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SOI N-Channel Field Effect Transistors, CHT-NMOS80, for Extreme Temperatures

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Scope

Extreme temperatures, both hot and cold, are anticipated in many of NASA space exploration missions as well as in terrestrial applications. One can seldom find electronics that are capable of operation under both regimes. Even for operation under one (hot or cold) temperature extreme, some thermal controls need to be introduced to provide appropriate ambient temperatures so that spacecraft on-board or field on-site electronic systems work properly. The inclusion of these controls, which comprise of heating elements and radiators along with their associated structures, adds to the complexity in the design of the system, increases cost and weight, and affects overall reliability. Thus, it would be highly desirable and very beneficial to eliminate these thermal measures in order to simplify system's design, improve efficiency, reduce development and launch costs, and improve reliability. These requirements can only be met through the development of electronic parts that are designed for proper and efficient operation under extreme temperature conditions.

Silicon-on-insulator (SOI) based devices are finding more use in harsh environments due to the benefits that their inherent design offers in terms of reduced leakage currents, less power consumption, faster switching speeds, good radiation tolerance, and extreme temperature operability. Little is known, however, about their performance at cryogenic temperatures and under wide thermal swings. The objective of this work was to evaluate the performance of a new commercial-off-the-shelf (COTS) SOI parts over an extended temperature range and to determine the effects of thermal cycling on their performance. The results will establish a baseline on the suitability of such devices for use in space exploration missions under extreme temperatures, and will aid mission planners and circuit designers in the proper selection of electronic parts and circuits.

The electronic part investigated in this work comprised of a CHT-NMOS80 high temperature N-channel MOSFET (metal-oxide semiconductor field-effect transistor) device that was manufactured by CISSOID [1]. This high voltage, medium-power transistor is fabricated using SOI processes and is designed for extreme wide temperature applications such as geothermal well logging, aerospace and avionics, and automotive industry. It has a high DC current capability and is specified for operation in the temperature range of -55 °C to +225 °C. Table I shows some specifications of this transistor [1].

The CHT-NMOS80 device was characterized in the temperature range of -190 °C to +225 °C. Performance characterization was obtained in terms of its voltage/current characteristic curves, drain-source on-state resistance (R_{DS}(on)), and gate threshold voltage V_{GS}(th). These properties were obtained using a Tektronix 370B programmable curve tracer. The SOI transistor was characterized at test temperatures of +22, 0, -50, -100, -150, -175, -190, +50, +100, +150, +175,

+200, and +225 °C. Limited thermal cycling testing was also performed on the device. These tests consisted of subjecting the transistor to a total of twelve thermal cycles between -190 °C and +225 °C. A temperature rate of change of 10 °C/min and a soak time at the test temperature of 10 minutes were used throughout this work. Post-cycling measurements were also performed at selected temperatures on the investigated properties. In addition, re-start capability at extreme temperatures, i.e. power switched on while the device was soaking for a period of 20 minutes at the test temperatures of -190 °C and +225 °C, was investigated.

Table I. Manufacturer's specifications of CHT-NMOS80 transistor [1].

Parameter	**Rating**	**Units**
Operating temperature, T	–55 to +225	°C
Drain current, I_D	3.5 to 6	A
Drain-source breakdown voltage, V_{DS}(BR)	> 80	V
Drain-source on-state resistance, R_{DS}(on) at V_{GS}=5V & V_{DS}=50mV	0.55 to 0.9	Ω
Gate threshold voltage, V_{GS}(th) @ V_{DS} = 50mV	1.3 – 1.9	V
Gate-source voltage, V_{GS}	-0.5 to 5.5	V
Package	TO3	
Lot Number	2080136.1	

Results and Discussion

Although two devices of this CHT-NMOS80 transistor were evaluated in this work, data pertaining to only one is presented due to the similarity in the results of both devices.

