WHITE PAPER

Optical Characterization of Electronic Systems and Materials after Radiation Exposure

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Title: Optical Characterization of Electronic Systems and Materials after Radiation Exposure

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Executive Summary

Space radiation can cause degradation in electronic systems ranging from temporary glitches to permanent failure. Radiation-hardened electronic systems are designed to survive extreme cosmic and ionization radiation. However, drawbacks such as significantly higher costs, delayed time-to-market, etc., limit their use in space applications. Commercial-off-the-shelf (COTS) electronic components are a more feasible option for space systems due to their advantages in performance, size, weight, and cost. However, COTS components pose a challenge for radiation assurance due to the significant variability in radiation susceptibility. Understanding the physics of radiation interactions and identifying dominant effects are essential for reliable COTS operation in space environments. The key personnel in this white paper propose to conduct optical characterization of a selected assortment of COTS electronic components and materials after subjecting them to varying levels of radiation exposure to understand the underlying degradation and failure mechanisms and determine target radiation thresholds.

The Challenge:

- **NEC 5SDH-2 Pelletron (2.1 MV terminal voltage), tandem accelerator**

The proton beam will be generated from an NEC 5SDH-2 Pelletron (2.1 MV terminal voltage), tandem accelerator. The NEC 5SDH-2 Pelletron would be utilized primarily for the irradiation of our samples. The Pelletron is capable of accelerating protons at energies of up to 4.2 MeV, alpha particles up to 6.3 MeV, and higher mass ions at a (q+1)*Vterminal energy, where q is the ion's charge state. Due to possessing a low mass, beams comprised of protons require high fluences to observe amorphization of Si (and other semiconductors), to induce defects in decapped single board computers (SBCs), and to displace lattice atoms. Nevertheless, the radiation damage caused by protons can be substantial due to the imparted energy being capable of causing primary effects and inducing secondary effects. The radiation damage will be due to displacement, and total dose. Additionally, the formation of e-h pairs in operating devices can cause massive device faults caused by short circuits in computational hardware components.

• **Raman Measurements:**
As previously stated, COTS electronic components may not meet the USSF requirements, since they are comprised of materials that easily degrade in space due to radiation. Space radiation changes the chemical composition of many materials, which can be detected using Raman spectroscopy. The proposed Raman spectroscopy method can detect damaged materials, as well as identify advanced materials that are less affected by solar radiation. These materials represent a more cost-effective way to shield sensitive COTS components from the effects of space radiation.

• **Machine Learning:**
Machine Learning (ML) is required to aid inexperienced Raman system operators in instruction of use, as well as interpretation of data. ML enables computers to learn and make decisions or predictions without being explicitly programmed. The key personnel in this white paper can assist in all areas of need pertaining to ML.

Proven Technical Capabilities & Breakthroughs

The key personnel in this white paper have demonstrated Raman spectroscopy as a viable approach for assessing the service life of missile propellants. The Raman spectra of both inorganic and organic molecules is a finger-print that can not only identify the molecules but also characterize the chemical changes to their structure due to chemical reaction and degradation. Raman systems operating with 532 nm and 785 nm laser sources are being used at AAMU-RISE to investigate a range of chemicals including inorganic and organic explosives for the Army, as well as rocket-fuel stabilizers such as MNA and 2NDPA. The Raman system consists of a portable laser and spectrometer coupled to a fiber-optic probe. The cooled CCD detector can typically record Raman spectra in a time of few seconds. During the past decade, white paper key personnel have used Raman spectroscopy techniques to detect and evaluate the health of propellant stabilizers commonly used in missiles stored under a range of ambient conditions in support to the Army DEVCOM AvMC mission.

1. Raman monitoring and evaluation of the aging effects of rocket propellant stabilizers

Some of the advanced technologies developed under the "assessment of service life of missile propellants using Raman spectroscopy" project are published in refereed journals.

• <u>Aged Live Propellants</u>**:** For the past decade, collaborative efforts with DEVCOM AvMC personnel have been conducted to take Raman measurements of live missile propellant samples to detect additives for purposes of shelf life and viability.

• <u>Artificially Aged Samples</u>**:** Collaborative efforts with DEVCOM AvMC personnel have been conducted to develop methods to artificially age propellant samples and take Raman measurements for comparison with naturally aged samples.

2. Raman detection of extra virgin olive oil adulterated with cheaper oils

• <u>Remote Sensing</u>**:** The Raman system has been used to detect the degree of adulteration in food items, such as extra virgin olive oil from remote locations. A 2" telescope allows for standoff

Raman measurements at distances ranging from 1-5 meters. An 11” telescope that allows for measurements ranging from 15-250 meters. Low SWaP Fresnel lens telescopes that allow for measurements from 1-15 meters has also been designed and constructed.

• Rapid Data Analysis**:** A quick and easy way to analyze Raman data, which involved comparison of line integrals that resulted in a significant increase in sensitivity, as well as a decrease in integration time, was developed.

USSF Commercial Space Solutions Addressed

Our proposed approach supports the high-priority mission profiles defined by the Space Force. Innovative experimental techniques will be adopted to understand the physics of radiation interactions that cause the gradual degradation of electronic systems and materials subjected to prolonged exposure to space radiation and identify the dominant effects. Our proposed approach involves characterizing two sets of samples: 1) silicon and 2) single board computers (SBCs), such as the Raspberry Pi. Each set of samples will be irradiated with a proton beam with fluences of 1010 p/cm2, 1011 p/cm2, 1012 p/cm2, 1013 p/cm2, 1014 p/cm2, 1015 p/cm2, 1016 p/cm2. Silicon was selected as it is a material commonly utilized in COTS HPC components. The Si-based samples will be fabricated from a <100> wafer, grown by Bridgman method, and the SBCs were selected as their failure under radiation can be observed in vivo. In addition, UV light sources (both lamps and lasers), as well as other proton beam sources, will be considered. X-ray and gamma ray light sources are accessible via collaboration with colleagues at other universities and National Laboratories.

A portable Raman system will be used to assess: 1) the gradual buildup of trapped charges in insulators and semiconductor junctions leading to leakage currents, threshold shifts, and eventual functional failure, 2) the damage from low-energy particle interactions, such as displacement damage in semiconductors, which can reduce carrier mobility and device efficiency, and 3) the alteration in the optical properties of polymer materials. A 785nm Raman system, along with a 532nm Raman system, is used for standard Raman measurements, as well as standoff Raman and microscopic Raman measurements. The main thrust of this research is to monitor different materials before and after being subjected to radiation. This will allow us to assess the damage done to these materials over time, which when paired with lots of data and AI/ML, can be used to predict remaining lifespan of electronics and certain materials.