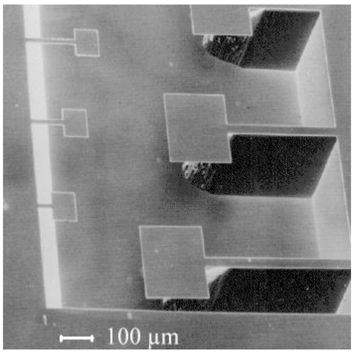
7.2 Processes and Specialities

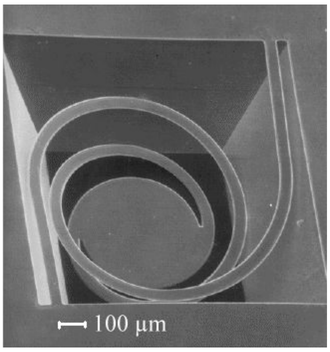
7.2.1 Processes and Materials - General Consideration

General Processing

- How do we make a MEMS device? By using all processes and tricks we know from microelectronics *plus* a growing number of special processes and materials developed and optimized for one of the many MEMS products.
- There are a few general processes and materials specific for most of MEMS technology as can be appreciated by just looking at the pictures of MEMS structures already shown. In particular we often have free-standing structures, only supported at a few points or not at all
  - Let's look at two examples from early MEMS research to clarify this point:

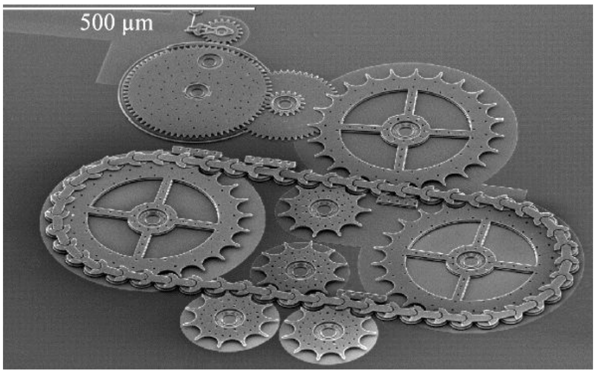


Courtesy of ISIT



Courtesy of ISIT

  - 1. We need to be able to make deep **cavities** into the Si substrate.
    2. We need to be able to make "**cantilevers**" as the paradigm of a free-standing something.
    3. We need to be able to make **membranes**.
  - The pictures from very early (**1982**) MEMS **R&D** illustrate the first two points quite nicely; the third point follows as a kind of ***corollary*** if you consider devices like pressure sensors.
  - The left picture also shows one of the many problems we may encounter: There is still some **Si** under the three large cantilevers - whatever etching procedure produced the cavity below the cantilevers was not yet quite done below the larger ones.
- If we contemplate these structures (and maybe this one) again, and consider what the finished product must look like, we will also be forced to conclude the following:
  - We must avoid **stress** in the various layers at all cost.
  - We must be able to keep things absolutely **planar**- even on top of "topology".
  - We must find special ways to hermetically seal some devices (like the gyro) without impeding the movement of the oscillating parts; i.e. we must have special **packaging technologies**.
  - Why is it essential to avoid stress? Find out yourself!
    Class Exercise: *Consider that the layer of whatever it is that forms the cantilever in the picture above would be under tensile stress in its top part (maybe the cantilever consists of two different materials stacked on top of each other). What would happen?*
- All things considered, MEMS is really a system technology. While microelectronics can go a long way with standardized technologies, procedures and software tools, for MEMS many processes are component and application specific, with strong interdependencies between design, electronic interfaces, system integration, packaging and testing.
  - This means that even a very large box of tools and processes - far more than you would need to produce any sophisticated **IC** - might not yet be good enough for that particular MEMS device you are after and that means that we cannot even get close to a comprehensive survey here.
- Let's finish this paragraph by considering what we do *not* want to make: Scaled down versions of mechanical gadgets, a sort of ultra precision mechanics as shown in this picture:



Courtesy of SANDIA Labs.

- Pictures like that are very popular and shown a lot in "public science" magazines. Everybody can immediately see what that is and marvel at its tiny dimensions, while a picture like the one in the link would be received with a shrug.

But scaled down versions of **gear wheels**, and so on, are rather useless. They don't work for very long, if at all, because in the micro- or nano-world, things often behave quite differently from what would expect.

Gravitational forces, for example, become unimportant and other forces take over (why do small dust particles not fall to the ground?).

- **Friction** and **surface tension** may become extremely important because the surface to volume ratio increases if things get smaller, and forces transmitted via the surface (including friction) may dominate over forces scaling with the volume (like gravity or ***inertia***).

The key word now is "**stiction**", a newly coined word, meaning that parts of a MEMS device that should be able to move *stick* to other parts, effectively locking all movement.

- The word also alludes to "friction" because whenever microscopic entities slide across each other, friction, as always, does occurs - but in ways quite different from what we experience in the macroscopic world. Friction may then lead to stiction and "dead" MEMS devices.
- Avoiding stiction is a major concern in designing and making of MEMS structures; more about it in the link. Generally, one should avoid sliding movements - and that is the reason why designing device functionality by having a piece **A** sliding on a piece **B**, as in the gear wheel picture above, is not a good idea.
- The problem is that there is no simple way of obtaining efficient **lubrication** in those devices. You should now take a minute to think about the overwhelming importance of **lubrication** in everyday mechanical systems like cars, and what our civilization would look like if stiction would be a tough-to-fight macroscopic phenomena, too.

Special Materials

In terms of materials we use more or less everything microelectronics has to offer, and then some. We have already encountered some MEMS specific materials directly or indirectly. Let's see:

- Thermal couples came up in the context of a gyro. We need two different conductors (metals) to make one.
- The DLP chip works with mirrors. We need a highly reflective material (= metal) for that.
- Piezoresistors came up a few times, the first time in a pressure sensor.
- Special packaging needs have appeared a few times, necessitating special materials.
- And we can be sure that there is a lot we have not yet covered.

- We know from microelectronics that the introduction of a new material into a process sequence takes a lot of **R&D** and therefore time and money. While in microelectronics we always have "Moore's law" as a powerful economic driver, MEMS materials are usually very application specific and progress may be slower due to economical restraints.

But lest's be clear about one thing:

Progress in MEMS technology
comes from
specific **Materials** and
Processes

- The reason for that is simple: Progress in general **Si** processing comes from microelectronics - and is taken over by MEMS as soon as it become affordable. MEMS by itself could never "pay" for, let's say, the next generation lithography technology.
- For Materials Scientists and Engineers this are good news - you are going to be needed!