

Thermal Management of Integrated Circuits in Burn-in Environment

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Abstract—Burn-in screening test technology has been an important method to ensure integrated circuits(IC) quality and reliability. But there are many problems remains to be solved during burn-in and accurate junction temperature of IC during burn-in is one of these problems. Leakage currents are rapidly increasing with CMOS IC technology scaling, and this will lead to high junction temperature of IC in burn-in environment. Positive feedback between junction temperature and leakage currents result in continual junction temperature increases, and thermal runaway will probably happen. In addition, differences of frequency during burn-in and variation of device parameters, all these lead to the junction temperature of IC not the same even in the same burn-in environment. To solve these problems, a closed-loop temperature controlled system and corresponding integrated IC's case temperature acquired method are presented in this paper. Under the ambient temperature of burn-in oven, each socket is a microenvironment managed by closed-loop temperature controlled system. Several small thermal resistors which measure the temperature of different areas of the IC are mounted on the surface of the IC in the burn-in socket and we choose measured maximum temperature as the feedback signal of the temperature controlled system. Compared with junction temperature of IC without temperature controlled system, junction temperature of different IC with temperature controlled system in burn-in environment almost the same, and steady state error is in the range of 0.2°C which is far less than differences of junction temperature without temperature controlled system. Rise time and dynamic response time are all much faster. All these advantages make burn-in process reliable and integrated circuits of great reliability.

Keywords—Integrated circuit; burn-in; junction temperature; temperature controlled system

I. INTRODUCTION

Reliability of IC has been an important guideline for IC design and customer's choice Since IC emerge. Along with the development of semiconductor technology, size of IC unceasingly expands, integration level is increasing, and requirements for IC's reliability is much higher. So, appropriate screening and identifying scheme seems more and more urgent for IC circuits. At present, burn-in test

technology has been an important method to ensure IC quality and reliability[1-2]. Burn-in is a process to accelerate early life failures of semiconductor so that product can be removed from the population before shipped to customers or actual using. The semiconductor during burn-in is usually under temperature and voltage stress. According to Arrhenius equation, junction temperature reflects stress intensity of Burn-in, so the junction temperature has been the standard evaluation parameter of burn-in. Burn-in test will usually achieve the best effect while the junction temperature is controlled below 200°C.

With scaling of IC technology, burn-in of IC faces unprecedented challenges. Off-state leakage of IC is the most serious problem and the proportion between leakage current and total current is increasing [3]. So, the leakage power is the dominant power during burn-in. Since leakage power is exponentially increased under stress condition. Besides, Positive feedback between junction temperature and leakage currents exists. Leakage current increase will cause junction temperature rise, and junction temperature rise will further accelerate the increase of leakage current. And sustained growth of junction temperature will lead to thermal runaway. Except IC technology scaling, the difference between semiconductor device parameters is one of the problems. Silicon technology causes these differences in the same process, and even at the same wafer [4-5]. These differences can result in the junction temperature uneven and the range of the temperature is very wide. That is, the junction temperature of tested devices under burn-in is not the same even in the same ambient temperature and under the same stress. So, the junction temperature of some devices is higher than the required temperature of burn-in while some are lower. The higher will induce good devices damaged, therefore, the cost of burn-in increases. The lower do not meet the requirements of burn-in test, and it is probably that the defective semiconductor devices are employed in use. Thus, the reliability problem will happen. To ensure the junction temperature during burn-in constant, a closed-loop temperature controlled system is proposed in this paper.

II. METHOD OF ACQUIRED TEMPERATURE OF IC

A. Junction temperature of IC

Usually, junction temperature is defined as flowing equation[6].

$$T_j = T_c + P \times \theta_{jc} \quad (1)$$

Where T_j , T_c are junction temperature and case temperature of chip respectively, P is the total power dissipation of the chip, and θ_{jc} is junction to case of chip thermal resistance.

