Diode Leakage Current Based Low Power, On-chip High Temperature Sensor Circuit

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In recent years silicon-on-insulator (SOI) based high temperature circuits have gained popularity in extreme environment applications like automotive, geothermal exploration, well-logging, aircrafts, and space exploration. Often these circuits are designed for operation at or above 200°C ambient temperature. For safety of these circuits, mechanism to detect die temperature in excess of allowed upper limit needs to be integrated along with the actual circuit. This work presents an extremely low power, on-chip high temperature sensor circuit designed in 0.8 micron 2-poly, 3-metal SOI process. The scheme presented here efficiently utilizes the exponential increase in diode leakage current with the increase of temperature to determine whether the die temperature has exceeded the maximum allowed temperature. If it does, then this circuit generates a fault signal which can be employed to shut down the circuitry that this sensor is monitoring. The fault signal is automatically removed only when the die temperature cools down below a pre-defined level lower than the upper limit which activates the fault signal. Main advantage of this circuit is its extremely low power consumption in the normal operating temperature range (≤200°C).

One of the most popular methods to realize on-chip temperature sensor uses the difference between the base-emitter voltages of two substrate PNP transistors (thermal diode) of same size, which are forward biased by two different currents usually in the range of hundreds of micro amps [1-4]. Main drawback of this approach is the continuous power loss even when the die temperature is in the normal operating range. Some researchers have utilized time-to-digital-converter, or a ring-oscillator to realize the temperature sensor [5]. This approach requires large chip area and consumes excessive power at required sampling rate. All these approaches are also restricted to limited operating temperature range (≤130°C). This paper presents a simple temperature sensor which can be used to monitor die temperature up to 250°C. Fig. 1 shows the schematic of the proposed circuit. The core temperature sensing part of this circuit is the reverse biased diode, D_{sense}. Several (M) p-n junction diodes are connected in parallel to increase the total leakage current which depends on the die temperature. Fig. 2 shows the measured and simulated diode leakage current for $M=1$. For the same values of measured and simulated leakage currents there exists a 20°C offset. This was taken into consideration to set the target maximum allowable die temperature. Diode leakage current, which is in the nA range, is first multiplied by the PMOS current mirror ratio (1:60) and then converted to a voltage signal by the resistor R_L. Voltage drop across the resistor R_L is applied to the input of a Schmitt trigger which is buffered with one stage inverter circuit to drive the output node. With the increases in the die temperature, voltage drop across R_L goes high and once it exceeds the low-to-high threshold voltage of the Schmitt trigger, V_{out} shifts to logic high (V_{DD}) indicating a fault condition. This can be used to shut down the main circuitry in the die. To ensure the true removal of the factors triggering the excessive die temperature, the high-to-low threshold voltage of the Schmitt trigger is set at a lower value corresponding to 15°C reduction in the die temperature. This hysteresis will prevent the circuit to be turned ON by temporary recovery of the fault condition.

Fig. 3 shows the sensor output signal, V_{out} with the increase in die temperature for two different settings of the number of reverse biased diodes in the circuit ($M=20$ and $M=5$). 20 diodes in parallel set the fault triggering temperature at 230°C, whereas 5 diodes set it at 263°C. Fig. 3 also shows the logic high to low transition for V_{out} when the die temperature goes down. By proper sizing of the devices in the Schmitt trigger, 15°C hysteresis was provided in the sensor circuit. Monte Carlo simulation of the circuit shows less than 1°C variation due to process variation and device mismatch. Power consumptions of the sensor part and the complete circuit are shown in Fig. 4. From this figure it is evident that this sensor circuit consumes very little power in the desired temperature range. At 150°C total power consumption is only 0.6 μW which goes to 9.63 μW at 200°C. The spike in the total power consumption is due to the logic level transition of Schmitt trigger's output node. External control of the target upper limit of the die temperature can be provided by keeping provision to change the number of diodes connected in parallel to construct D_{sense}, which generates the temperature sensitive leakage current. Table 1 shows a comparison of this scheme with other temperature sensors reported in literature in terms of power consumption and maximum temperature range.

Reference:

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[5] P. Chen et al., *IEEE J. Solid-State Circuits,* vol. 40, no. 8, pp. 1642-1648, Aug. 2005.

