Heterogeneous integration of carbon nanotubes, graphene and nanowires on CMOS for sensing applications

Sameer Sonkusale
Tufts University, Boston, USA

We demonstrate a novel paradigm for realization of miniaturized sensors that exploit the amazing properties of nanomaterials such as carbon nanotubes, graphene and metal oxide nanowires.

Although preliminary research indicates great promise for these nanomaterials, challenges remain for reliable top-down manufacturing for very large scale integration. Some of the prominent challenges for top-down approaches are: (1) achieving a tight distribution with identical properties; (2) low-resistance contact formation; (3) accurate placement and orientation of nanomaterials on the substrate; (4) development of CMOS compatible catalyst and processes; and (5) low temperature and low-cost processing. While challenges for top-down fabrication of these devices are being addressed, there is an immediate need for an alternate pathway for realization of functional devices and systems geared for sensing applications. Such a pathway should facilitate heterogeneous integration of multiple nanomaterials on the same platform so that one can harness their individual exotic and synergistic properties. One expects such an approach to be very low-cost that can provide reasonable yield and reliability.

We have recently proposed a highly unconventional yet powerful candidate to meet this need for low cost nanofabrication. The approach utilizes top-down fabricated silicon CMOS die (or wafer) as an electroactive functional substrate for bottom-up directed assembly of nanomaterials like CNT and graphene on multiple electrodes in an array. This new paradigm brings the top-down approach of conventional CMOS technology with a bottom-up approach of directed assembly based on ac dielectrophoresis. It extends the role of CMOS technology for nanoassembly (C4NA). Another key barrier is the realization of reliable ohmic contacts, which were addressed using controlled electrodeposition *in-situ*. Following assembly and contact formation, the integrated circuits in the CMOS can now be reconfigured for low-noise readout from individual electrode sites for sensing. This entire process of assembly is mask-less, low-cost and scalable, and fills an intermediate need for large-scale high throughput integration of nanomaterials for nanosensor-on-chip realization.

The proposed C4NA approach is an ideal pathway for heterogeneous integration of multiple nanomaterials on the same platform for variety of applications such as nanosensors-on-chip for environmental and biological sensing. We show some preliminary investigations in C4NA approach of single walled carbon nanotubes, DNA-functionalized carbon nanotubes, and graphene for sensing of volatile organic compounds in the environment with potential for breath-based biomedical diagnostics.