

Test of SOI 555 Timer with High Temperature Packaging

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ABSTRACT

The thick oxide layer of silicon-on-insulator (SOI) devices significantly reduces the junction leakage current at elevated temperatures compared to similar Si devices, resulting in an elevated maximum operating temperature. The maximum operating temperature, specified by manufacturers, of commercial SOI devices/circuits with conventional packaging is usually 225°C. It is important to understand the performance and de-ratings of these SOI circuits at temperatures above 225°C without the temperature limit imposed by commercial packaging technology. This work tested a low frequency square-wave oscillator based on an SOI 555 Timer with a special high temperature ceramic packaging technology from room temperature to 375°C. The timer die was attached to a 96% aluminum oxide substrate with high temperature durable gold (Au) thick-film metallization, and interconnected with Au wires. The timer die was soaked in a table-top box oven while all the discrete passive components were at room temperature during the testing. The square-wave parameters such as frequency, pulse duration, amplitude, and rise time of the square wave as well as the total DC current supply were measured as functions of temperature. The major oscillation parameters changed a few percent from room temperature to 375°C, while the rise time increased from 37.5 ns to 42.5 ns. The

test results up to 375°C and failure phenomena are discussed.

INTRODUCTION

High temperature electronics are essential for automobile under-hood engine control as well as intelligent aerospace engines with a distributed control system [1-3]. Silicon-on-insulator (SOI) circuits are important to these application fields at temperatures above the upper limit of standard silicon electronics technology due to their high temperature capability.

A thick buried silicon dioxide layer between the bulk Si substrate and the pn-junctions significantly reduces the number of isolation junctions as well as the overall junction area of an SOI chip compared with a similar Si circuit chip. Therefore, the leakage current of the SOI circuit chip is much lower compared with that of a similar Si chip. Consequently, the drain leakage current of an SOI NMOS transistor based on the top Si layer (for devices structure fabrication) at 250°C is reduced by two orders of magnitude from that of a bulk Si NMOS transistor [4]. Reduced leakage current improves the device performance at elevated temperatures, consequently, SOI devices can operate up to 225°C according to manufacturer specifications. However, most SOI devices/circuits do not fail or deteriorate at temperatures immediately above 225°C [5]. In order to explore the intrinsic temperature limit of SOI circuits

imposed by device physics or material durability, it is critical to understand the performance and the failure phenomena of core SOI devices/circuits at temperatures above 225°C without external limitations such as packaging. This paper reports the testing results and the failure phenomenon of an SOI 555 Timer [6] with high temperature packaging that has capabilities beyond that of commercial packaging, from room temperature to 375°C.

EXPERIMENTAL

The 555 Timer chip was attached to a gold thick-film metallized aluminum oxide substrate [7] using silver particle filled high temperature epoxy, as shown in Figure 1. Au wires with diameter of 1 mil were used for electrical interconnection between the die and the metallization pads on the packaging substrate. The packaged 555 Timer chip was soaked in a box-oven. Au wires of 10 mil diameter were used to further connect the metallization pads of the packaging substrate to the passive circuit

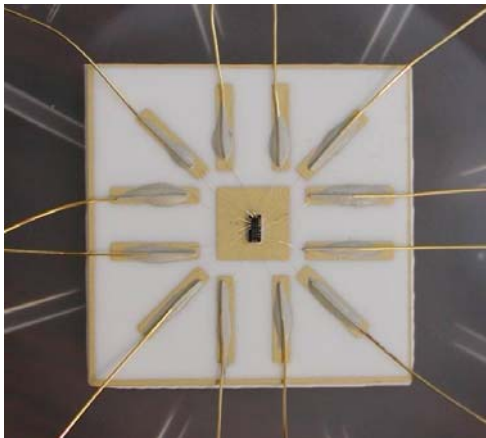


Figure 1: Semi-packaged 555 Timer for high temperature testing. The timer die was mounted on an alumina substrate with Au thick-film metallization. 1 mil Au wires were used to connect the chip and the metallization pads on the substrate. 10 mil Au wires were mounted on the substrate with silver particle filled high temperature epoxy to connect the packaged devices to the instruments outside the oven.

components (passives) and the instruments outside of the oven. A low frequency RC oscillator was constructed; and the circuit diagram is shown in Figure 2.

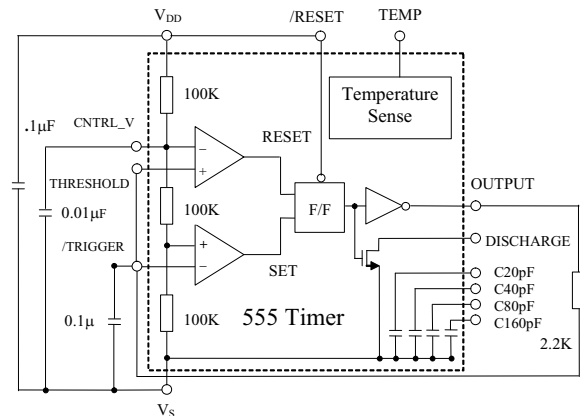


Figure 2: The circuit diagram of a square wave oscillator based on a 555 Timer. A simplified circuit diagram of the 555 Timer is shown in the dashed box. The timer is soaked in a table top box oven during the testing while all the external passives were outside of the oven.