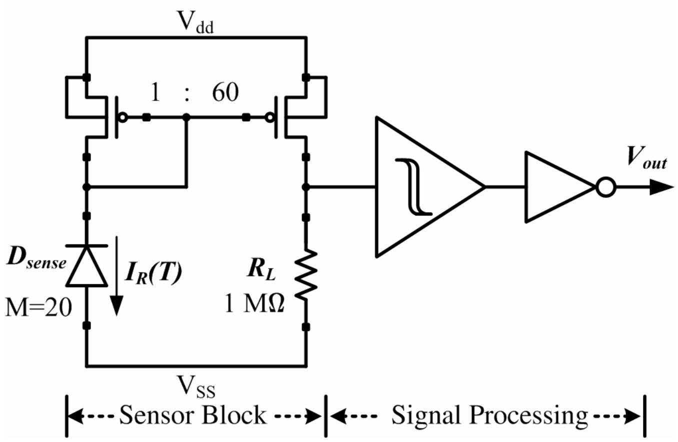

Fig. 1. Schematic of the temperature sensor circuit.

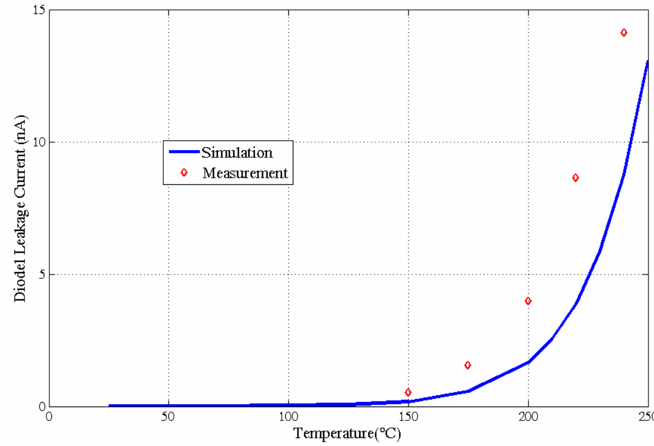

Fig. 2. Diode leakage current vs. temperature

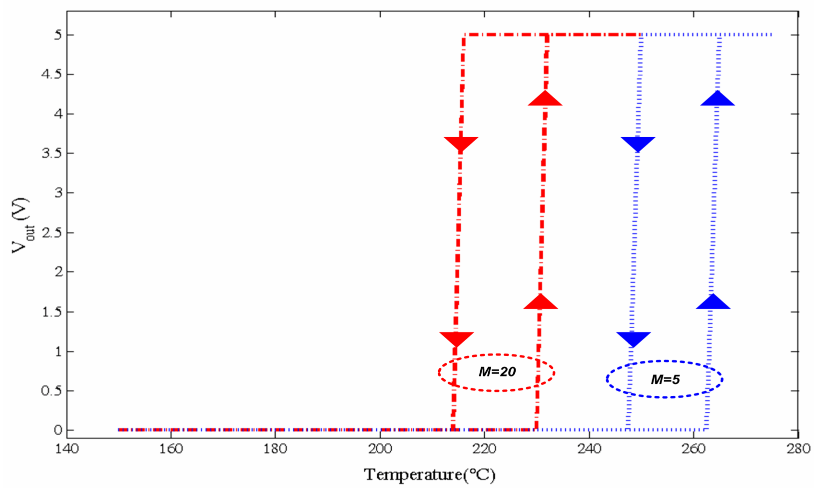

Fig. 3. Sensor circuit output (V_{out}) with the increase and decrease of die temperature (*M* is the number diodes connected in parallel for temperature sensing)

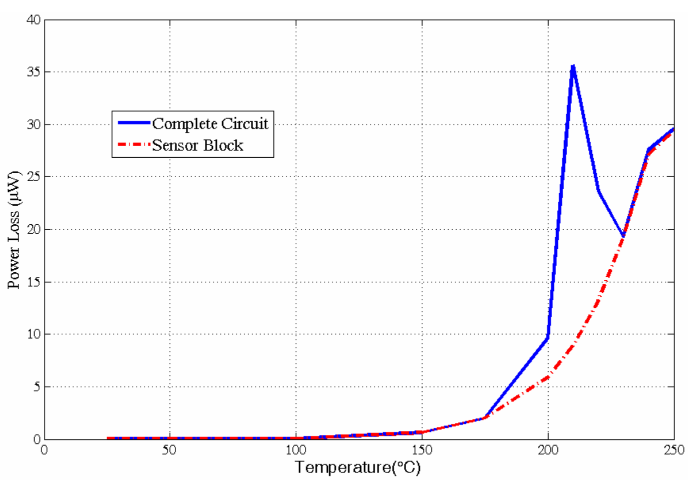

Fig. 4. Power loss in the sensor block and in the complete circuit vs die temperature

Table 1. Performance comparison

Sensor	Maximum Temp. (°C)	Power Consumption (μW)
1	100	100
2	130	0.49
3	125	1
4	125	429
5	100	10
This work	250	35.7