SKUTTERUDITE-BASED ADVANCED THERMOELECTRIC COUPLES FOR INTEGRATION INTO AN ENHANCED MMRTG

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Introduction: Radioisotope Thermoelectric Generators (RTGs) generate electrical power by converting the heat released from the nuclear decay of radioactive isotopes (typically plutonium-238) into electricity using a thermoelectric (TE) converter. RTGs have been successfully used to power a number of space missions including the Apollo lunar missions, the Viking Mars landers, Pioneer 10 and 11, and the Voyager, Ulysses, Galileo, Cassini, and New Horizons outer planet spacecrafts. MSL's Curiosity rover is powered by the Multi-Mission Radioisotope Generator (MMRTG). Teledyne Energy Systems Inc. (TESI) and prime contractor, Pratt & Whitney Rocketdyne, working in partnership with the Department of Energy, produced this generator for Curiosity. RTGs have demonstrated their reliability over extended periods of time (tens of years) and are compact, rugged, radiation resistant, scalable, and produce no noise, vibration or torque during operation. NASA's Radioisotope Power Systems Technology Advancement Program is pursuing the development of more efficient TE technologies that can increase performance over state-of-practice RTGs, which are limited to device-level thermal-to-electrical energy conversion efficiencies of 7.5% or less, and system-level specific power of 2.4 to 5.1 W/kg. The Jet Propulsion Laboratory (JPL), under funding from the NASA Radioisotope Power Systems Project, under the Advanced Thermoelectric Couple (ATEC) task, has developed couples based on advanced skutterudite (SKD) thermoelectric materials. Conversion efficiency values on the order of 9% have been demonstrated for SKD-based un-segmented couples when operating at a hot-junction of 873K and a cold-junction of 473K. This represents ~ a 25% improvement over the conversion efficiency of PbTe/TAGS MMRTG couples. JPL, in collaboration with TESI, has initiated a project to transfer the technology to TESI, to further mature this technology, to develop the manufacturing capabilities for SKD TE materials, couples, and modules at TESI, and to demonstrate their performance and lifetime potential for insertion into an enhanced-MMRTG (eMMRTG). This paper provides a status of the technology development at JPL, the initial development work at TESI, as well as a brief description of the technology maturation plan.

Materials and components development status: The advanced skutterudite (SKD) materials are: p-$Ce_{0.9}Fe_{3.5}Co_{0.5}Sb_{12}$ and n-$(Ba,Yb)_xCo_4Sb_{12}$. The synthesis of these materials, using a ball milling technique, has been reproducibly scaled up to ~100-200g batches. Several kilograms of both n-and p-type have been synthesized to date at JPL. The synthesis techniques have been transferred to TESI, which has initiated the development of manufacturing capabilities for these SKD materials. To date, the stability of their thermoelectric properties has been demonstrated for up to 1 year at 873K and for 1,500 hrs at 898K. The testing is continuing and is also being extended to up to 923K. A version of an ambient dried aerogel has been developed to provide the needed sublimation suppression at high temperature. The sublimation suppression has been demonstrated up to 873K for up to 1 year. A stable metallization has been developed for both the p- and n-type SKD materials [1]. Figure 1 shows a 63 mm diameter metallized puck. Figure 2 shows diced metallized SKD elements.

Figure 1. 63 mm diameter metallized p-type SKD puck fabricated at JPL

Figure 2. Metallized SKD elements

The SKD materials were also tested for potential damage due to exposure to neutron radiation. It was found that the thermoelectric performance of the materials were unaffected when exposed to a neutron dose equivalent to 17 years of operation in an RTG.

Couple development status: SKD couples have been fabricated using a combination of brazing and diffusion bonding techniques. Figure 3 shows a photograph of SKD couple fabricated at JPL. Figure 4 shows the same couple encapsulated in aerogel. Several couples have been tested under prototypic thermal conditions. Figure 5 shows the predicted and measured power output, total couple voltage, and p- and n-leg voltages. The agreement between the calculated values (based on the measured TE properties and hot- and cold-junction temperatures) is excellent. The corresponding couple conversion efficiency when operating at a hot-junction of 873K and a cold-junction of 473K is about 9.3%. Figure 6 shows the both the calculated and measured conversion efficiency for SKD couples as a function of hot- and cold-junction temperatures. The conversion efficiency for PbTe/TAGS MMRTG couples is shown for comparison. An increase in conversion efficiency of about ~25% can be achieved for SKD couples (at Th = 873K) relative to MMRTG couples. Life testing of selected SKD couples is in progress at JPL to further assess the potential of this technology in the long term.

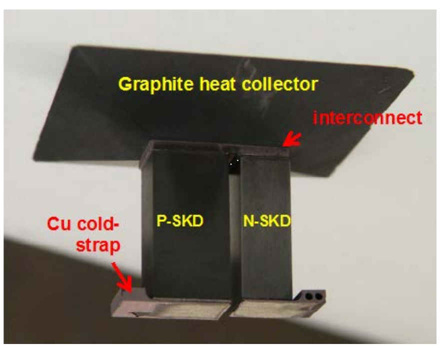

Figure 3. SKD couple with a heat collector.

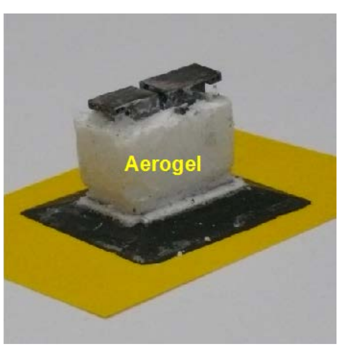

Figure 4. SKD couple encapsulated in aerogel.

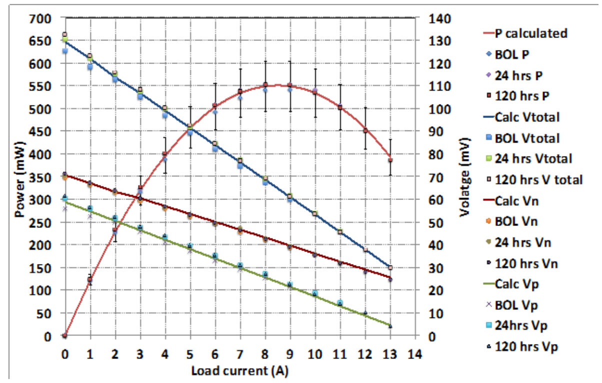

Figure 5. Predicted and measured power output, total couple voltage, and p- and n-leg voltages for a SKD couple at a hot-junction at 873K and at a cold-junction at 473K.

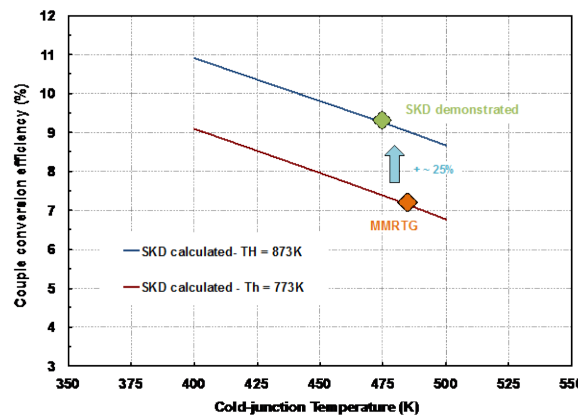

Figure 6. Predicted and measured conversion efficiency for SKD couples. The conversion efficiency for PbTe/TAGS MMRTG couple is shown for comparison.

References:

[1] US Patent # 20120006376