A simplified circuit diagram of the 555 Timer is shown in the dashed box of Figure 2. All the external passives were at room temperature (outside of the oven). V_{DD} (V_{SS} was grounded as zero) was 5V for all of the tests. The output square wave parameters such as frequency (period), amplitude, positive pulse width, rise time, fall time, and the DC current were recorded at various test temperatures and different dwell times. The circuit design was basically identical to that previously reported as a temperature sensing circuit for applications at elevated temperatures [8,9]. The major purpose of this test was to examine the performance and durability of the 555 Timer at temperatures above the maximum operation temperature (225°C) specified by the manufacturer. Thus, external passives were used, and were kept at room temperature. A digital oscilloscope with input impedance of 1 M Ω and 13 pF was used for all of the parameter measurements as well as for recording the

waveforms. A series resistor of 200 Ω between the circuit output and the input of the digital oscilloscope was used with an internal low-pass filter (of the oscilloscope) with 20MHz bandwidth to reduce high frequency ringing at the rising and falling edges. This added damping resistor and filter may slightly overestimate the rise and fall times measured. However, without the damping the high frequency parasitic oscillations at rising and falling edges may underestimate the rise and fall times.

The circuit was first characterized at room temperature by measuring the square wave parameters as well as the DC current. Then the circuit was characterized at temperatures of 50, 100, 150, 200, 225, 250, 275, 300, 325, 350, and 375°C. The temperature ramp rate between each temperature step was 40°C/min, as shown in Table 1. The intentional dwell times at temperatures above 225 °C are also listed in Table1. After testing at 375°C for over 746 hours, the circuit was characterized again at room temperature. After room temperature characterization, the temperature was again raised to 375 °C.

Table 1: The heating history of the 555 Timer during the testing. The oscillation circuit was in constant operation during the testing.

Ramp	T (°C)	Dwell	Observation
40°C/min	T _R		normal
40°C/min	50		normal
40°C/min	100		normal
40°C/min	150		normal
40°C/min	200		normal
40°C/min	225		normal
40°C/min	250	18 hrs	normal
40°C/min	275	72 hrs	normal
40°C/min	300	100 hrs	normal
40°C/min	325	148 hrs	normal
40°C/min	350	260 hrs	normal
40°C/min	375	746 hrs	normal
-10°C/min	T _R	24 hrs	normal
40°C/min	375		failure

WAVEFORM PARAMETERS

The output square-waves at room temperature (before), 225°C, 300°C, 375°C, and room temperature (after) are shown in Figure 3. All the waveform parameters are relatively stable in the entire test temperature range as shown below.

Figure 4 shows the rise edges of the square-waves, at room temperature before heating, recorded with and without the 200 Ω resistor and 20MHz low-pass filter. The rising edge recorded with 200 Ω resistor and 20 MHz filter shows no high frequency ringing. But as was discussed earlier, the damping resistor and the low-pass filter may slightly over-estimate the rise times.

Figure 5 shows the rising edges of the output waveforms at various temperatures. As it will be discussed later, the rise time does not change much with the temperature.

The frequency of the square wave is plotted against the temperature of the 555 Timer, as shown in Figure 6. The frequency shifts from 3.208 kHz to 3.361 kHz as the temperature changes from 23 °C to 375 °C. After 750 hours continuous operation at 375 °C, the oscillation frequency shifts to 3.385 kHz. After testing at elevated temperatures, the oscillation frequency at room temperature is 3.236 kHz, an increase of 0.87% from the initial frequency at room temperature before heating.

Figure 7 shows the plot of positive pulse duty cycle vs. the temperature of the timer. The duty cycle is quite stable with respect to the temperature of the timer circuit. The duty cycle has less than 1% deviation from 50% between room temperature and 350 °C, the duty cycle is 50.6% at 375 °C. The duty cycle at room temperature after the testing at elevated temperatures is 50.05%.

