An Device Case Temperature Closed-loop Control System During Burn-in Test

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Abstract—**Burn-in is used to force the failure of marginal devices before using into products. Usually devices are placed in a burn-in oven. The burn-in time mainly depends on the device junction temperature, so the junction temperature control is very important during burn-in test. Usually the oven ambient temperature is closed-loop controlled during burn-in, but the device junction temperature is open-loop, not accurately controlled. Consequently some devices may be at a lower temperature (junction temperature lower than required) and others may be at a higher temperature (junction temperature higher than required) in the same burn-in oven. Latest silicon processing technology results in significant power variations between chips produced even on the same wafer, thus some devices with higher power dissipation will be burned at a hotter temperature, which means a potential for thermal runaway. At the same time, high leakage currents that are rapidly increasing with technology scaling become more crucial during burn-in test with stressed voltage and temperature applied, and excessive leakage may lead to higher junction temperatures, possible thermal runaway. Thermal runaway means temperature increases uncontrollably and can result in damage to the socket. To solve above problems and avoid thermal runaway, each device junction temperature should be stable during burn-in test. Controlling the device junction temperature accurately by each socket is a solution. This paper describes a closed-loop device case temperature control system, which can ensure that the device junction temperature is stable. Each socket becomes a controlled environment during burn-in test for a wide range of influences, for example, process variations and ambient temperatures. Once disturbance occurs, for example, the burn-in oven temperature change, the control system with better dynamic response can get the case temperature quickly back to stable.**

Keywords- Device case temperature control, burn-in, closed-loop system.

I. INTRODUCTION

Burn-in was an important test technique used to force the failure of marginal devices before using into products. The burn-in time mainly depended on the device junction temperature. Due to presence of a positive feedback between temperature and leakage during burn-in, thermal runaway could occur if the temperature was not properly controlled. The temperature control was therefore very important during burn-in test.

To solve thermal stabilization problem in burn-in test, different methods have been proposed [1, 2]. In [3] and [4], an electro thermal analysis tool was developed to observe thermal runaway possibilities due to leakage, which avoided thermal runaway by predicting an ambient temperature that will keep junction temperature around desired temperature at burn-in conditions. However, this method was not reliable under variations in process, supply voltage, and ambient temperatures across the burn-in oven. In [5] and [6], different leakage reduction mechanisms were suggested to restrict the increase in leakage during burn-in. These methods cannot reliably control the leakage to avoid thermal runaway or ensure quality of burn-in test at the same time [1]. Another method was proposed [2] to control junction temperature accurately by each socket, in which each device had a heater and a controller. This suggestion got a good steady-state result, but it didn't show a better dynamic system response when disturbance occurred.

This paper described a closed-loop device case temperature control system, which could ensure the device junction temperature stable. Each socket fixed with a heater and a cooler became a controlled microenvironment during burn-in test. Once disturbance occurred, for example, the burn-in oven temperature changed, the control system with better dynamic response could get the case temperature quickly back to stable.

II. METHOD

A. Design

In the temperature closed-loop control system introduced below, case-to-ambient thermal resistance was controlled to keep device case temperature stable so as to stabilize junction temperature. In the control system, fan was used to reduce the equivalent thermal resistance while heater was used to increase it. Controlling case temperature as constant could reduce junction temperature variance owing to the difference in ambient temperature and thermal resistance, and get better dynamic response when disturbance occurred as well.

The block diagram of the proposed control system is shown in Figure 1. The temperature sensor measured the case temperature of the device in socket as feedback temperature. K was the feedback factor. Once the system worked, the feedback temperature, T_feedback was compared with the desired burn-in case temperature, T_ref.

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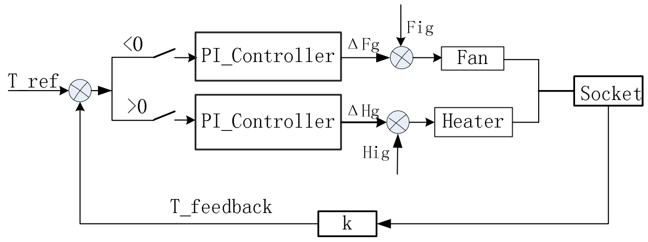

Figure 1 Block diagram of temperature control system

If T_ref was larger than T_feedback, heater worked to increase the case temperature, or else fan went to work to reduce the case temperature. Fan and heater were controlled by input voltage, which was supplied by a controller adopting PI algorithm.

