Influence of high temperature reliability test of 1200V SiC MOSFET on static parameters

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Abstract. The gate oxide interface state of SiC MOSFET is the main factor that affects the high temperature reliability of the device. Therefore, the high temperature reliability test of planar gate depleted 1200V20A SiC MOSFET is carried out in this paper. The relationship between leakage current and temperature is studied by comparing the change process of leakage current and temperature in the initial stage of high temperature gate bias and high temperature reverse bias. After the HTGB and HTRB test, the threshold voltage and on resistance are measured at room temperature. The influence of the HTGB test and HTRB test on device parameters is further analyzed, and the relationship between them is revealed.

Keywords: SiC MOSFET, HTGB, HTRB, High temperature reliability test.

1. Introduction
As the third generation semiconductor devices, SiC MOSFET has good electrical characteristics [1], so it has been paid more attention in power system [2]. Commercial SiC MOSFET products with 600-1700V voltage grade has been successively launched by foreign semiconductor manufacturers, such as CREE and ROHM Company and gradually applied to photovoltaic power generation, new energy vehicles other fields [3]. However, the gate oxide layer of SiC MOSFET devices has the problem of high interface state, which leads to its high temperature reliability problem [4-6]. Because the domestic development of SiC MOSFET transistors started late, and there is no commercial product at present, so there are few papers to fully study the influence of temperature on the high temperature reliability test of SiC MOSFET devices, as well as the influence of high temperature reliability test on device characteristic parameters.

In this paper, three 1200V20A SiC MOSFET devices produced by our company are selected as the research objectives. The internal chip is single planar grid depletion SiC MOSFET. The metal packaging structure is filled with silicone gel as chip protection and insulation medium, and the size of the device after encapsulation is 1.0×1.0×0.5cm. Inside the module, Al-wires with the diameter of 15 mil (25.4μm/mil) are bonded and connected. Gate leads and source leads are 1 and 2 copper wires, as shown in the figure of Table 1.

High temperature gate bias (HTGB) test and high temperature reverse bias (HTRB) test were carried out for the three devices in turn. Based on the comparison of the surface temperature change of the device and the temperature change of the environment box, the change process of gate leakage current...
(IGSS) during the stage of HTGB test and HTRB test are analyzed. By testing the threshold voltage and on resistance of the initial state before high temperature reliability test, after HTGB test and after HTRB test. The influence of HTGB test and HTRB test on the device parameters is studied.

2. Analysis of static parameters

Six 1200V20A SiC MOSFET devices (marked as 1#, 2#, 3#) packaged by metal with single chip were selected as the research object and the static parameters at room temperature were tested, including drain cut-off current ($I_{DSS}$), gate source threshold voltage ($V_{GS(th)}$), on resistance ($R_{DS(on)}$), positive and negative gate leakage current ($I_{GSS}$), etc. With considering that the device is not symmetrical, the test conditions of IGSS are different in forward and reverse test, as shown in Table 1:

| Parm. | $I_{DSS}$/μA | $V_{GS(th)}$/V | $R_{DS(on)}/mΩ$ | $I_{GSS}$/nA | SiC MOSFET |
|-------|-------------|--------------|----------------|-------------|------------|
| TCR   |             | $V_{DS}=1200V$ | $V_{DS}=V_{GS}$ | $V_{GS}=20V$ | $V_{GS}=20V$ | $V_{DS}=0V$ | $V_{GS}=8V$ | $V_{DS}=0V$ |
| 1#    | 0.0         | 2.56         | 170.1           | 0           | 2          |
| 2#    | 0.0         | 2.53         | 167.6           | 1           | 2          |
| 3#    | 0.0         | 2.60         | 170.2           | 3           | 1          |
| Av.   | 0           | 2.563        | 169.3           | 1           | 1.667      |
| Uni./%|             |              |                 |             | 97.269     | 98.464     |

Note: 1) Since the minimum resolution of the measuring device is 0.1μA, for currents less than 0.1μA, 0μA is usually marked.
2) Uniformity = (1-(Max-Min)/average)*100%
3) Parm.: Parameter; TCR: Test Condition Requirements; Uni.: Uniformity; Av.: Average

According to the data in Table 1, the uniformity of the static parameters screened at room temperature is very excellent and basically meets the consistency requirements. What needs to be added is that the $V_{GS(th)}$ and $R_{DS(on)}$ can be used to research the influence of HTGB and HTRB.

3. High temperature reliability test and analysis

In order to analyze the influence of high-temperature reliability test on the static parameters of the device and study the relationship between them, the high-temperature reliability tests of the three devices are carried out successively, including HTGB test and HTRB test.

