HIGH-CURRENT THIN FILM MULTIJUNCTION THERMAL CONVERTERS AND MULTI-CONVERTER MODULES*

Joseph R. Kinard, Thomas E. Lipe, Clifton B. Childers, and Donald B. Novotny
National Institute of Standards and Technology†
Gaithersburg, MD 20899-0001

De-Xiang Huang
Ballantine Laboratories, Inc.
Cedar knolls, NJ 07927

Abstract

High-current, thin-film multijunction thermal converters (HCFMJTCs) have been fabricated at NIST with heater ranges from a few milliamperes to 1 A. Multi-converter modules containing HCFMJTCs have also been constructed to measure currents up to several amperes.

Introduction

The NIST reference thermal current converter standards are a set of thermoelements (TEs) rated from 2.5 mA to 20 A [1,2]. For ranges up to 250 mA, the TEs are vacuum enclosed with a single thermocouple attached to the midpoint of a short, relatively straight heater by an insulating bead. The converters rated at 250 mA and above contain temperature compensation, heat sinks attached to the heaters, and low-inductance current-return paths. The highest current units also have tubular heaters. This construction provides a reasonably low reactance and moderate skin effect. The output emfs of these devices are generally from about 7 mV to 12 mV at their rated input current.

Although traditional TEs in the current range of 250 mA and below have small ac-dc differences which are reasonably independent of frequency, higher current, conventional TEs may exhibit large errors from skin effect in the heater and lack of suitable thermal lagging or compensation. The specially constructed high-current TEs in use at NIST are no longer commercially available and attempts to rebuild failing units have been only partially successful. Current shunts can be used, but they present more problems from stray impedances to ground, thermal drift, and exhibit greater errors from skin effect at 20 kHz and above.

For these reasons, high-current, thin-film multijunction thermal converters (HCFMJTCs) with both Evanohm‡ and aluminum heater structures, have been designed and fabricated for currents up to 1 A. This paper reports on the fabrication and performance of these HCFMJTCs as well as the construction and results from multi-converter modules containing up to six of these HCFMJTCs.

Design Considerations of HCFMJTCs

A primary source of error in high-current TEs is skin effect arising from the relatively thick heater structures. To minimize this error, the heater structure of the HCFMJTCs is less than 1 µm thick and composed of either aluminum or Evanohm, sputtered on to a silicon wafer using the fabrication methods described in earlier publications [3,4].

The distributed inductance and capacitance of the TE heater structure may also result in significant contributions to the ac-dc difference of the device. To overcome this error, the heater of the HCFMJTC is quite short - on the order of 1 mm. This geometry, made possible by photolithography technology, results in a heater with much less inductance than that of a traditional TE. In addition, since the HCFMJTCs are small and in good thermal contact with their mounting substrates, they lend themselves to coaxial geometry providing improved ac current definition and reduced sensitivity to the proximity of other conductors.

Because of the thin isothermal membrane supporting the heater structure, the HCFMJTC is much more efficient than wire TEs. The voltage drop across the HCFMJTC heater is of the order of tens of millivolts, rather than the 0.15 V to 1 V drop of traditional thermal current converters or shunts. There is therefore much less self-heating in the HCFMJTC, and errors introduced by heating of the structure are minimized. The low thermal conductance of the thin membrane and the use of twenty thermocouples increase the output emfs to about 20 mV at nominal input current. An illustration of a HCFMJTC is shown in Figure 1. Additional

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† Electricity Division, Electronics and Electrical Engineering Laboratory, NIST, Technology Administration, U.S. Department of Commerce.

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ground tracks on the silicon, not shown in the diagram, further reduce the inductance.

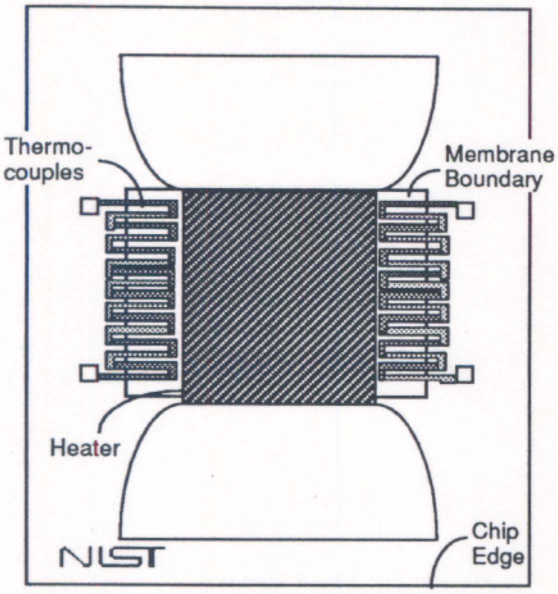

Figure 1. Top view of HCFMJTC. Heater dimensions are approximately 1 mm × 1 mm.

Two different metals have been used for the HCFMJTC heaters to provide different current ratings. Devices with Evanohm heaters have been tested up to 80 mA, while aluminum heaters have been tested up to 1 A. Both heaters can withstand a 200% overload for a few minutes.

High-Current Thermal Converter Module

A multi-converter module composed of up to six HCFMJTCs has been constructed. A cutaway diagram of the high-current module is shown in Figure 2.

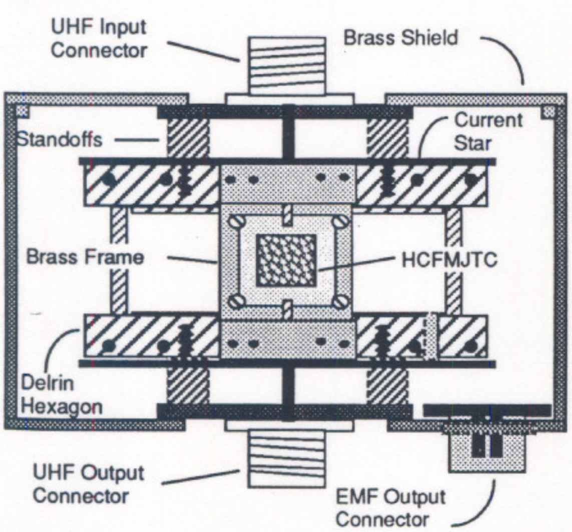

Figure 2. Cutaway section (side view) of high-current module. Outside diameter of can is approximately 125 mm.

The HCFMJTCs are mounted on brass frames for good thermal lagging in order to maintain the alumina substrates at a constant temperature. The inputs to the devices are paralleled through a six-fingered "star", and the outputs are connected in series-aiding, providing an output emf of about 100 mV at 5 A.

The HCFMJTC frames are mounted on a hexagonal structure made of delrin, and the assembly mounted inside a cylindrical brass can to preserve coaxial symmetry. Input and output coaxial connectors permit three-terminal, series connection of the module. Existing chip designs and existing multi-converter modules permit the construction of ranges up to 5 A; however new chip geometries and modules under development will make ranges up to 20 A possible.

Some results of ac-dc difference tests on HCFMJTCs are shown in Table 1. Low-frequency compensation on the individual converters and in the multi-converter module can be used to improve the low-frequency error due to the very short time constants of these chips.

Frequency (kHz)	0.1	1	20	50	100
(20 mA)	+2	0	0	+5	+14
(50 mA)	+27	+1	+7	+3	-1

Table 1. Ac-dc Differences (in μA/A) for HCFMJTCs.

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