Temperature Effects

The pre-cycling output characteristics of the SOI CHT-NMOS80 transistor at selected test temperatures between -190 °C and +225 °C are shown in Figure 1. These characteristics are defined as the drain current (I_D) versus drain-to-source voltage (V_{DS}) curves at various gate voltages (V_{GS}). Upon examination of the operation of the transistor in the temperature regime between +22 °C and -190 °C, two changes in its output characteristics are observed with decreasing test temperature. The first is the reduction in the transistor's linear region as reflected by the increase in the slope of its I_D/V_{DS} curves as temperature is decreased. This gradual increase in the slope of the curves with decreasing temperature is an indication of a decrease in the transistor drain-to-source on-state resistance R_{DS}(on). The second change exhibited by the transistor comprised of a gradual but slight increase in its gate threshold voltage (V_{GS}(th)) as temperature decreased. At the other end of the temperature spectrum, i.e. high temperatures, the SOI transistor exhibited similar dependency in its characteristics but with opposite trend. In other words, as temperature was increased from +22 °C to +225 °C, the drain-to-source on-state resistance R_{DS}(on) exhibited an increase, and the gate threshold voltage (V_{GS}(th)) underwent a decrease. Changes in the on-state resistance R_{DS}(on), obtained at V_{GS} = 5V and V_{DS} = 1V, and the gate threshold voltage (V_{GS}(th)) are depicted in Figures 2 and 3, respectively. It is believed that these changes in these properties are attributed to thermal stressing of the transistor that can lead to channel dopant redistribution and possible diffusion into the oxide gate, and to surface potentials that are created by interface and mobile ionic charges, especially at high temperatures.