3.1. Test conditions and schematic diagram of HTGB and HTGB

The three devices were tested by HTGB and HTRB according to the following test conditions. The experimental conditions and temperature load are shown in Table 2.

| Test  | HTGB | HTRB |
|-------|------|------|
| TCR   | 0~84h| 84h-168h| 0~168h|
| Failure basis | $I_{GSS}$$\leq$10μA, Change rate of $V_{GS(th)}$$\leq$15%, Change rate of $R_{DS(on)}$$\leq$15% | IDSS$\leq$10μA, Change rate of $V_{GS(th)}$$\leq$15% | Change rate of $R_{DS(on)}$$\leq$15% |
| T     | 150°C| 150°C|

Three devices were tested for HTGB and HTRB according to GB/T 4586-94 (IEC747-8-1984)[7]. As the positive and negative characteristics of SiC MOSFET devices do not have symmetry, during the HTGB test, the $V_{GS}$ is set to 20V for 84 hours during forward testing stage, and then the $V_{GS}$ is set to -8V for 84 hours during reverse testing stage. And the $I_{GSS}$ curve of each device was continuously monitored as the reference index to determine whether the failure basis. With the same temperature load...
(150°C) setting conditions of HTGB test, and the $I_{DSS}$ change curve of each device is recorded to judge whether the device is failure. According to the test standard of HTRB test, $V_{DS}$ was applied to each device as 960V. Under the test conditions set in Table 2, the test time lasted for 168 hours. The test circuit principle of the device during the HTGB test and HTRB test is shown in Figure 1.

Three devices are tested for 168 hours of HTGB test firstly, and then the static parameters are tested. If they remain in the HTGB failure range in table 2, the HTRB test will continue. Before the HTGB and HTRB test, the temperature loading process of the environment box was set according to the temperature conditions in table 2. After the environment box is heated to 150°C, the devices are put into the environment box and conducted by the HTGB and HTRB in turn. In addition, considering the small size of the device and the uneven temperature in the environment box, the actual temperature change curves of three device surfaces during the stage of HTGB and HTRB test were monitored in this experiment and compared with the temperature of the environment box, as shown in Fig.2.

As can be seen from Fig.2, the temperature of the device surface does not synchronously change according to the loading temperature of the environment box, but presents a slight delay and a small
amplitude jitter. At the beginning of the test, when the device is put into the high temperature chamber from the normal temperature environment, the temperature begins to rise sharply and finally approaches the ambient chamber temperature.

3.2. Results and analysis of HTGB test

HTGB test is divided into two stages in 168h: The $V_{GS}$ is set to 20V for the 84-hour in the first forward test stage, then the $V_{GS}$ is set to -8V for 84-hour in the second reverse test stage. The $I_{GSS}$ change curves of the three devices detected during two stages were shown in Figure 3.

![Figure 3. $I_{GSS}$ curve during HTGB test with $V_{GS}$=20V@84h (left) and $V_{GS}$=-8V@84h (right).](image)

Fig.3 (left) shows that the $I_{GSS}$ of three devices increase rapidly at the constant temperature of 150°C, and then tends to different steady state which are about 1.3μA(1#), 1.2μA(2#) and 1.14μA(3#), respectively. At the beginning of the test, the main reason which $I_{GSS}$ rapidly increase is: Although the environment temperature is constant temperature in the oven, after the devices are put in the environment of high temperature from room temperature environment, need to warm up over a period of stage. So the $I_{GSS}$ of the devices also rise with the increase of the device itself temperature. With the temperature of the device tends to ambient temperature finally, $I_{GSS}$ tending to stable. The relationship is not linear and synchronous, the $I_{GSS}$ does not show the same rapid change process as the temperature change process at the beginning period.

As can be seen from Fig.3 (right), $I_{GSS}$ curves of the devices showed a rapid decline in the initial period. This is because $V_{GS}$ changed at 84h suddenly when $V_{GS}$ was set at 20V to the reverse $V_{GS}$ set at -8V, $I_{GSS}$ was undergoing a transition from the original steady state value. From this point of view, due to the abrupt change of $V_{GS}$ setting conditions, $I_{GSS}$ also changed sharply. Different $V_{GS}$ correspond to different steady state values of $I_{GSS}$.

3.3. Results and analysis of HTRB test

After cooling three devices which have completed the HTGB test to normal temperature for static parameter test, $V_{GS(th)}$ and $R_{D(ON)}$ of the device were tested to Judge whether their change rate is beyond the failure range according to table 2. If the device parameters are qualified, the HTRB test will continue. With the same temperature load setting conditions of HTGB test, the $I_{DSS}$ change curve of each device is recorded all the way. At the same time, the temperature of the device surface in the environment box is also detected.