Figure 8 shows the data of square wave amplitude vs. the temperature. The

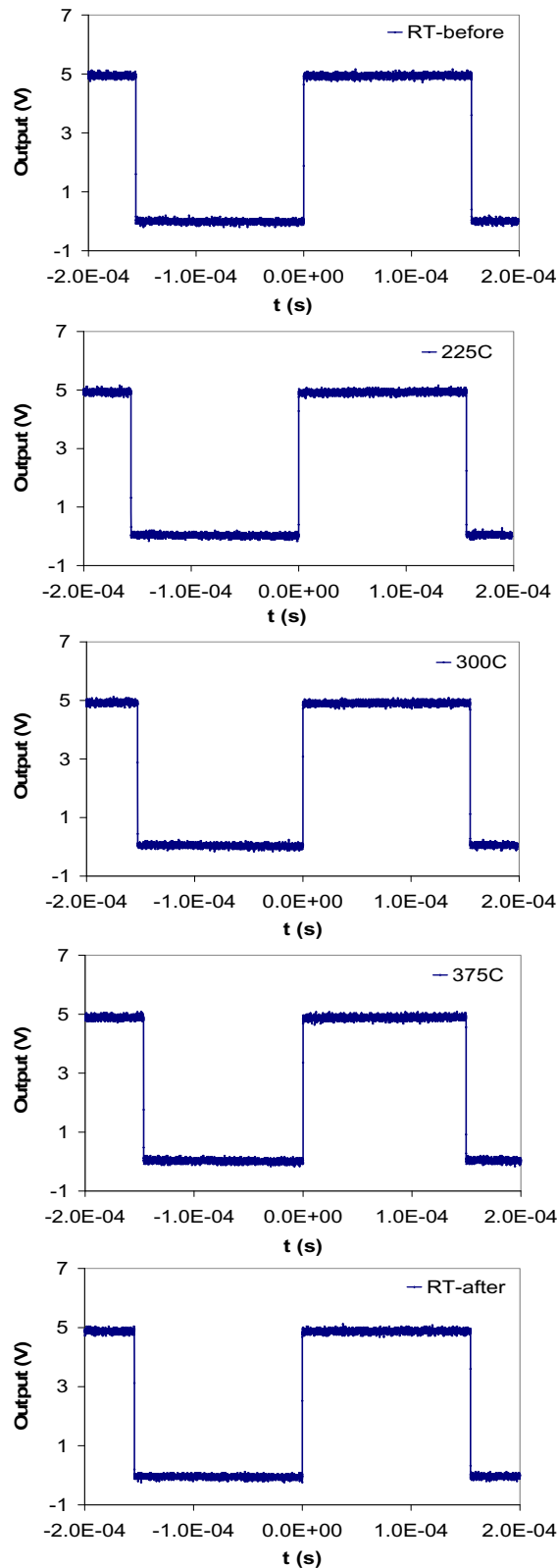


Figure 3: The output of square-waves at room temperature (before), 225°C, 300°C, 375°C, and room temperature (after).

output is 4.94V at room temperature

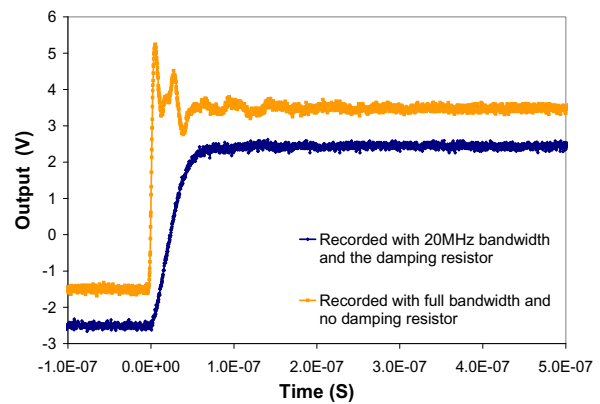


Figure 4: The rising edges of the square waves recorded at room temperature before heating with and without the damping resistor and 20MHz low-pass filter. The upper curve was shifted up 1 V to avoid the overlap.

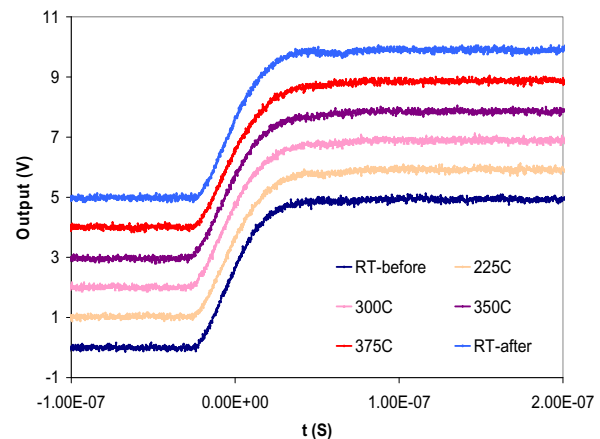


Figure 5: The rising edges of the waveforms at room temperature (before), 225°C, 300°C, 350°C, 375°C, and room temperature (after). The signals were recorded with a 200 Ω resistor between the output of the circuit and the digital oscilloscope to reduce high frequency parasitic oscillations at rising and falling edges. The bandwidth of the oscilloscope was set at 20 MHz. The curves were shifted up 1 V from each other to avoid overlapping.

initially. The amplitude decreases very slowly with temperature. At 375 °C, the amplitude is 4.9V. It is still 4.9V at room temperature at the end of testing (at elevated temperatures).

Figure 9 shows the data of DC current supply vs. temperature. The solid line is the best linear fit of the data of the current vs. temperature. Basically, the DC