High Temperature Endurance of Packaged SOI Devices for Signal Conditioning and Processing Applications

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Abstract

Silicon on Insulator (SOI) device technology is fulfilling a niche requirement for electronics that functions satisfactorily at operating temperatures of >200°C. Most of the reliability data on the high temperature endurance of the devices is generated on the device itself with little attention being paid to the packaging technology around the device. Similarly, most of the reliability data generated on high temperature packaging technologies uses testpieces rather than real devices, which restricts any conclusions on long term electrical performance.

This paper presents results of high temperature endurance studies on SOI devices combined with high temperature packaging technologies relevant to signal conditioning and processing functions for sensors in down-well and aero-engine applications. The endurance studies have been carried out for up to 7,056 hours at 250°C, with functioning devices being tested periodically at room temperature, 125°C and 250°C. Different die attach and wire bond options have been included in the study and the performance of multiplexers, transistors, bandgap voltage, oscillators and voltage regulators functional blocks have been characterised.

This work formed part of the UPTEMP project which was set-up with support from UK Technology Strategy Board and the EPSRC. The project brought together a consortium of end-users (Sondex Wireline and Vibro-Meter UK), electronic module manufacturers (GE Aviation Systems Newmarket) and material suppliers (Gwent Electronic Materials and Thermastrate Ltd) with Oxford University - Materials Department, the leading UK high temperature electronics research centre.
Keywords: Silicon-on-Insulator devices, signal conditioning circuits, high temperature electronics packaging

Introduction

There is a growing desire to install electronic power and control systems in high temperature environments to improve the accuracy of critical measurements and reduce the cost of cabling from remote and hostile locations. Typical applications include down-hole petroleum/gas/geothermal exploration and production and turbine engines for aircraft propulsion and power generation.

This requirement has posed a challenge to the traditional limit of 125°C for high temperature exposure of electronics systems. The leap in operating temperature to above 200°C in combination with high pressures, vibrations and potentially corrosive environments means that different semiconductors, passives, circuit boards and assembly processes are needed to fulfil the target performance specifications.

Although silicon based electronics have been shown to function at temperatures of up to 200°C, the key problem is the performance degradation due to an increase in leakage currents at elevated temperatures. This problem can be virtually eliminated through the use of Silicon-on-Insulator (SOI) technology, where a monocrystalline film of silicon is deposited on top of an insulating layer. This technology has provided the main impetus for the development of high temperature electronic devices. Other materials such as Silicon Carbide (SiC) have promise for even higher temperature performance, and development is on-going to realise basic device functions for signal processing applications [1].

Although much attention has been paid to the development of semiconductor devices that can operate at higher temperatures, robust packaging and reliable interconnections are the key to the success of high temperature electronics systems. Alongside this integrated circuit development, packaging technologies for single chip and multi-chip modules for operation at 250°C for up to 2000 hours have been demonstrated, covering die attach, wire bond interconnect, passive attach materials and ceramic substrates [2].

Most of the reliability data on the high temperature endurance of the devices is generated on the device itself with little attention being paid to the packaging technology around the device. Similarly, most of the reliability data generated on high temperature packaging technologies uses testpieces rather than real devices, which restricts any conclusions on long term electrical performance of the devices. This paper presents results of high temperature endurance studies on SOI devices combined with high temperature packaging technologies relevant to signal conditioning and processing functions. A previous paper described initial results of endurance testing up to 2,000 hours at 250°C. [3]. These endurance studies have been extended up to 7,056 hours at 250°C, with functioning devices being tested periodically at room temperature, 125°C and 250°C. Different die attach and wire bond options have been included in the study and the performance of transistors, comparators, oscillators, voltage regulators, PTAT (Proportional to Absolute Temperature) functional blocks have been characterised.

This work formed part of the UPTEMP project which was set-up with support from UK Technology Strategy Board (TSB) Technology Programme and the EPSRC, which started in March 2007. The project brought together a consortium of end-users (Sondex Wireline - representing down-well applications, Vibro-Meter UK - representing aeroengine applications), electronic module manufacturers (GE Aviation Systems - Newmarket) and material suppliers (Gwent Electronic Materials and Thermastrate Ltd) with Oxford University - Materials Department, a UK based high temperature electronics research centre providing the detailed analysis of the failure mechanisms.

High Temperature Endurance Studies on SOI Devices

Within this project, a SOI based integrated circuit based on the X-FAB 1 μm SOI process has been designed and manufactured with analogue signal conditioning, ADC/DAC (Analogue to Digital Conversion/Digital to Analogue Conversion) and simple logic control, see Table 1 for a summary of functional blocks contained and Fig. 1 for a picture of the device, which had dimensions of 4.5mm x 4.0mm.