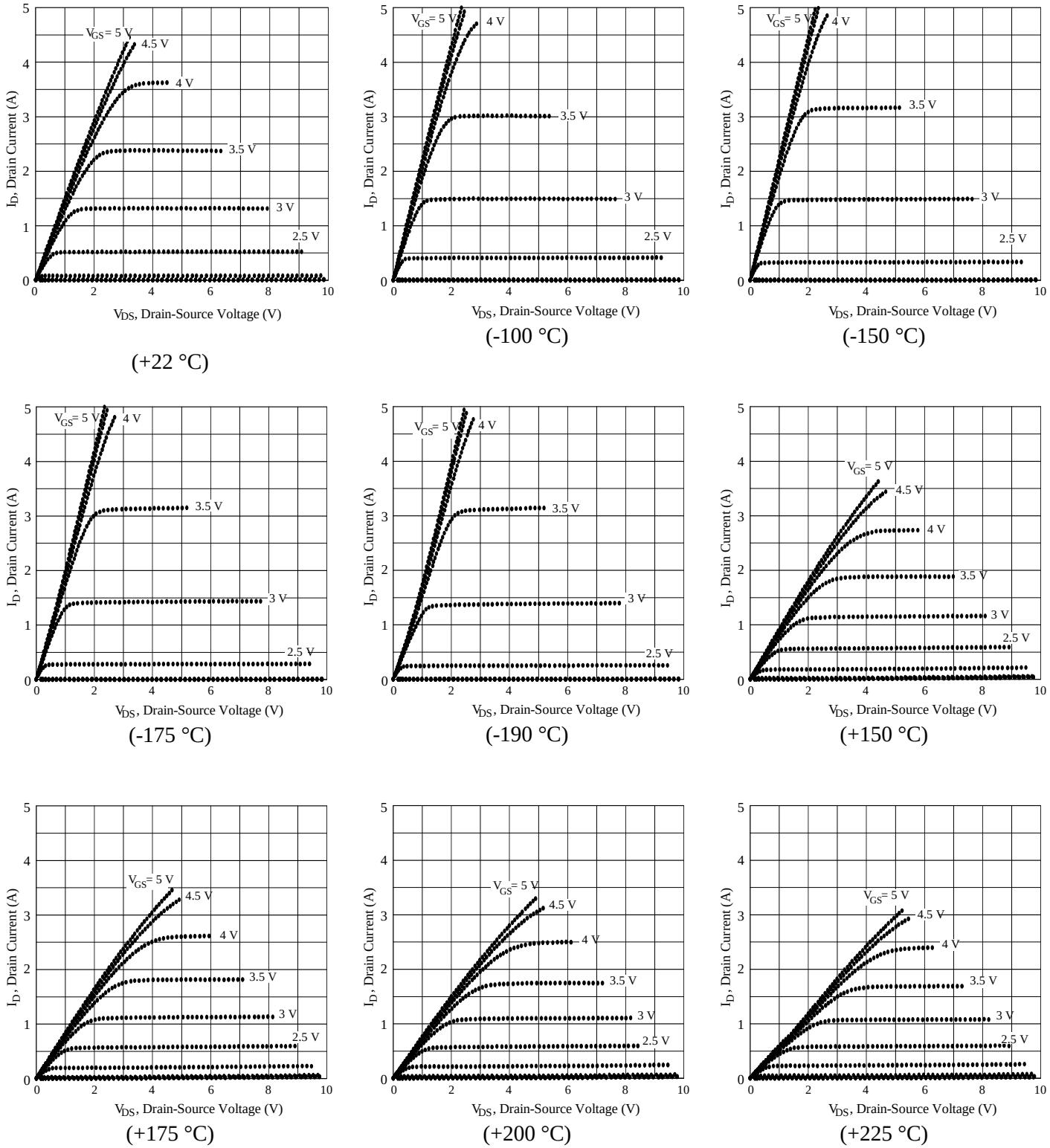


Figure 1. Pre-cycling characteristics of the CHT-NMOS80 transistor at various test temperatures.

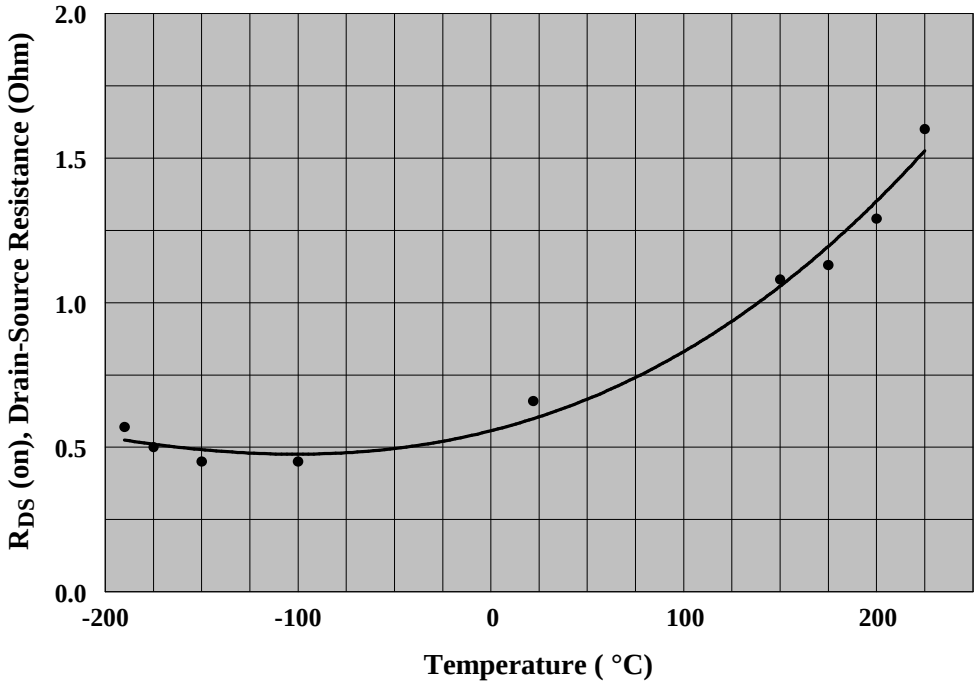


Figure 2. On-state resistance of the SOI NMOS80 transistor versus temperature (taken at V_{GS} = 5V and V_{DS} = 1V).

