Practical Nanotechnology in Electronics

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ABSTRACT

Nanotechnology has been hailed as the "next wave" to replace CMOS as the process of choice to make logic devices using technologies as diverse as carbon nanotube grids, polymer semiconductors and even "wetware" – ionic/electronic systems mimicking biological processes. In fact most of the nanotechnology applications will be complementary and even extend the life of CMOS devices in areas such as improved thermal conductivity, new interconnect structures and new active and passive devices. The presentation will illustrate this with real examples of enhanced thermal conductivity materials, printed electronics and ESD protection structures

BACKGROUND

Electronics has been dominated by Moore's law for many years. There are consumer expectations based on a doubling of transistor density about every 18 months giving increased speed, smaller size and lower cost products. Now we are starting to run into some difficulties. As we concentrate transistors the heat output per wafer is increasing to a stage where consumer products are starting to use liquid cooling. Clock speed is no longer the badge of honor on a processor but dual processing and multi-threading types of technologies increase processing performance without increasing heat load.

It's going to get worse technically. The ITRS (International Technology Roadmap for Semiconductors) 2005 roadmap focusing on the semiconductor industry has identified that between 2015 and 2020 we will start to hit quantum effects as the feature sizes on semiconductors start to approach the wavelength of a conduction electron. As conductors approach more closely, electrons (conduction electrons can have an equivalent wavelength of about a nm) start to show more wave than particle behavior and can have an increasing probability of being in 2 adjacent conductors, leading to leakage and other issues. In addition, these smaller structures are more susceptible to thermal diffusion so will have a lower operating temperature and processing temperature.

iNEMI (International Electronics Manufacturing Initiative) has been focusing on the rest of the supply chain in electronics with a view to supporting the continued use of CMOS (which is not going to go away) as well as understanding what will be the requirements from a customer perspective. The electronics industry is now a maturing trillion dollar industry heavily driven by consumers and is undergoing global redistribution and supply chain rearrangement.. Following the completion of the 2004 iNEMI roadmap, an Innovation Conference was called with speakers and participants from throughout the world looking at how the electronics industry could get out of what some commentators see is a slump towards being commodity driven. There is a concern that no new huge "killer app" such as video games, personal computers or cell phones is on the horizon. There are worries that the three cylinder engine - that has so successfully driven new products - the combination of revenue, profitability growth, and investment in R&D - is becoming unbalanced. .

Nearly all the speakers at the iNEMI forum mentioned nanotechnology as a key factor in future electronics development. The Semiconductor Research Council, many of whose members are active in the ITRS semiconductor roadmap, recently formed the Nanoelectronics Research Corporation to support and encourage University work in this area coordinating with the National Science Foundation and the US National Nanotechnology Initiative. The European Nanoelectronics Initiative has similar goals.

So let's explore three ways we can use nanotechnology as a way to support CMOS devices and extend their useful life

NANOTECHNOLOGIES AND ELECTRONICS

Nanotechnology isn't really one technology, it's a grouping of techniques – vapor phase, liquid phase, solid state, self-assembly - that allow us to manipulate materials and structures at the nano scale – less than 100nm (0.1 micron) . There is still some debate about the exact definitions of nanotechnologies. IA new ISO Standards Committee – TC229 – has been formed and one of its tasks is to develop a consistent nomenclature for nanotechnologies. ASTM and other agencies are also active in this. Readers may be amused to know that there is still debate internationally in the electronics industry on the definitions of package, module, system in a package after all these years making them!

It is a really flexible toolkit for the electronics industry, giving us tools that allow us to make nanomaterials and nanostructures with special properties modified by ultra-fine particle size, crystallinity, structure or surfaces. These phenomena become commercially important only when it gives a clear cost and performance advantage over existing products or allow us to create new products.

Often there is a clear size effect with nanomaterials - a " tipping point" – below which the surface energy of particles and features or quantum effects start to take effect. In the case of silver powder, for example, the sintering temperature starts to decline rapidly below 100nm with a dramatic reduction to below 200^0C when the particle size is below 50 nm – and this for a metal whose melting temperature is 961^0C! This is the basis for the widely accepted definition of nanotechnologies and nanostructures where one of the key dimensions is below 100 nm.

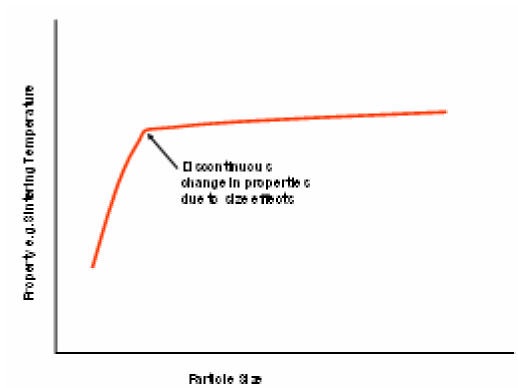

Figure 1. The "tipping point" in particle and feature properties.

