Nanoparticles: A Route to Post-Shrink Information Systems

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Moore's law is approaching limits for features between 10 and 20 nm that appear difficult to overcome. Primary among this is power dissipation and off-state leakage. If this proves to be a hard limit, this may provide an opening to move from a chip-performance perspective to a system performance perspective. A necessary step for this is the ability to monolithically integrate electronic, optical, PV, rf, and perhaps magnetic devices on arbitrary substrates. This represents an extreme materials challenge. Most high performance electronic and optoelectronic systems are built on semiconductor wafers. Devices made this way are highly stable and have excellent performance (i.e. high mobility and long carrier lifetime), but are difficult to integrate into low cost mobile applications such as plastic electronics. Amorphous and organic materials are inexpensive and much easier to integrate, but have low performance and poor reliability. The challenge is to find a way to monolithically integrate a wide variety of stable single crystal materials on a single substrate. Novel materials such as nanowires, nanotubes, and graphene show some promise, but daunting device problems remain.

This talk presents a different approach to developing such a platform: the use of crystalline semiconductor nanoparticles (NPs) as the active elements in both thin film transistors and light emitters. Both n- and p- channel Schottky-barrier, surround-gate silicon-NP transistors have been built and characterized with gate lengths as small as 15 nm without the use of high resolution lithography. Good on/off performance has been demonstrated with on-current densities as large as 10^7 Amp/cm^2. Novel techniques for particle localization and threshold voltage adjustment will be discussed for the ultimate manufacture of circuits using these devices. We have developed techniques to passivate the surface of silicon NPs, obtaining solution-based efficiencies approaching 80% and thin film compatible quantum efficiencies as high as 40%. Colors from blue to red have been demonstrated. We have incorporated these NPs into conducting polymer films to make hybrid OLEDs. We have succeeded in making near-white sources by combining NP emission with polymer emission and are currently optimizing the process to obtain saturated colors needed for on-chip displays.