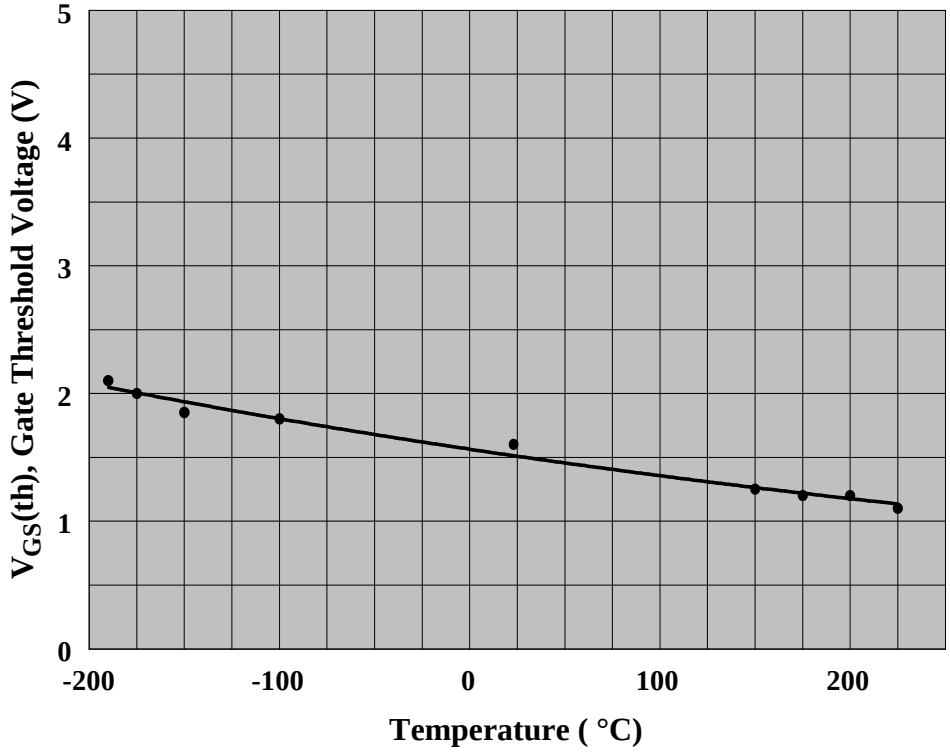


Figure 3. Gate threshold voltage of the SOI NMOS80 transistor as a function of temperature.

Re-Start at Extreme Temperatures

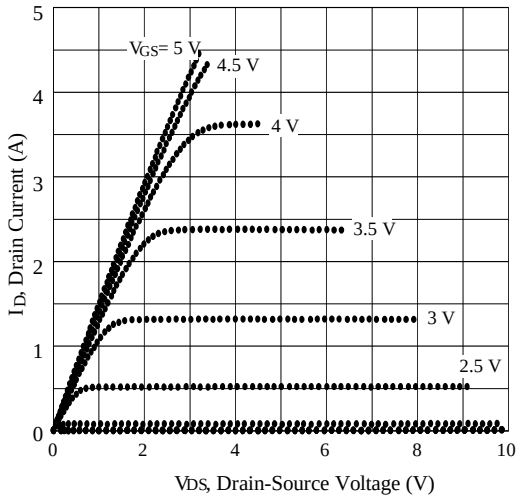
Re-start capability of the N-channel SOI NMOS80 transistor was investigated by allowing it to soak at each of the extreme test temperatures for at least 20 minutes without the application of electrical bias. Power was then applied to the device and measurements were taken on the output characteristics. The SOI transistor was able to successfully re-start at either extreme, i.e. -190 °C and +225 °C, and the results obtained were the same as those obtained earlier at each corresponding temperature.