θ_{jc} is an intrinsic parameter of the chip, and it is almost a constant for the same specification chip. If we apply appropriate burn-in power, T_c can be substituted T_j as the guideline of the burn-in effect.

B. Case temperature of IC

There are several functional modules in the IC, such as A/D, D/A, EPROM. Accordingly, surface of the IC is divided into different functional areas. Burn-in process of IC is based on these functional modules. And the temperature of the area which is running program is higher than others. We evenly placed four small thermal resistors on surface of the case in the burn-in socket in order to get accurate temperature distribution of the IC' case under burn-in test. If we choose the maximum temperature as the feedback signal of the proposed temperature controlled system, the module running program meets the requirements of burn-in while others will be under the stress of burn-in. Thus, each module will have a chance to meet the requirements of the burn-in in a cycle. If we choose the average temperature of all areas' temperature, all the modules of the IC are most likely under the stress. In order to improve the reliability of the tested devices, at last we choose measured maximum temperature as feedback signal of the temperature controlled system.

III. TEMPERATURE CONTROLLED SYSTEM

The block diagram of the proposed temperature controlled system is shown in fig.1. From this diagram, we can clearly see that this temperature controlled system is a closed-loop controller. Temperature sensors acquire the case temperature of the IC under burn-in test. In the experiment we place 4 temperature sensors on the surface of the IC, then measured maximum temperature is as the case temperature (T_c) of the IC. T_c compares with the expected temperature T_{ref} . If T_{ref} is larger than T_c , the temperature of the IC increase by the heater of the proposed temperature controlled system. If T_c is larger than T_{ref} , the temperature of the IC decrease by the fan placed below the burn-in board. Temperature controlled system continuously control on and off condition of the heater and fan to

stabilize the case temperature of the IC. So, thermal runaway can avoid.

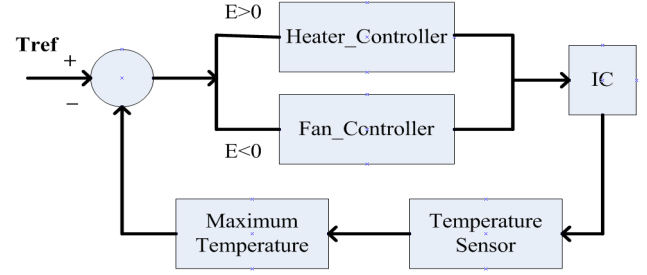


Fig.1 block diagram of proposed temperature controlled system

IV. EXPERIMENTAL RESULTS

A. Simulation results

The simulation tool of this temperature controlled system is simulink module of Matlab, and the simulation model of it is as fig.2 shown. The maximum case temperature of the tested device is as controlled object, and the controlled method adopts traditional PID algorithm.

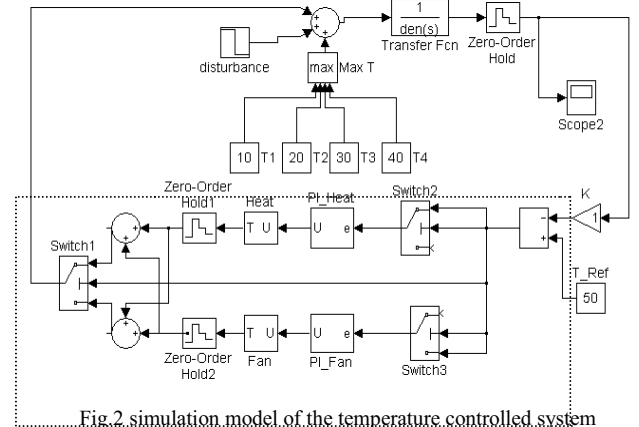


Fig.2 simulation model of the temperature controlled system

In the fig.2, the modules in the dotted line box are the core of the temperature controlled system. PI_Heat and PI_Fan closed-loop controlled modules are responsible for heating and cooling respectively. And Heat and Fan are transfer function of heating and cooling respectively. The sum of controlled variable, initial maximum case temperature and disturbance variable is the maximum case temperature at present and it compare with expected temperature T_{Ref} after interaction with corresponding transfer function(Transfer Fun) and gain coefficient K. Zero-Order is to avoid temperature jumping happen in the simulation. The simulation results are as fig.3 and fig.4 shows.

