Solution to

All Quick Questions / Class Exercises to

2.2 Silicon

Illustration

- What is the approximate lateral size of *one* transistor in an **IC**?
  - Given that state-of-the-art transistors have smallest dimensions of **32 nm**, one could guess that that the total lateral area would be in the order of **(100 - 200) nm^2**. Be that as it may, an answer of "below **1 µm^2**" is acceptable
- Why are there no **16 GB** memory chips *now*?
  - Because that would be a **16 ×8 = 128 Gbit** chip. With a chip area of **1.5 cm^2** with **1.28 cm^2** for the memory cells (the rest is needed for the periphery), one memory cell would be
    1.28 cm^2/1.28 × 10^{11} = 1.28 × 10^{14}nm^2/1.28 × 10^{11} = 10^3 nm^2.
    In other words, one memory cell, needing at least one transistor, would be about **30 × 30 nm^2** and that is not yet (**2008**) feasible.
- What properties should a semiconductor have for making **IC**'s?
  - Well. there is no end to the list:
    - Bandgap not too small to make it too temperature sensitive around ***RT***, or too large to allow easy doping and contacts plus some conductivity. So **Ge** is out now but **GaAs** etc, are still in. **Si** is OK, but a somewhat higher bandgap would be preferable.
    - Large defect free and "cheap" single crystals must be possible. Pretty much all semiconductors but **Si** are out.
    - A process compatible dielectric must exist with very high breakdown field strength and suitable dielectric constant. It's very difficult to beat **SiO_2** here. Big advantage for **Si**.
    - Precise doping establishing a precise conductivity must be possible. Many semiconductors meet this requirement, but **Si** is one of the easiest to dope.
    - The mobility of the carriers should be large for high-frequency applications. **Si** is mediocre in this respect, but still good enough for most applications.
  - ***Conclusion:*** There is no other semiconductor out there that comes even remotely close to **Si** as the best compromise.

- What exactly produced complexity and market growth rates of **30 %** for more than **30** years (for **Si IC**'s)?
  - There is only *one* reason: The **price per function** (e.g. **€** per bit of memory space, per logical operation, per numbers of operations per second, per kWh, ...) comes down substantially.
- Where will it end?
  - Nobody knows. The absolute limit is the size of an atom ≈ **0.3 nm**. How many atoms does it take to make a transistor = switch? A few hundred, occupying a volume of **< 10 nm^3** are enough. So we are a far cry from the limit with our present **2**-dim. integration of logical switches.
  - But maybe the cost limit (see question above) is reached before the technical limits are even close? Check the link for details
  - Wherever and whenever the limits will be felt, one thing is quite likely: Moore's law, maybe with a somewhat slower rate of growth, will go on for at least until **2015** because all essential ingredients are already in the laboratory stage.

- What do you know about **MEMS**?
  - Probably nothing yet. That will change. But you have definitely seen **MEMS** in action and very likely own **MEMS** products:
  - Many **beamers** contain a MEMS chip with roughly **1 Million** little mirrors that can be individually addressed to process one pixel of the light you see on the projection screen.
  - The *acceleration sensors* in your car that tell the microprocessor that it is time to inflate the air bags, as well as the *gyros* (sensors for rotational speed) that allow the microprocessor to calculate how to individually brake the wheels in order to keep you in line when you start to slip, are typical **MEMS** products.
- Are there any other uses of **Si** you know off (or can find quickly)?
  - Let's see: We had solar cells and MEMS. What else?

- **Si** wafers are the cheapest *perfect substrates* for all kinds of applications (in particular optics, including X-ray "optics").
- **Si** single crystals are used as perfect Bragg diffractors to produce, e.g. monochromatic Neutron beams.
- If you make nanoporous **Si** and fill the pores with something containing a lot of oxygen (e.g. **$KMnO_4$**), you have produced a high explosive with up to **3** times more bang per **kg** than TNT. A big project was launched to explore that as an integrated fuse for blowing up air bags.
- Si "nanwires" might be the ideal anode for better Li ion batteries.
- And so on - activate this link for some details.