MULTILA' (ER THIN-FILM THERMAL CONVERTERS

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Abstract

Multilayer, thin-film multijunction the mal converters (MJTC's) are being produced at NIS'r. This paper describes the thermal and physical designs and materials chosen to reduce ac-dc differences. Experimental results on prototype converters are also given.

Introduction

For more than a decade there has been considerable interest in the use of micro-machining of silicon and photo-lithography on thin-films to produce highperformance thermal sensors as well as 1 any other types of sensors. Several prototype multi layer, thin-film multijunction thermal converters for the measurement of ac voltage and current have been designed, fabricated, and tested [1,2,3].

In the MJTC's described here the heater resistors and many thermocouples are fabricated on top of a thin, multi-layer membrane supported by a s licon frame, see Fig. 1. The silicon chip is mounted on a ceramic substrate sealed with a ceramic lid. The thermal design, physical arrangement, and materials have been chosen to reduce ac-dc difference over a broad frequency range.

Thermal Design for Small AC-DC Differences

Photo-lithographic fabrication used for thin-film MJTCs produces more accurate dimensions of the heater and thermocouples than is attainable with wire MJTC's built by hand [4]. Because of the planar design and by optimizing the distance between the thermocouples and the edge of the membrane, the temperature distribution along the heater and hot junctions in the film MJTC will be more uniform than for wire MJTC's. The contribution to ac-dc difference from the Thomson effect is reduced by this constant temperature along the heater as well as by the choice of heater alloy. The temperature coefficient-of-resistance of the heater is minimized by choosing the appropriate sputtering alloy and by thermal conditioning.

The thermal conductivity of silicon is higher than that of many metals, so the silicon frame is a good heat sink for the thermocouple cold junctions. The silicon frame is mounted directly on an aluminum oxide substrate to provide an even more effective heat sink. To reduce errors due to the Peltier effect, the contact pads for wire-bonding leads are placed over the silicon frame. These thermal and physical design characteristics also contribute to very small dc reversal errors.



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Sensitivity and Reliability of Structure

Very thin membranes and metals for heaters and thermocouples have been fabricated to achieve very low thermal conductivity, high thermal efficiency, and therefore, very high overall sensitivity. Sensitivities of more than 10 mV per mW for these converters have been obtained. Such sensitivities permit lower heater temperatures which reduce ac-dc difference further.

Membranes in some earlier thin-film structures were too thin and could be easily broken. To overcome this problem, multilayer membranes with very low overall stress were developed. To investigate the thin-film MJTC's structural reliability and the variations in 4 thermal conductivities of the materials, one converter's overall efficiency was measured from +80°C to -196°C. Not only did the MJTC not fail, but its overall efficiency increased with falling temperature to about 42% higher at -196°C than at room temperature. The increase in output occurs, even though the Seebeck coefficient is falling, because the thermal resistances of the membrane and metals are increasing proportionally faster, thus producing a net gain in efficiency. Another device withstood the thermal shock of going from room temperature to liquid helium temperature and back without failure. The new converters routinely undergo commercial cleaning, mounting, wire bonding, and sealing, thus demonstrating that they are not too delicate to withstand these necessary operations. Many of the new converters have undergone repeated measurement related thermal cycling for more than half a year and can withstand 100% overload for several minutes.

Measurement Results

AC-DC difference measurements indicate some good performance; however, some characteristics, e.g. capacitance-to-ground from the heater structure, can be improved. Some representative results include ac-dc differences of only a few ppm or less from 1 to 100 kHz and only several tens of ppm at 1 MHz for a bifilarheater MJTC used as a voltage converter. Measurements on the high current MJTC's show ac-dc differences of 10 ppm or less at 50 mA from 1 to 100 kHz. The dc reversal errors are only a few ppm or less as expected. The output emf measured at 1 millitorr in a vacuum chamber is 7.7 times higher than at atmospheric pressure. This indicates that the thermal resistance of the nembrane is very high, so that it is possible to use vacuum mounted MJTC's down to currents as low 1 nA and voltages below 100 mV.

Conclusion

Multilayer, thin-film MJTC's are amenable to mass production and should be suitable for use as primary and working standards as well as in instrumentation.

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