B. Device

The actual control system device is shown in Figure 2. Fan was fixed in the bottom side of burn-in board to cool the device while heater was in the other side to heat the device.

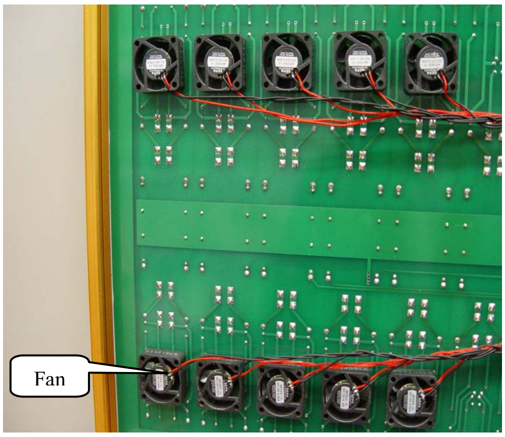

Figure 2(a) Bottom of the control system

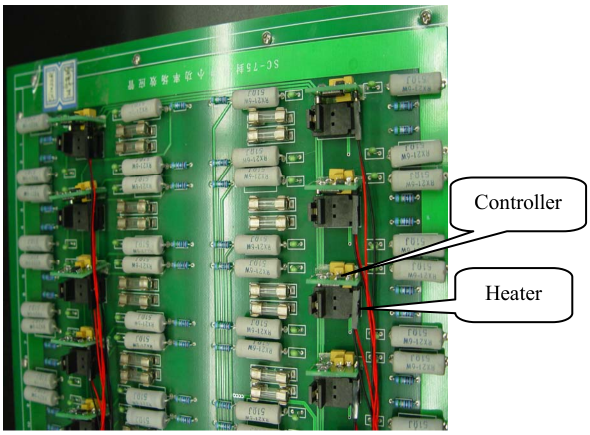

Figure 2(b) Top of the control system

In the actual system, MCU was used as the controller, which executed calculation of PI algorithm, AD conversion and input voltage of fan and heater.

Figure 3 showed the actual burn-in system. Based on the burn-in system platform, results of the actual control system were obtained.

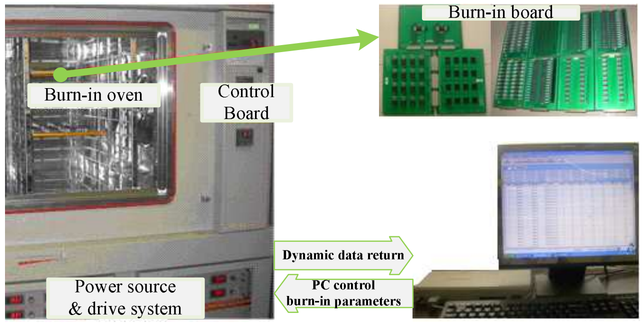

Figure 3 Burn-in system diagrams

C. Simulation

To simulate the actual control system, a simulation model was established in the platform of MATLAB/Simulink, which is shown in Figure 4.

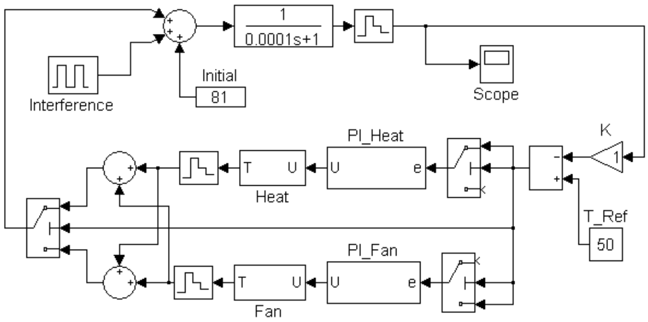

Figure 4 Simulation model of the control system

In Figure 4, Initial module referred to device case temperature before control system worked. Interference module referred to disturbance during burn-in test. PI_Heat was the controller of heater, and PI_Fan was the controller of fan. Heat module referred to transfer function of heater, and Fan module was the transfer function of fan.