Table 1. Features contained within UPTEMP SOI device for high temperature operation

Function	Details
Op-amps/Comparators	Standard cells Larger transistors/Higher voltage
ADC/DAC	Standard cells – 10 bit
Voltage Regulator	Stabilised over temperature
Oscillator	RC Oscillator
Mux/Comparators	4:1 Multiplexer
Logic	Voltage divider Data acquisition
Test Cells	Op-amps Transistors Digital Gates and Flip-Flops

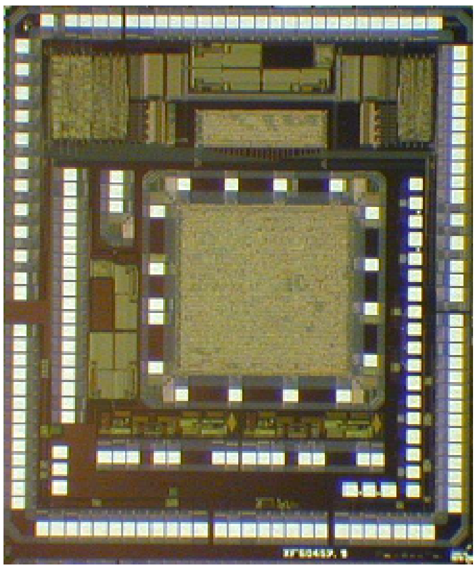

Fig 1. Silicon on Insulator device for high temperature operation developed in UPTEMP project

For the high temperature endurance study, samples using the SOI device have been assembled in HTCC packages, see Fig 2, with different bonding options to characterise the following device functions:

- Multiplexer
- N-Transistor
- Bandgap Voltage
- Oscillator
- Voltage Regulator

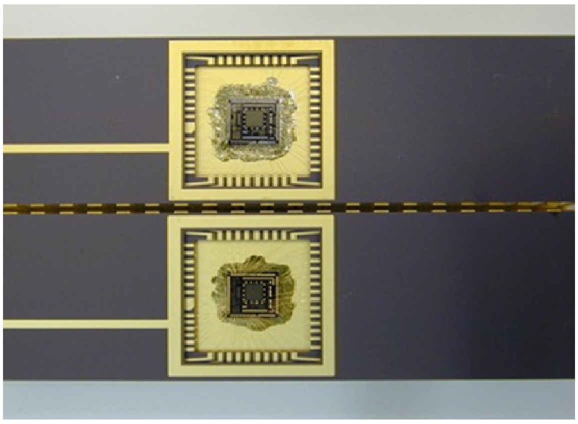

Fig 2. Samples of SOI devices assembled in HTCC package for assessment of electrical performance at 250°C

The assembled packages were submitted to temperature storage at 250°C for up to 7056 hours, with measurements performed at 25°C, 125°C and 250°C before high temperature storage (0 hours) and after storage for 3360 hours, 4704 hours and 7056 hours. The tests are continuing to extend the temperature endurance at 250°C up to 9,000 hours.

The results showed that in general stable performance was achieved for all the functions evaluated, which indicates that the device architecture and packaging technology can withstand the continuous 250°C environment for at least up to 7056 hours exposure. Failure analysis of the devices will be undertaken when the electrical performance of the various functional blocks show significant signs of deterioration.

Conclusions

High temperature Silicon on Insulator (SOI) devices representative of analogue signal conditioning and processing functions, mounted into HTCC packages have shown stable performance at 250°C for up to 7056 hours.

Acknowledgements

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References

[1] McGonigal J A et Al "Research and Development of an Extreme Temperature Silicon Carbide CMOS Semiconductor Process" Proceedings of the HITEN 2009 Conference, Oxford, 13-16 Sept 2009, pp78-82

[2] Riches S T et Al "Development of High Temperature Electronics Packaging Technology for Long Term Operation at 250°C" Proceedings of the HITEN 2009 Conference, Oxford, 13-16 Sept 2009, pp153-160

[3] Riches S T et Al "Application of High Temperature Electronics Packaging Technology to Signal Conditioning and Processing Circuits" Proceedings of the HITEC 2010 Conference, Albuquerque, New Mexico, 11-13 May 2010, pp89-96

Table 4. Summary of Electrical Test Results on SOI Devices assembled in HTCC Packages

Device Function	Measurement	Temperature °C	Storage Time at 250°C (hours)			
			0	3360	4704	7056
Multiplexer	Connect 2.5V Measure Resistance - Ohms	25	3405 Ω	3740Ω	3517Ω	3434Ω
		125	3667Ω	3779Ω	3782Ω	3768Ω
		250	3795Ω	3838Ω	3778Ω	3778Ω
N-Transistor	Connect transistor source Apply gate bias of 2V Measure DRAIN current to 0V – micro-Amps	25	112µA	110µA	110µA	109µA
		125	190µA	188µA	190µA	161µA
		250	295µA	295µA	268µA	294µA
Bandgap Voltage	Apply 7V Measure voltage on BANDGAP - Volts	25	2.61V	2.61V	2.61V	2.62V
		125	2.66V	2.66V	2.66V	2.64V
		250	2.70V	2.69V	2.69V	2.69V
Oscillator	Connect 2.5V to OSCREF Connect 2.425V to RC Check OSCOUT is 0V Increase RC to 2.575V Check OSCOUT is at 5V	25	4.97V	4.96V	3.34V	3.19V
		125	5.26V	4.95V	4.89V	4.89V
		250	4.32V	4.95V	4.87V	4.87V
Voltage Regulator	Connect AVDDH to 7V Connect RREG to VREG via 22kohms Connect RTEMP to TEMP via 68kohms Measure V on VREG	25	4.38V	4.38V	4.36V	4.36V
		125	4.56V	4.56V	4.55V	4.50V
		250	4.82V	4.80V	4.80V	4.79V