 nm** in diameter or some roughness of the two layers before they make contact will already be enough to prevent bonding between **A** and **B** on an atomic scale. After all, if you put a macroscopic piece of metal **A** on top of a metal **B** the adhesion will always be zero.
- Things of any kind, brought into what we think is "close contact" do practically never stick together, and we sure are glad for this!
- That leads straight to a trivial, but important insight: Not counting some exotic techniques ("Wafer bonding"), we *never* produce a thin film by "putting" the film **B** on **A**.

<div style="border: 1px solid black; text-align: center;">

Thin films are always *grown*
on their substrate

</div>

◤ Now to the second question: *Can we measure the interfacial energy between **A** and **B**?*

    ● Yes, of course - but... . Let's look at the "standard" techniques first. Essentially you try to delaminate your layer by "pulling" or "pushing". Measuring the force needed to do that gives you a quantitative number that you may be able to convert into the interfacial energy.

    ● The simplest technique is to attach an adhesive tape ("Tesa") to your layer. If there is better adhesion at the interface tape- layer than at the interface layer-substrate, you might be able to pull off your layer as shown. Or you make a hole in the substrate and push up with a small piston, or you pull down the piston after glueing it to the thin film.
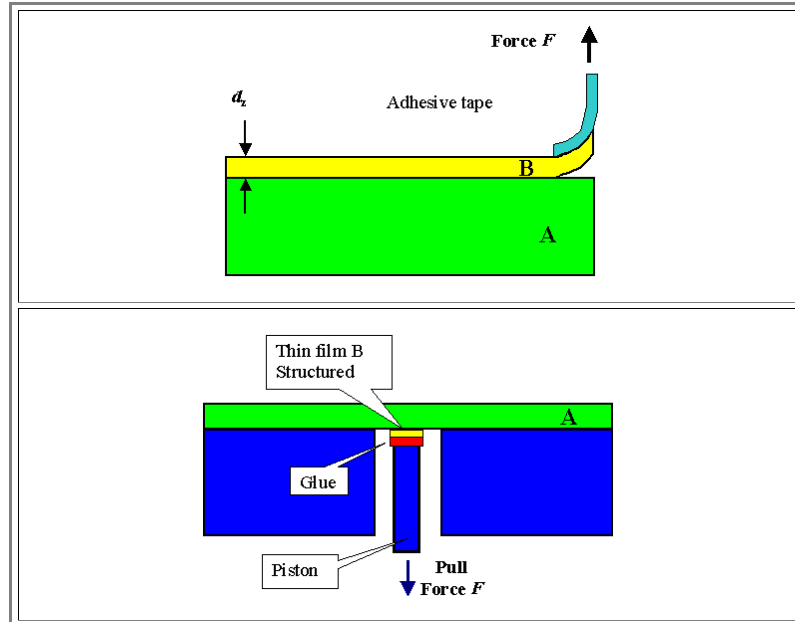
    ● If you can structure your layer as shown in the second picture, you could glue some "piston" to it and try to pull the layer off

◤ If that looks pretty unconvincing - that's because it is! Imagine doing that to a **5 nm** film. You won't even be able to see if anything is doing.

    ● Nevertheless, these techniques often work, and, of course, we can conceive of more sophisticated versions, too. But quite often you must admit defeat. You just can't measure the interfacial energy of your thin film easily or at all - in particular if their is very good adhesion, i.e. a high interfacial energy.

    ● The good news in this case, of course, is that you don't care much then.

◤ We have one question left: *Is the interface energy always the same*, or does it depend on, e.g., the thickness d_z or the detailed structure of the interface between **A** and **B**?

    ● What do you expect? Of course it does, at least to some extend. A soon as we look at epitaxial growth, we will see what might happen in interfaces and how it relates to its energy.