Controller of the fan was the same with that of heater, as shown in Figure 5. The controller consisted of proportional component and integral component.

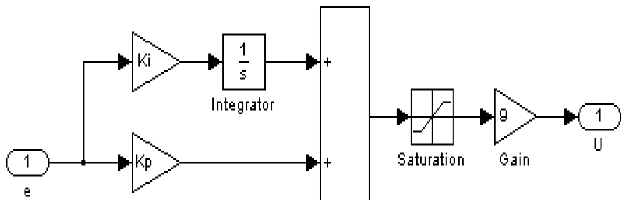

Figure 5 MATLAB/Simulink model of closed-loop controller

Transfer of fan or heater was dependent on the actual system. The more accurate the transfer was, the more accurate the system was.

The system stabilized the case temperature at the set-point by selecting proper parameters of PI controller. To avoid thermal runaway and ensure better control performance at the same time, parameters should be chosen carefully.

III. RESULTS

The test results for the simulation and actual control system were summarized as follows.

A. Simulation

The simulation result is shown in Figure 6. The desired burn-in case temperature was 50℃. Before the control system worked, the case temperature was 40 ℃. If disturbance occurred at 50 minutes, the system response is shown in Figure 6.

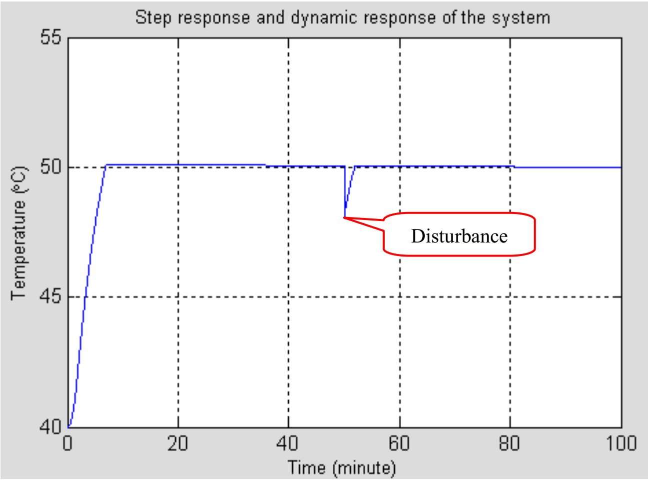

Figure 6 Step response and dynamic response of the system

As shown in Figure 6, the temperature control system mentioned above could stabilize the case temperature at set-point in 10 minutes when case temperature was 10℃ lower than desired temperature, and stabilize temperature back at target point in 5minutes when 2℃ temperature reduction interference occurred. The results of the simulation showed a shorter regulation time and smaller overshoot of the system.

Regulating range of the control system is shown in Figure 7. Simulation results showed that effective temperature regulating range was -16℃～16℃, which meant that system could stabilize the temperature back when temperature was in the regulating range.

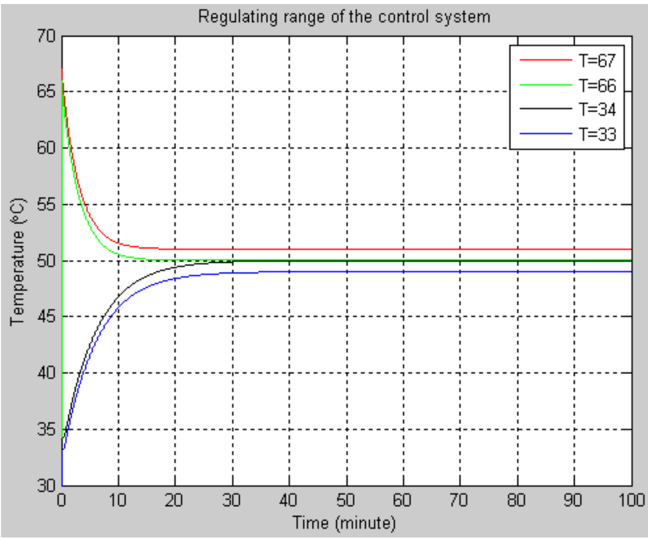

Figure 7 Regulating range of control system

B. Device

The results of actual control system are shown in Figure 8 and Figure 9.

