The Alchemy of Nanotech - Part II

(Practical Technology)

Ken Gilleo PhD
ET-Trends LLC

INTRODUCTION

Part I [IPC reference] dealt with early nanotechnology to show that "technology of the small" has been a valuable tool for some time. Today, nanotechnology is being increasingly applied to electronics and the day will come when Nanoelectronics is the standard. This article explores present uses of nanotechnology and then looks to the future. Our search for practical nanotech begins with materials. Later, we evaluate the status of electronic devices as we examine Nanoelectronics and try to discover where it can lead. We'll use the broad, but admittedly imperfect size definition, and will seek examples with novel utility.

NANOMATERIALS

Nanomaterials can be characterized by size features that fall within the 1-nm to 100-nm range. The smallest particles in this nano realm are only half the diameter of the DNA helix. The largest nanoparticles are only 1/100 the diameter of a human hair. Although individual nanoparticles must fall within the 1-nm to 100-nm size scale, structures with larger dimensions can also be included when their fine structure, such as grain boundaries, or coating thickness, meet this size criterion. Our focus will be on particles in the 1 to 100-nm range and their application to PCBs, electronic materials, and electronic devices.

Dielectrics

Most electronics consist of dielectrics and conductors - wires and insulation. A complex printed circuit board is a skillfully crafted arrangement of patterned conductors on, and in, a dielectric medium. But getting the conductors and insulation in just the right locations is our ever-increasing challenge as density climbs while size is reduced. Most PCB dielectrics are composites - materials comprising two or more components, with one serving as a binder, or continuous phase, and the other as an insoluble particle, or filler. Most are compositions of organic binder with inorganic mineral or glass filler. The most common PCB throughout the history of electronics is a composite of glass-filled epoxy resin typified by FR4. While epoxies are thermoset plastics with a good balance of properties, their thermal expansion is too high (75-85 ppm/^{o}C) and mechanical stability is marginal. But the addition of low-expansion inorganic filler produces a composite with reasonably good circuit board characteristics. Glass weave is the most common "filler". Much finer nanofibers and wires could be used in the future to provide thinner laminates that are easier to drill, laser machine, and plate. Nanoparticles are already being added.

A large variety of nanoparticles, and a smaller number of nanofibers, are available that can be useful fillers and reinforcing agents. They include the most common dielectric, silica (SiO_2), but also aluminum nitride (AlN) known for high thermal conductivity. In fact, AlN nanotubes are available with diameters that could allow them to be filled with atoms and molecules. Additives, including catalysts and flame retardants, have been nano-sized and more are on the horizon. But what benefits might we expect by just reducing size? Smaller filler size can produce a more homogenous composite to boost efficiency and produce a better composite. When particle size is reduced, area per unit weight increases proportionally, and this is valuable for catalysts and many additives. Flame retardants can be more effective at lower levels and thermal conductors, especially nanotube structures, could provide a significant improvement over conventionally sized equivalents. But there are some unique situations, like "no flow" underfill, where nanofillers have already solved problems.

Underfills are typically made by adding micron-size silica to low viscosity epoxy, and this has worked well for capillary flow products. But the same strategy fails for pre-dispensed, or "no flow" underfill. The silica particles interfere with solder joint formation and yields become unacceptable. But, according to 3M, nano-silica does not obstruct solder joint formation since the particles are so tiny [1, 2]. Nanoparticles also can have valuable optical properties, including high optical clarity, potentially useful for optoelectronics and MOEMS. Nanomaterials are also finding use in batteries, fuel cells, low-shrinkage encapsulants, EMI shielding, conductive adhesives, and high-powered capacitors.

Conductors

Ink jet electronics is finally poised for action after decades of R&D and one of the reasons is that nano-size conductive fillers are small enough to enable jettable inks. This is an active area in both equipment and materials, and we can expect to see further commercialization [3]. Ink jetted conductors are being applied to flat panel displays, and eventually, we will be able to "print" electronics [4]. Although true printed circuits have been around since WWII when cermets were screened onto alumina substrate, we should expect advancements in this area as nanotechnology enables faster, finer, and more economical placement of conductors.

