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Nanotube based structures for high resolution control of thermal transport

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The ability to control heat transfer on small time and length scales would have a significant impact in many areas. For example, in just three applications: thermoelectric micro-coolers, DNA amplification via Polymerase Chain Reaction (PCR) and harvesting waste heat to do work on the microscale, this capability would immediately improve the performance of these devices. To be able to control heat transfer to thermoelectric coolers, micromachined PCR devices and micro heat engines a type of thermal switch or thermal valve is required. Such a thermal switch would be able to change its effective thermal conductivity in order to turn heat transfer on and off.

In this work we incorporate carbon nanotubes into microscale composites to create a new kind of mesoscale device, a thermal switch. Arrays of thermal switches will then be produced in batch to create sheets with spatially and temporally controllable "digital" thermal conductivity. Carbon nanotubes (CNT's) bridge scales from nanometers to micrometers, and MEMS techniques bridge scales from micrometers to millimeters. Manufacturing across six orders of length scales from nano to meso is made possible by utilizing the mixed-scale architectures of high aspect ratio CNT's and two-dimensional lithographic-based low-aspect ratio MEMS fabrication techniques.

We first take advantage of the nanometer-scale diameter of CNT's and their exceptional thermal and mechanical properties. We then fabricate aligned CNT composite blocks to the same scale as the micrometer length of the CNT's. By fabricating composite blocks in which each of the individual CNT's stretch across the entire block we expect to see the very large thermal conductivity measured for individual CNT's reflected in a very high overall thermal conductivity for the aligned CNT composite blocks. Finally, using lithographically-based fabrication techniques, we will manufacture meso-scale devices/materials with spatially and temporally controllable "digital" thermal conductivity. Individual CNT composite blocks will be distributed across a silicon wafer, and aligned opposite an array of thin membranes. Making and breaking contact between the high thermal

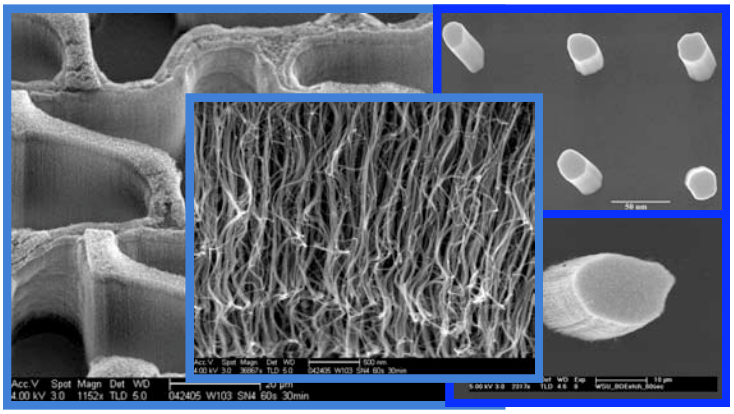

Fig. 1 Patterned vertically aligned carbon nanotube turf.

conductivity CNT composite blocks will enable the thermal conductivity through the device to be changed and controlled at will.

Currently research has been focused on the patterning and growth of CNT turf and measuring and modeling both mechanical and thermal properties of the resulting structures. To date we have successfully patterned and grown CNT's on silicon substrates to create vertically aligned carbon nanotube turf or VACNT turf as shown in figure 1.

CNT growth was accomplished via a chemical vapor deposition (CVD) method. An iron nitrate sol gel catalyst is spun onto the wafer followed by photoresist and then patterned. CNT growth is achieved at 700°C for 30 minutes with an admixture of H_2 and C_2H_2. Characterization is performed using a field emission scanning electron microscope and a high-resolution transmission electron microscope equipped with an energy dispersive x-ray spectrometer. To better understand the response of carbon nanotubes in concert contacting a relatively large surface, a Berkovich diamond tip with an effective tip radius of 1.79 μm was used to apply a load to the resulting VACNT structure. The relative stiffness of this extremely compliant structure is related to the number of contact sites between tubes. Elastic deformation occurs despite energy dissipation during compression. Effective elastic modulii are depth dependent and range between 1 and 0.04 GPa for high and low numbers contact sites. The depth dependence is likely due to compression of pre-buckled geometries.

References

[1] For further information about this project link to **<http://www.mme.wsu.edu/~ThermalSwitch>** or email **<cill@wsu.edu>**

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