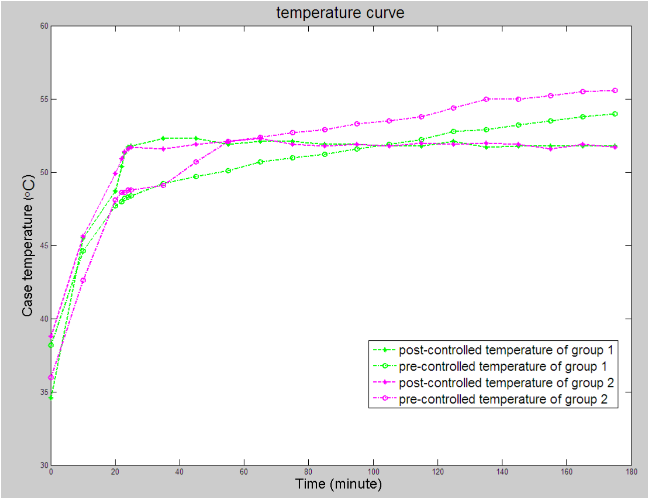

Figure 8 Results of the actual system

Figure 8 showed that case temperature variance existed at the same burn-in oven before temperature control system worked, and with control system being used, case temperature reached the desired temperature sooner and more accurate.

Before control system stared to work, temperature of group 2 was larger than that of group 1, and temperature of both continued to increase. This result proved that the variation of the temperature existed even in the same burn-in oven during test. After control system worked, case temperature of both group stabilized at the desired temperature sooner, which demonstrated the effectiveness of the control system.

Figure 9 showed the dynamic response of the control system when disturbance occurred. When 4 ℃ temperature increasing interference occurred, the control system stabilized the temperature back at target temperature in 10 minutes, which showed a better performance.

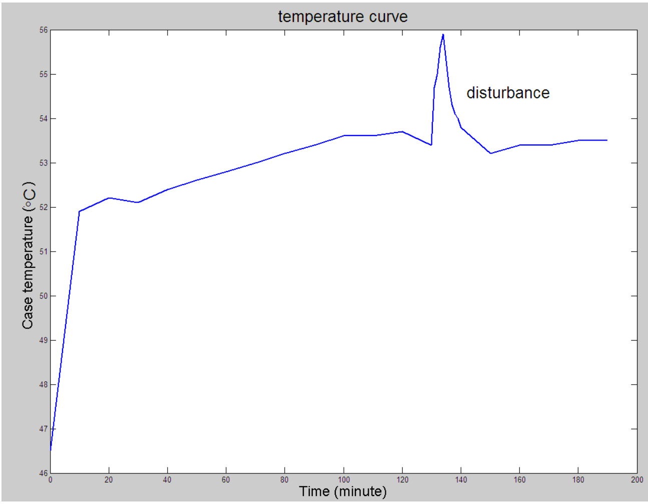

Figure 9 Dynamic response of the actual system

IV. DISCUSSION AND CONCLUSIONS

Thermal stability during burn-in test was an increasingly important problem. In this paper, we described a case temperature closed-loop control system. The control system stabilized the case temperature at target temperature by controlling equivalent case-to-ambient thermal resistance to maintain the junction temperature at the target burn-in temperature. This system provided case temperature stability for a wide range and better dynamic response for temperature disturbance. The system was therefore promising for enhancing quality of burn-in test and saving cost of the burn-in test.

In this paper, the device case temperature was the control target to stabilize the junction temperature, which was accepted by many manufacturers, for the suggestion was easy for operation and effective to reflect the junction temperature indirectly. If effective methods of measuring the junction temperature directly and conveniently were suggested, the control system proposed in this paper would be fit as well, which changed case temperature for junction temperature as the control target. To obtain larger regulating range of control system during burn-in test, advanced methods of cooler and heater could be adopted, such as oil cooling and water cooling technique for cooler, and constant temperature heating technical for heater.

The control strategy of the system in this work was separately controlled which meant either the fan worked or the heater worked. Also mixed strategy in which fan and heater worked together at the same time would be interesting and of better performance.

The test object in the actual system was NTS4101, which was discrete device. Compared with integrated circuit, the methods of measuring temperature for discrete device were easy. For integrated circuit power loss differed in its various function module, effective suggestion of measuring temperature and burn-in strategy should be considered.

ACKNOWLEDGMENT

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