Phase II Summary Report

HIGH-CONDUCTANCE THERMAL INTERFACES BASED ON CARBON NANOTUBES

Period of Performance: **DECEMBER 1, 2006–NOVEMBER 30, 2009**

Prepared for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, AL

Contract No. NNM07AA26C
Contract Amount: $599,982 (Competitively Awarded)
Phase II Proposal No. 05—2-S6.07-9233

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November 2009
Project No. 6238

1 PROJECT SUMMARY

Purpose of the Research. NASA's Science Mission Directorate (SMD) Division is committed to studying how our global environment is changing. The new devices and missions to achieve the aims of the SMD are creating increasingly demanding thermal environments and applications. These demanding thermal environments are driven by several mission-based requirements: the increased integration of the thermal system with the mechanical and optical components; the increasing size and decreasing temperature of spacecraft optics; the use of a fleet of spacecraft or robots that share resources; and the potential use of high temperature and high flux heat sources. A key element that drives the design of thermal management systems in these demanding applications is the Thermal Interface Material (TIM) between mating surfaces. For example, thermal switches have been considered for use on the James Webb Space Telescope (JWST) to extend the life of the solid hydrogen dewar for the 6 K Mid-Infrared Instrument (MIRI). They are designed to achieve a low thermal resistance when they are closed (ON) and high thermal resistances when they are open (OFF). Currently, the metal-to-metal interfaces used in thermal switches (Figure 1) designed for applications such as the JWST result in thermal resistances of the order of 2000 mm^2 K/W at high contact pressure when closed (ON). Because the time constant of the cool-down rate of the optical component is directly proportional to the resistance of the thermal pathway between the hydrogen dewar and the component, the high resistance of the closed thermal switch increases hydrogen consumption and lengthens cool-down time.

Figure 1. Representative Thermal Switches. These switches were designed for use on the James Webb Space Telescope to extend the life of the solid hydrogen dewar for the 6 K Mid-Infrared Instrument (MIRI). They are designed to achieve low thermal resistances when they are closed (ON) and high thermal resistances when they are open (OFF). However, the thermal resistance of the metal-to-metal thermal interface in the closed (ON) position is 2000 mm^2 K/W, which results in an overly long cool-down and inefficient coolant usage. The pictured switches, manufactured by Space Dynamics Laboratory, are about 14 cm long and about 6.5 cm in diameter.

Our innovation is a novel, vacuum-compatible, heat-conduction interface that employs carbon nanotube (CNT) arrays directly anchored on the mating metal surfaces via microwave plasma-enhanced, chemical vapor deposition (PECVD). By directly anchoring the CNTs to the metal surface, the joint thermal resistance is substantially reduced over current TIMs due to the elimination of thermal contact resistance at the metal surface-TIM interface. During the Phase I project, we demonstrated thermal resistance values of approximately 35 mm^2 K/W at a contact pressure of 0.7 MPa in testing at Creare for a direct-deposited, CNT-based thermal interface on copper substrates. CNTs deposited on a copper substrate during our Phase I project are shown in the photograph of Figure 2. Using this approach, our team partner, Purdue University, has demonstrated thermal resistance values as low as 8 mm^2 K/W, demonstrating the remarkable potential of this innovation. The use of our innovative CNT-based TIMs will enable increased reliability, decreased size, and increased performance of spaceborne thermal

management systems for the SMD. As indicated by our partner, the Space Dynamics Laboratory (SDL). Our innovation has the potential to substantially increase the closed conductance of the thermal switches for JWST, resulting in decreased cool-down time and hydrogen consumption.

Research Carried Out. During the Phase II project, optimized the CNT fabrication process, characterized the CNT performance under realistic operating temperatures and pressures, demonstrated that these interfaces have a conductance that exceeds the state of the art for thermal switch applications, are durable, maintain their performance at cryogenic temperatures, and can be scaled up to larger systems. The resulting CNT surfaces have been integrated into a Thermal Switch Simulator that demonstrated the improved thermal performance enabled by CNT integration.

Phase II Final Results. Creare has successfully demonstrated the integration of the CNT-based TIM into a thermal switch simulator, demonstrating the effectiveness of the CNT for thermal switching applications. In collaboration with NASA personnel, a thermal switch for JWST was chosen to be an excellent demonstration platform for our innovation, and using the Thermal Switch Simulator developed on this project, Creare demonstrated that integrating CNTs into existing thermal switch geometries provides several benefits, including:

- Increased thermal conductivity reduces temperature drops and decreases cool-down time in thermal switching technology by several-fold, maximizing mission efficiency and minimizing the usage of finite cooling resources.
- The CNT surfaces provide a reliable, repeatable, and stable thermal interface surface suitable for repeated Thermal Switch operation without the contamination or integration issues involved with similar thermal interface materials.

Thus, we demonstrated our innovation in a simulated application that addresses near-term NASA needs for high-performance thermal switching.