Research on Online Junction Temperature Measurement of MOSFET Devices

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Abstract. In order to detect the MOSFET junction temperature, the paper measures the MOSFET junction temperature by electrical method without affecting the normal operation of the devices and the circuits. In addition, the method of optimizing the temperature calibration curve proposed is helpful for engineers to efficiently monitor the junction temperature and prevent the risk of failure caused by high temperature.

1. Introduction

In high-power systems such as aerospace and thermal power grids, power MOS devices have become excellent switching control components due to its fast switching speed and good thermal stability, thus are widely used in various power modules in circuits. However, the large current flowing through the control loop causes the power MOS device to bear huge power consumption, which will cause the MOS junction temperature to rise and bring a series of reliability problems. Frequently turn-on and turn-off of devices will aggravate this effect and seriously threaten the safe operation of circuits and modules. J. Zarebski et al. and P. Spirito et al. respectively studied this phenomenon by constructing electric heating models and using numerical analysis methods. A. Knop et al. analyzed the effect of this process on device performance. It can be concluded that temperature is an important factor affecting device reliability. On-line monitoring of junction temperature has positive practical significance. In this paper, the junction temperature is measured by electrical method. Through the pre-built temperature calibration curve, MOS junction temperature can be effectively monitored online during the operation of power MOS devices. The selected temperature sensitive electrical parameters (TESPs) are the same as those under the actual operation, thus avoiding the influence of the additional test signals on the circuit operation and causing no interference to the device. Internationally, D. L. Blackburn and D. W. Berning have made a preliminary exploration to discuss the implementation plan and difficulty level of relevant parameters.

There is no doubt that temperature rise cannot be introduced in the process of temperature calibration curve construction, and pulse measurement must be adopted under the condition of high current and voltage. The paper proposes a simplified scheme of temperature calibration curve, which simplifies the complicated testing process and the dependence on testing equipment. Through real-time online monitoring of the MOS junction temperature, it is helpful for engineers to master the actual working condition of the device and reasonably avoid the damage of the device. The above has certain guiding significance for guiding circuit improvement and module optimization.
2. Selecting TESP and constructing a temperature calibration curve

In recent years, many schemes have been put forward to measure the junction temperature of semiconductor devices in the world\(^{[6]-[8]}\). Among them, the electrical method of temperature measurement has attracted the extensive attention of many scholars due to its unique high response speed and low destructive power\(^{[9]-[10]}\). The electrical method builds a matching temperature calibration curve in advance, and then deduces the junction temperature through the collection of TESPs.

In order to monitor the MOS junction temperature, the source-drain voltage \(V_{DS}\) and the source-drain current \(I_{DS}\) are chosen as TESPs in this paper to ensure that no extra electrical signals are introduced to disturb the circuit during the parameter acquisition process.

\[
I_{DS} = \beta ((V_{gs} - V_{T})V_{DS} - \frac{3}{2}V_{BS}^2)
\]

(1)

Since the device operates in the linear region under actual operating conditions, equation (1) can be simplified as follows:

\[
I_{D} = \beta (V_{gs} - V_{T})V_{DS}
\]

(2)

\(I_{DS}\) is drain-source current, \(V_{DS}\) is drain-source voltage, \(V_{gs}\) is gate-source voltage, \(V_{T}\) is threshold voltage, and \(\beta\) is gain factor:

\[
\beta = \frac{\mu_n C_{ox} W}{L}
\]

(3)

Where \(C_{ox}\) represents the gate oxide capacitance per unit area, \(W\) represents the channel width, \(L\) represents the channel length, and \(\mu_n\) is called carrier mobility.

When measuring the temperature calibration curve, the MOS is placed in a constant temperature environment with controllable temperature. In order to avoid the influence of the device self-heating on the test result, and a pulse measurement method is chosen under the condition of large current and voltage test. The temperature calibration curve test process is shown in Fig. 1.

Figure 2 shows the results of the temperature calibration curve measured. Since the TESPs selected are \(V_{DS}\) and \(I_{DS}\), the temperature calibration curve will be 3-D, and the temperature calibration curve library will be obtained by fitting the measured data with software algorithm and processing with interpolation algorithm, as shown in Figure 3.

![Fig 1 Testing process of temperature calibration curve](image-url)
The processing of the temperature calibration curve and the calculation of the temperature measurement results need to be supported by complex software algorithms, which increases the difficulty of engineering application. For this reason, the paper proposes a simplified scheme to optimize the selection of TESP\textsubscript{s} and the construction of temperature calibration curve: taking the slope of current and voltage $R_{\text{om}}$ as a new TESP\textsubscript{s}. Since the device works in the linear region, the slope $R_{\text{om}}$ is almost at a certain value under the condition of constant temperature, the slope $R_{\text{om}}$ is the same under the condition of high current voltage and low current voltage. However, when the test is carried out under low current conditions, the low power consumption will not cause temperature rise, so a simple cross flow measurement method can be used instead of the pulse measurement method mentioned above. Figure 4 shows the simplified temperature calibration curve.
3. Conclusion

Based on the electrical test method, this paper selects the electrical parameter in the actual working process of the MOS device as the TESPs to infer the junction temperature by collecting the operating parameters of the device without introducing additional test signals. A simplified scheme of temperature calibration curve is proposed, which makes the temperature measurement method have more general applicability, facilitates the simple and effective detection of junction temperature changes in the actual work of MOS power semiconductor devices in engineering, and prevents the failure of devices caused by high temperature damage and the reliability risks caused in particular. It has positive guiding significance for the safe work of integrated circuits and modules.

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