ENHANCED THERMAL CONDUCTIVITY MATERIALS

Each transistor on a semiconductor device dissipates a specific amount of heat: if the number of transistors is doubled (as has happened with Moore's law every 18 months) then the heat output doubles also all other things being equal. This means the thermal load on heat sinks and thermal interface materials is increasing.

One approach is to use oriented carbon nanotubes in heat spreaders. The theoretical end to end conductivity of nanotubes is well over 2000, compared with 400 for copper. A great deal of work is being carried out in orienting, crosslinking and embedding nanotubes in composites for this electrically conductive approach.

Where electrical conductivity is undesirable the approach may involve using an electrically insulating thermal interface material, typically containing boron nitride. Although boron nitride is a fine thermal conductor, the boric oxide surface formed through atmospheric hydrolysis impedes processability and reduces the effective loading and therefore the overall thermal conductivity. Atomic layer deposition of less than ten nanometers of alumina using a vapor phase fluid bed technique leads to an inert surface allowing the preparation of a more effective thermal interface material. Figure 2 shows a grain of boron nitride prepared in this way.

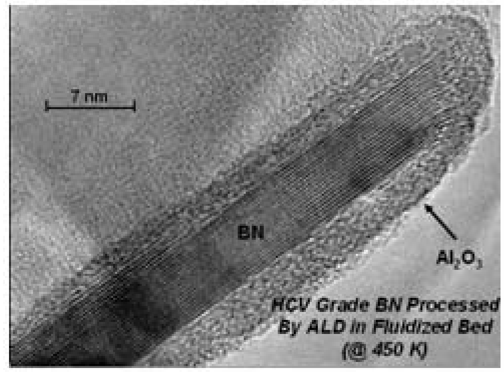

Figure 2. Boron nitride grain encapsulated in alumina. (ALD NanoSolutions Inc.)

PRINTED ELECTRONICS

An area receiving a great deal of attention in nanotechnology is printable electronics. The concept of printing circuit traces is not new - the technique been used in ceramic hybrid circuits and in flexible circuits used in membrane switches and keypads for many years. The printed electronics market is difficult to quantify exactly right now because definitions differ but what is agreed by many experts is that it is poised to grow dramatically over the next 5 years.

Materials which can be printed include:

- Conductors: In order to use low-cost substrates such as polyester and even paper instead of epoxy, polyimide or ceramic, process temperatures must be reduced to below 2000C.
- Semiconductors: Polymers or polymer composites can be printed as components of structures such as solar cells (Graetzl cells), light emitting diodes for displays, or transistors.
- Dielectrics: high-K for example for embedded capacitors or low K for insulation.
- Phosphors and other functional materials.

Materials under development for printing include metal powders and nanotubes – silver for conductors, nickel for MLCC electrodes, copper for component terminations, carbon nanotubes for thermal and electrically conductive structures and some examples are illustrated below in Figure 4.

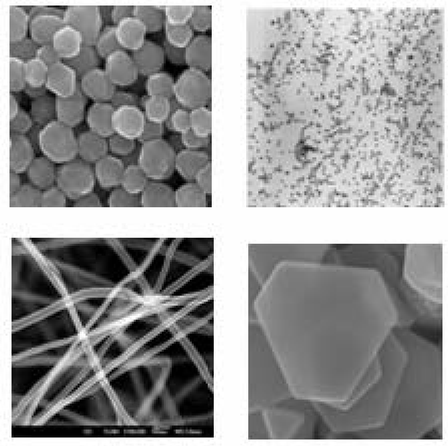

Figure 3. Nanomaterials developed for applications in printed electronics – clockwise from top left: 200nm nickel, 20 nm silver, 500nm silver platelets, 50 nm diameter multiwall carbon nanotubes. (NanoDynamics Inc.).

ESD PROTECTION STRUCTURES

Nanowires and other structures using atomic cluster deposition show promise for interconnects, ESD protection structures and sensors whose small size and the opportunity to integrate on to silicon logic circuits using lithography or other imaging techniques coupled with low-temperature assembly promise rapid response and low cost.

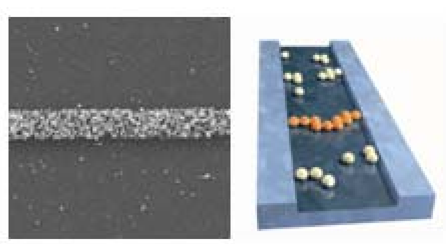

Figure 4. A high surface area nanowire structure assembled by cluster deposition (left) and schematic of a percolating pathway (Nano Cluster Devices Inc.)

One exciting concept being developed by Silicon Pipe Inc. and NanoDynamics Inc. is to use a system of percolating pathways as shown schematically above as a way of creating "quick blow" fuses for ESD protection. Because the cluster density can be controlled precisely, a low capacitance structure can be prepared which can have multiple nanowire pathways with similar resistances which will blow for example at 50.0 volts, 50.1 volts, 50.2 volts and so forth to effectively provide an array of fuses that behave essentially like a circuit breaker that resets after each energy pulse.

REFERENCES

1) ITRS roadmap http://public.itrs.net/
2) iNEMI roadmap http://www.inemi.org