NANOELECTRONICS

The carbon atom is perhaps the most unusual, versatile, and important element in the universe, as it readily bonds with other carbon atoms to form hexagons, and other structures that can fuse together into a myriad of shapes. Carbon can form planar sheets (graphite), spheres (fullerenes - or bucky balls), and cylinders, as well as 10-million compounds. The cylindrical structure, called carbon nanotube (CNT), just might be the future building block for electronic devices. The CNT structure looks like hexagonal chicken wire rolled up into a cylinder that may be closed at one end (see Fig. 1). The CNT can have valuable electrical characteristics depending on its molecular arrangement. The CNT, in its semiconductor configuration, is the basis for most nanotransistors. Several laboratories, especially those of IBM, have been able to construct useful CNT transistors (see Fig. 2) over the past several years and advancements are occurring at a quickening pace [5]. But lab nanotransistors have been made by carefully affixing CNTs, a rather impractical method for manufacturing [6]. Progress is also being made with the interconnecting, or integration, of CNT-based transistors. While there are significant challenges still ahead, many believe that practical Nanoelectronic ICs are no more than a decade away.

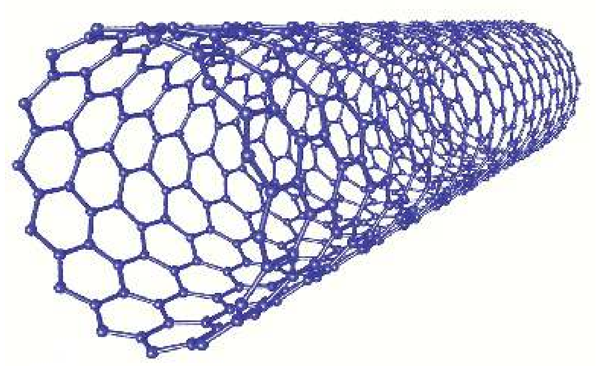

Figure 1 - Carbon Nanotube (Wikipedia)

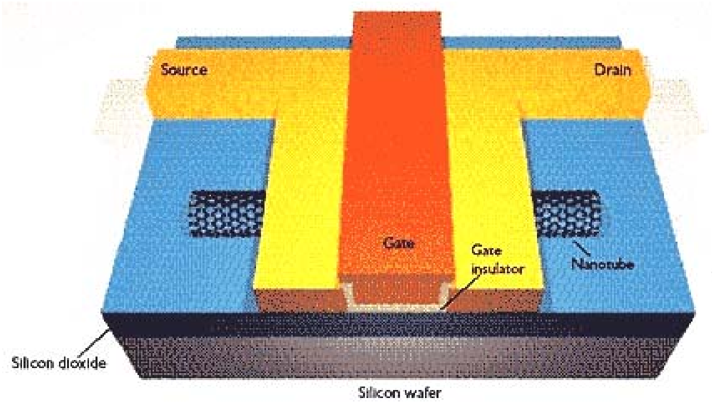

Figure 2 - CNT-Based Transistors (IBM)

FUTURE

Assuming that the nanotech community solves device integration, streamlines processes, and launches products, what should we expect from the Nanoworld? Successful Nanoelectronic devices will be at least 10 times smaller and 10 times faster than silicon transistors to provide products that are more powerful. The Nanoelectronic systems could be energy efficient to significantly reduce power consumption and obviate heat management problems that we are now fighting with silicon ICs. The PCB might also utilize carbon-based technology where conductive patterns, perhaps nanowires, are “grown” in place by first jetting plating catalyst, or by nanoimprinting techniques. Or we might form a “mesh”, or neural network, where devices linked up with the closest circuit board network node. Perhaps the devices and circuitry will be a single integrated system - no solder, no flux, and no metal. Improbable? Consider that the best computer of all time, the human brain, is a carbon-based highly integrated 3D network without a single solder joint or metal track.

REFERENCES

1. Husman, J., “Nanomaterials at 3M”, PennState Materials Day, April 15, 2004;
(http://www.mri.psu.edu/materialsday/2004/presentations/husman.pdf)
2. Hackett, S., “Advanced Capillary Underfill for Flip Chip Attachment”, SMTA International, Sept. 22, 2002 Chicago, IL.
3. H. Jiang. et al, “Surface Functionalized Silver Nanoparticles for Ultrahigh Conductive Polymer Composites” Chem. Mater., 18 (13), 2969 -2973, 2006
4. Gamota, D, Brazis, P., Kalyanasundaram, K. and Zhang, J., Printed Organic and Molecular Electronics, Springer Publishing; 1st edition, January 2004.
5. “IBM Develops Alternative to Silicon Transistors”, *Electronic News*, 4/27/2001
6. Bullis, K., “Carbon Nanotube Computers”, MIT Technology Review, May 26, 2006;
http://www.technologyreview.com/read_article.aspx?id=16931&ch=nanotech