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Nanotechnology for semiconductors

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Modern semiconductors are manufactured with feature sizes measured in nanometers. Despite this, semiconductors are not traditionally classed as nanotechnology. A transistor made with 0.5μm technology does not behave in a manner greatly different to one at the 32nm node. To fit with the modern definition of nanotechnology, materials must exhibit properties that are different from those predicted by simple scaling of dimensions. Their properties are influenced by the laws of physics because the feature size is of the same order as the critical size for physical phenomena. Often the difference is manifest as a step change. For example, the radius of the tip of a crack is typically tens of nanometers. Conventional crack propagation and consequent mechanical failure are impossible if the material dimensions are smaller than this.

Nanotechnology is likely to manifest itself in the semiconductor industry in two forms. The first of these is semiconductor devices themselves. It is well known that we cannot go on shrinking devices ad infinitum. Once the device size approaches single atoms quantum physics comes into play -- a transistor may, or may not, switch, depending on the prevailing statistics. Building traditional logic gates out of such devices is not sensible, but other decision-making architectures based on quantum devices are being developed. For solid state memories, an important metric of the material used is the ratio of change between the 1 and 0 states. In a well-designed and fabricated flash memory, the ratio will be around 10,000. By exploiting phase change in the nanomaterial graphene, it is possible to obtain ratios of conductivity over 1 million. If realized in a full-sized memory, this would result in a five-fold increase in storage capacity.

In the near term, the most likely application of nanotechnology to semiconductors is in the area of interconnects. Most recent research effort has been concentrated on carbon nanotubes (CNTs). These materials are ballistic conductors with quantum behavior and exhibit exceptionally low electrical resistance. Values around 10^{E-4} Ohm-cm have been measured, and they have stable current densities as high as 10^{E12} A/cm^2. One of the major causes of power consumption and propagation delay in semiconductor circuits is the RC time constant of interconnects; reducing R by a factor of 10 will confer significant benefits to conventional semiconductors.

Nanotechnology may even replace the ubiquitous gold plating found on the connectors of virtually every plug-in card. Gold is an excellent conductor, but needs to be a minimum thickness to adequately resist corrosion and add durability. The recent spike in the price of gold is having a measurable effect on connector pricing. Nanomaterials are under development that essentially mimic the electrical and mechanical properties of gold. Because they are base metal alloys, their prices are low and remain stable.

It has been said that the twentieth century was the era of the electron, and the twenty-first century will be the era of the photon. USB3, with its optical interface, is an example of this transition. Nanotechnology, by virtue of its dimensions, is conducive to interacting with light. A well-known example is the quantum dot, one use of which is wavelength conversion. These offer the prospect of designing light-emitting semiconductors with high electro-optic efficiency, and changing the emitted light to the desired spectrum using an engineered coating.

Conclusion

Although there are few examples of commercialized semiconductor nanotechnology, there is no doubt that it offers the prospect of significant innovation by providing materials with properties outside of the current domain. The semiconductor industry, with its large and focused R&D base, is likely to be an early adopter. Research journals abound with papers on nanotechnology, offering a tantalizing glimpse of what the future may hold.

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