Effects of Thermal Cycling

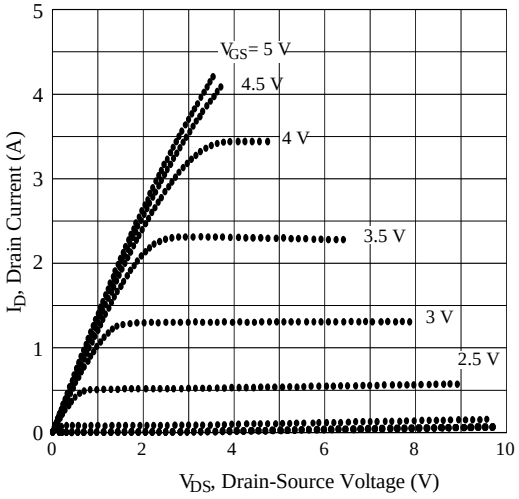
The effects of thermal cycling under a wide temperature range on the operation of the NMOS80 transistor were investigated by subjecting the device to a total of 12 cycles between -190 °C and +225 °C at a temperature rate of 10 °C/min and a soak time at the extreme temperatures of at least 10 minutes. This limited cycling is, by no means, a method to determine the long-term reliability of any electronic device, however, it can give a preliminary indication of the effects of temperature swings on the performance of the device. I_D versus V_{DS} curves at various gate voltages (V_{GS}) were then taken at +22 °C, -190 °C, and +225 °C. Comparison of the output characteristics of the SOI transistor at these selected test temperatures before and after the thermal cycling are depicted in Figure 4. It can be seen that the NMOS80 transistor did not display any significant change in its characteristics. Accordingly, little variation was noted in the drain-to-source on-state resistance $R_{DS}(on)$ and the gate threshold voltage ($V_{GS}(th)$) as depicted in Table II for three test temperatures before and after the thermal cycling. As far as device packaging is concerned, the NMOS transistor exhibited no structural deterioration or physical damage due to this limited thermal cycling.

Table II. Pre- and post-cycling values of $R_{DS}(on)$ and $V_{GS}(th)$ at different temperatures.

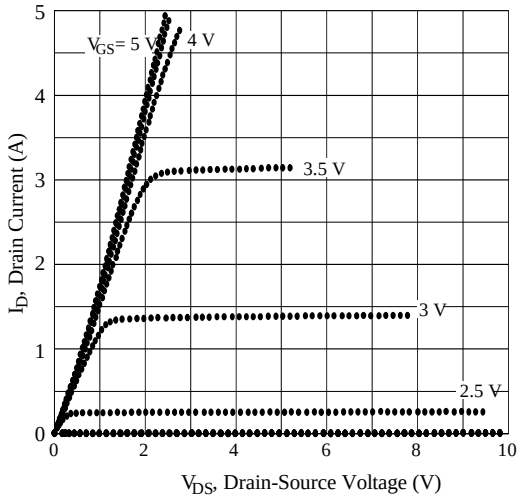
	$R_{DS}(on)$ in (Ω)		**$V_{GS}(th)$ in (V)**	
Temperature (°C)	**Pre-cycling**	**Post-cycling**	**Pre-cycling**	**Post-cycling**
+22	0.66	0.71	1.60	1.57
-190	0.57	0.53	2.10	2.10
+225	1.60	1.52	1.10	1.07