Fig.3 and fig.4 are unit step response of temperature controlled system. The response curve in fig.3 is unit step response without disturbance and curves in fig.4 are unit

step response with disturbance. Suppose that initial maximum case temperature is 40℃, and final controlled temperature is 50℃. From fig.3 and fig.4, we can see it takes about 10 minutes to achieve steady state. If there is a disturbance, it takes 5 minutes to recover steady state for positive disturbance and 10 minutes for negative disturbance.

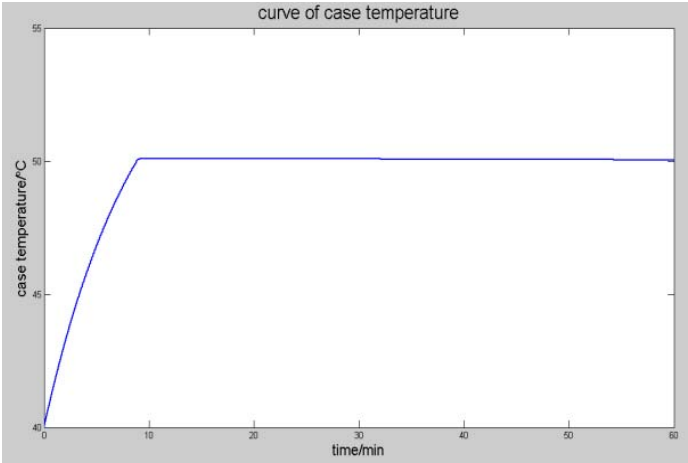
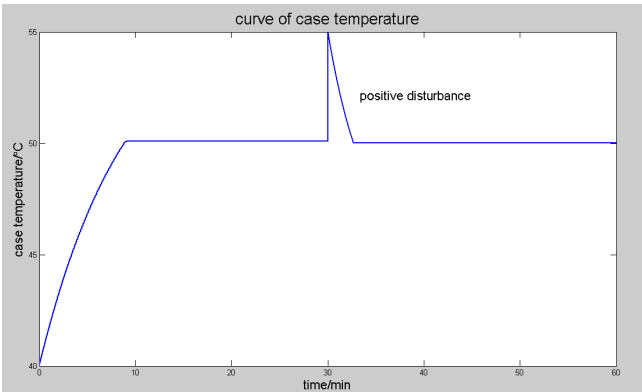
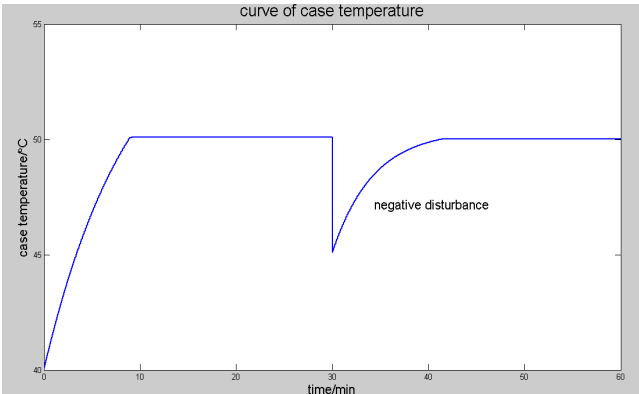


Fig.3simulation result of unit step



(a) Simulation result with positive disturbance



(b) Simulation result with negative disturbance

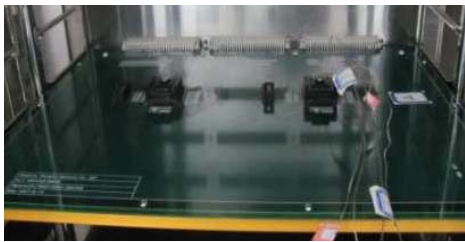
Fig.4simulation results with disturbance

B. Experimental Results

Burn-in equipment, burn-in board and software interface are as fig.5 shown.