Fig.4 shows the comparison of $I_{DSS}$ curve between three devices during HTRB test. The curves in Fig.4 shows that when HTRB is tested in the constant 150°C, the change of $I_{DSS}$ of the device increases rapidly at first, reaches the peak value and then slowly decreases, and finally tends to steady state. The
peak value and steady value are different, the peak value of $I_{DSS}$ of 2# device is the largest but its steady value is less than that of 3# device. The peak value and steady value of $I_{DSS}$ of 1# device is the smallest.

![Figure 4. The $I_{DSS}$ curve of the device during HTRB test.](image)

Combined with the surface temperature curve of the device in Fig.2 (right), the $I_{DSS}$ change process of the device does not keep pace with the temperature rise process of the device, but the $I_{DSS}$ change slightly lags behind. We conclude that the relationship between $I_{DSS}$ and temperature is not a synchronous linear growth relationship, but $I_{DSS}$ has the hysteresis.

4. Influence of HTGB and HTRB test on $V_{GS(th)}$ and $R_{DS(on)}$

The HTGB and HTRB test results of the devices were analyzed above. The change value of $I_{GSS}$ and $I_{DSS}$ during HTGB and HTRB test were not beyond the range of failure judgment, and the influence relationship between the two parameters and temperature was obtained. The $V_{GS(th)}$ and $R_{DS(on)}$ of three devices were tested under the test conditions shown in table 1 each time. The test results of $V_{GS(th)}$ and $R_{DS(on)}$ are shown in Table 3. Based on the three test results of the $V_{GS(th)}$ and $R_{DS(on)}$ at different stages, the effects of HTGB and HTRB tests on the two parameters were further studied. In order to study their changing rule more intuitively, according to the data in the table 3, the changing curve of the $V_{GS(th)}$ and $R_{DS(on)}$ is drawn as shown in the figure 5.

**Table 3.** The change of $V_{GS(th)}$ and $R_{DS(on)}$ before and after HTGB test.

| Test NO. | HTGB/V | HTRB/mΩ |
|----------|--------|---------|
|          | 1#     | 2#     | 3#     | Av.     | 1#     | 2#     | 3#     | Av.     |
| Initial  | 2.56   | 2.53   | 2.60   | 2.563   | 170.1  | 167.6  | 170.2  | 169.3   |
| HTGB     | 2.52   | 2.41   | 2.53   | 2.487   | 167.5  | 161.04 | 164.99 | 164.51  |
| HTRB     | 2.58   | 2.43   | 2.61   | 2.54    | 164.29 | 160.23 | 159.51 | 161.34  |
The $V_{GS(th)}$ and $R_{DS(on)}$ of the three devices change in different degrees after HTGB and HTRB test in Fig.5, but each parameter of different devices change in the same way. Overall, after HTGB test, the $V_{GS(th)}$ is reduced, and the average value is reduced by 3%; After HTRB test, the average value of $V_{GS(th)}$ increases by 2.13% compared with that after HTGB test, and the $V_{GS(th)}$ of 1# and 3# devices even exceeds the initial value. By observing the change of $R_{DS(on)}$, it can be seen that the average value of $R_{DS(on)}$ of the device after HTGB and HTRB test is reduced by 2.83% and 1.93% respectively compared with the previous test results. Therefore, the HTGB test will reduce the $V_{GS(th)}$ and $R_{DS(on)}$, while the HTRB test will change the $V_{GS(th)}$ and reduce the $R_{DS(on)}$.

5. Conclusion
The change process of $I_{GSS}$ and $I_{DSS}$ during HTGB test and HTRB test are analyzed, and the relationship between initial temperature rise and leakage current is analyzed. The $V_{GS(th)}$ and $R_{DS(on)}$ of the device are measured after each test. The influence of high temperature reliability test on the $V_{GS(th)}$ and $R_{DS(on)}$ is studied by analyzing the change process of the two parameters. Finally, the following conclusions are drawn:

(1) At the beginning of HTGB test and HTRB test, the $I_{GSS}$ and $I_{DSS}$ of the device begin to increase quickly. The difference is that for the HTGB test, the $I_{GSS}$ increases rapidly and then tends to steady state. When the $V_{GS}$ changes from forward to reverse, the $I_{GSS}$ of the device also decreases sharply and then tends to steady state. The steady state values of forward and reverse tests are different. In the HTRB test, the $I_{DSS}$ increases rapidly and reaches the peak value, then slow decay to steady-state value.

(2) The HTGB test leads to the decrease of the $V_{GS(th)}$ and $R_{DS(on)}$, while HTRB test leads to the increase of the $V_{GS(th)}$ and the decrease of $R_{DS(on)}$. The relationship between $I_{GSS}$, $I_{DSS}$ and temperature is nonlinear positively correlated, and they are asynchronous, and The $I_{GSS}$ and $I_{DSS}$ lags behind the heating process at the beginning period of HTGB and HTRB test.

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