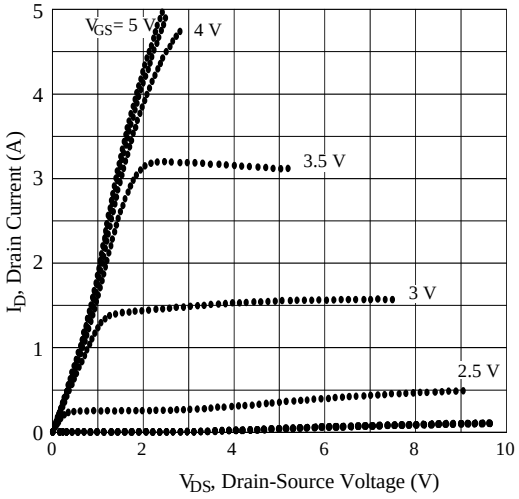
Pre-cycling at +22 °C



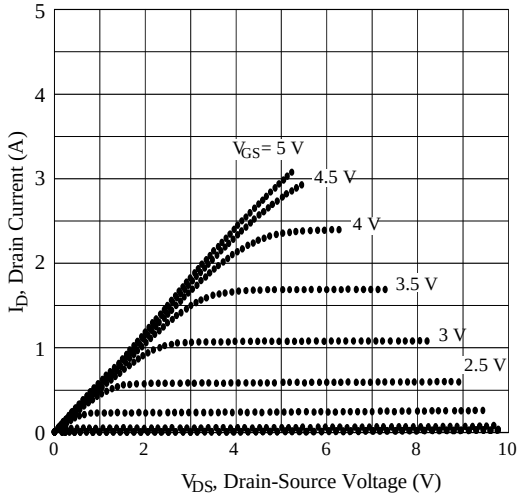
Post-cycling at +22 °C



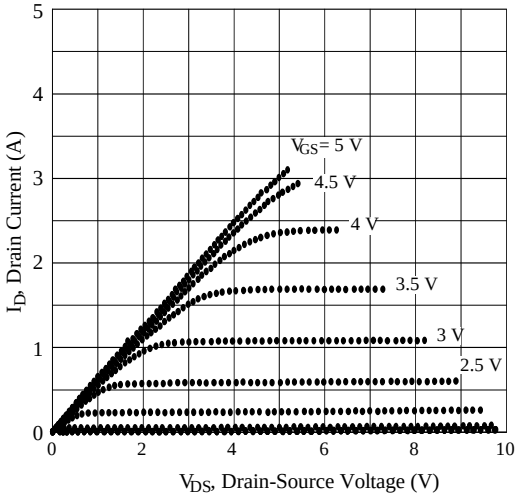
Pre-cycling at -190 °C



Post-cycling at -190 °C



Pre-cycling at +225 °C



Post-cycling at +225 °C

Figure 4. I_D/V_{DS} curves of the NMOS80 transistor for pre- & post-cycling at selected test temperatures.

Conclusion

A new N-channel SOI transistor, the Cissoid CHT-NMOS80, was evaluated in the wide temperature range of -190 °C to +225 °C for potential use at extreme temperatures. Performance of the MOSFET device was obtained in terms of its current/output characteristics, drain-to-source on-state resistance (R_{DS}(on)), and gate threshold voltage (V_{GS}(th)). Re-start at extreme temperatures and the effect of thermal cycling on the operation of the transistor were also investigated. The SOI MOSFET device was able to maintain good operation throughout the test temperature range of -190 °C to +225 °C with minimal changes in its characteristics. The temperature-induced changes consisted of a slight increase in the gate threshold voltage and a slight decrease in the on-state resistance when test temperature was varied from room temperature to -190 °C; and the trend was reversed when the transistor was subjected to high temperatures, i.e. +50 °C to +225 °C. The changes, however, were temporary as the device recovered to its original characteristics upon removal of the thermal stress. The SOI transistor was able to re-start at the extreme temperatures of -190 °C and +225 °C, and the applied limited thermal cycling has yielded no significant effect on its performance. These preliminary results suggest that the CHT-NMOS80 transistor has the potential for use under wide temperature conditions but further comprehensive testing is required to establish its reliability for long term application in extreme temperature space exploration missions.

References

[1]. Cissoid Company, "CHT-NMOS80 High Temperature, N-Channel Mid-Power Transistor" Data Sheet, Version: 04.00, May 9, 2008.

Acknowledgments

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