POTENTIAL OF RESILIENT NANOMATERIALS FOR SPACE APPLICATIONS

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Space exploration is entering a new era, with the advent of widespread use of new micro space probes. However, the increased use of miniaturized equipment corresponds to a decreased availability to carry radiation shielding against the space radiation environment. It is well documented that silicon micron and sub-micron electronics based on diffusive transport through a channel are degraded or irreparably damaged by space radiation environments that alter the well separated p-n-p charge regions required for transistor function[i,ii].

A switch to new nanoelectronics may obviate several of the problems encountered in conventional transistor electronics. In prototype carbon nanotube transistor circuits, there are no conventional pn junctions or isolated gates to damage, as transistor action occurs primarily by varying the contact resistance rather than the channel conductance[iii,iv]. Current transport becomes ballistic, meaning wavelike and therefore non-scattering, due to quantum confinement. Radiation interaction and damage propagation mechanisms that meet physics conservation law requirements also change fundamentally in reduced dimensionality systems, in ways that may result in enhanced radiation resilience[v]. Therefore, it is important to begin a program to uncover fundamental radiation issues in the new nanoscale material components and circuit architectures, to determine if the promise of ultra-lightweight circuits with improved space radiation resilience can be realized.

We will present research results from a series of experiments in which we have investigated the effect of heavy ion radiation on nano components. The radiation experiments were performed at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University, whose available beam energies well match the energy spectra of abundant charged particles in space radiation environments. Heavy ions are a serious source of non-recoverable electronic upsets for missions running in Low Earth High Inclination Orbits. The samples included single and multi walled carbon nanotube films, versus electrospun polymer nanofiber films and conventional, well-graphitized vapor grown carbon fibers mats as controls. The samples were irradiated using the Krypton-86 standard primary beam at 142A MeV/nucleon to simulate radiation doses from high-Z ions. As there are no published guidelines for beam exposure times in nanoscale materials, these experiments were conducted with doses and exposure times comparable to those that can be expected to affect (100 Gray), damage (1000 Gray), or destroy (10,000 Gray) current state-of-the art silicon circuits.

Pre versus post irradiated specimens were investigated for structural and chemical alterations. FE SEM and AFM were used to investigate changes to the external structure. TEM and HRTEM were used to investigate changes to the internal structure. Selected area diffraction was used to detect any departure from crystallinity. Micro Raman spectroscopy/Surface Enhanced Raman spectroscopy was used to investigate the molecular bonding and to monitor the appearance of any defects induced peaks.

Our results indicate unusually high heavy ion resilience on the part of both the single and the multi-walled carbon nanotubes versus obvious damage by known radiation interaction mechanisms to the electrospun carbon nanofibers and the vapor grown carbon fibers. These results have exciting implications for a revolutionary re-design of space electronic and optoelectronic components and circuits. To make this research ultimately useful to NASA it must involve not only nano components but also functioning nano devices, as quickly as possible. The design and investigation of a series of nanocircuits of specific interest to NASA is the focus of presently ongoing research, and preliminary results may also be reported.

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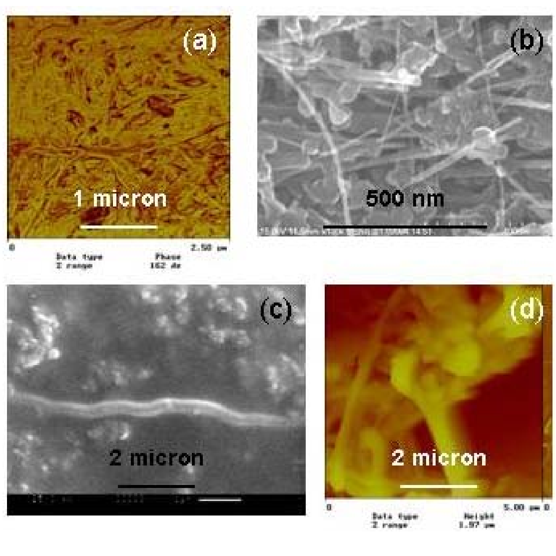

Figure 1. (a) AFM of Single Wall CNTs, (b) FE SEM of Multi Wall CNTs, (c) FE SEM of Vapor Grown Carbon Fibers, and (d) AFM of Electrospun Carbon Nanofibers. (a), (b) and (d) are at 10,000 Gray 86 Krypton heavy ion irradiation; (c) is at 1,000 Gray. The vapor grown carbon fibers showed few fibers remaining at 1,000 Gray and were completely disintegrated by 10,000 Gray. The electrospun carbon nanofibers showed large areas of local melting at 10,000 Gray. By contrast, the Single Wall and Multi Wall CNTs did not show any obvious physical damage at 10,000 Gray.

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