THE VIABILITY OF CARBON NANOTUBES FOR SPACE-RELATED TECHNOLOGY AND APPLICATIONS

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ABSTRACT

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Currently there is a critical need to develop non-Si based "radiation-hard" devices and nanotechnology for space applications. A "radiation-hard" device is a device able to withstand a dosage up to 1000 Gray (Gy) before failing. Space technology must be shielded from radiation encountered in space: heavy ions, protons, electrons, and neutrons. Methods for radiation-hardening have included using silicon-on-sapphire [1-5] or silicon-on-insulator substrates, which are however, expensive and fail after a period of time. Silicon-based devices fail due to destruction of p-n junctions. Carbon nanotube (CNT) based technology is not based on conventional p-n junctions with charge-separated regions. CNT-based space technology could also bring the advantages of cost and size reduction. At the time of this writing, only a few papers, which are theoretical [6-7], have been published on the potential effect of radiation on CNTs. However, to the best of this author's knowledge, the experiments outlined in this thesis are the first such experiments in which the effect of radiation on the properties of CNTs has been investigated in such a well calibrated experiment.

This work is dedicated to my family and friends for all their love and support, to my major professor Dr. Virginia Ayres, for her wonderful patience, guidance and support, and to God, the maker of all creation and to those around me who helped in all the "little ways"

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This work described in this thesis investigates the effect of space radiation, specifically at low-earth orbit (LEO), on the properties of carbon nanotubes (CNTs) in order to determine their viability for space applications. LEO is the region ranging from 10 km to 1000 km above the earth. Potential space applications of carbon nanotubes include: self-repairing materials for the skins of shuttles or space suits, new space-resilient electronics, flat-panel displays and even space elevators.

Heavy ions are a significant source of radiation and are encountered in LEO at high declination. The heavy-ion, and trapped particle regions are illustrated in Figure 1. Current transistor-based electronics technology requires radiation shielding against heavy ions, which are massive, charged particles. The amount of shielding required for effective defense against heavy ions would be mass-prohibitive. Radiation effects are classified into non-destructive errors, which can be overcome by device reset and destructive errors, which cause permanent device malfunction. Examples of radiation effects include: Single Event Upset (SEU), a change of state or transient induced by an ionizing particle such as a cosmic ray or proton in a device; Single Event Functional interrupt (SEFI)/Single Event Transient (SET), a condition where the device stops operating in its normal mode, and usually requires a power reset or other special sequence to resume normal operations; Single Hard Error (SHE), an SEU which causes a permanent change to the operation of a device; Single Event Latchup (SEL), a potentially destructive condition involving parasitic circuit elements forming a silicon controlled rectifier (SCR); Single Event Gate Rupture (SEGR), the burnout of a gate insulator in a power MOSFET and a destructive condition; Lastly, Single Event Burnout (SEB) which is a highly localized burnout of the drain-source in power MOSFETs, which is also a destructive condition. All the previously mentioned damage mechanisms are serious problems for current transistor-based electronics in space applications.

Since their discovery over a decade ago by Iijima [8], CNTs have spawned a wave of research into their potential applications. NASA is particularly interested in the development of CNT-based electronics and textiles which are space-qualifiable. Investigations into the potential use of CNTs as cold cathode sources have also been conducted [9-11].

CNTs are essentially self-closed sheets of graphite. CNTs are either single-wall or multi-wall. Single-wall CNTs can be either separate or bundled in a rope containing twenty to fifty individual nanotubes in a triangular lattice (hexagonal close-packed stacking); the latter is shown in Figure 2 (a)-(b). Individual single-wall CNTs are generally on the order of 0.7-2 nm in diameter and several microns in length. The mean diameters of single-wall CNTs (both individual and bundled), and the inter-tube distances for bundled CNTs, are dependent on the catalyst used and the growth conditions. Individual, separate single-wall CNTs, to best of this author's knowledge, have been synthesized only in the presence of any one of the transition metals such as iron, nickel, copper or cobalt or lanthanides, such as lanthanum, yttrium, gadolinium and neodymium.