(a)Burn-in oven



(b) burn-in board

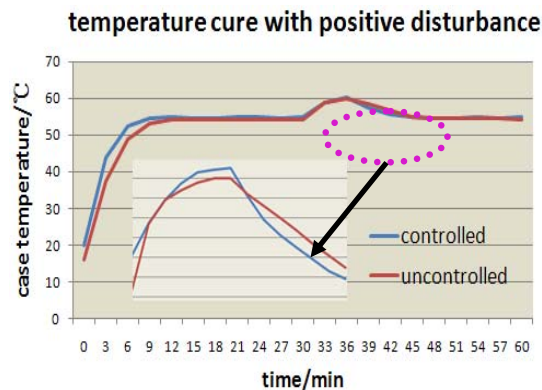
Number of area	device	election	State of 1-128	Total number	Number of error	First time of error	State of 129-256	Total number	Number of error	First time of error
1										
2										
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4										
5										
6										
7										
8										
9	MSP430F169RTD	√	Error free	87	0		error	86	86	2011-02-25 13:35
10										

(c) software interface

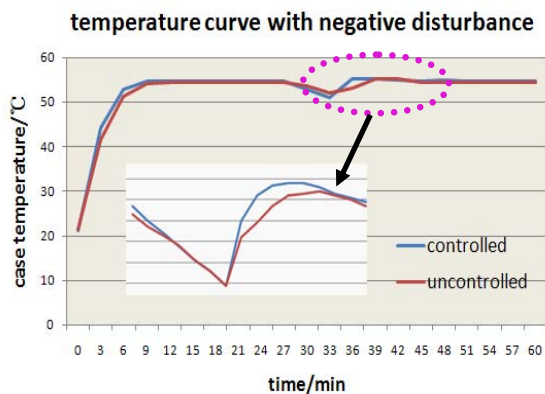
Fig.5 burn-in equipment and burn-in board

The burn-in system we use is as fig.5(a) shown. The system can contain ten burn-in boards and each board has two burn-in sockets. The burn-in board is as fig.5 (b) shown. The software in the computer is responsible for selecting type of the tested device, setting and sending parameters of the burn-in test, monitoring tested state and so on.Fig.5 (c) shows the interface of

Suppose the case temperature is controlled at 55°C under burn-in test and the unit step response of the burn-in system is shown in fig.6.



(a) Case temperature with positive disturbance



(b) Case temperature with negative disturbance

Fig.6 curve of case temperature

The curves in the fig.6 reflect the unit step response of the system. The blue and the red curves representatives the unit step response of the burn-in system with and without the temperature controlled system respectively. In fig.6, we can see the two lines almost coincide with each other. Taking a close look, we can see that respond speed of burn-in system with temperature controlled system is much faster. This is very important to us. With the help of the proposed temperature controlled system, thermal runaway will be avoided timely.

The steady-state error of the burn-in system is shown in table 1.

Table1 STEADY-STATE ERROR OF THE BURN-IN SYSTEM

Ambient temperature(°C)	52#	53#	52*
Steady-state error(°C)	-0.4	+0.6	+0.1

“#” is the sign of the burn-in system without temperature controlled system; “*” is the sign of the burn-in system with temperature controlled system

In the table 1, we can conclude that the case temperature of the tested device with closed-loop temperature controlled system is more accurate compared with the case temperature under burn-in without the closed-loop temperature controller. The traditional burn-in system for IC is equipped with an adjustable temperature oven, and the step of it is 1°C. So, the temperature regulation of the burn-in oven is rough which will lead to inaccurate case temperature of the tested device under burn-in. With the proposed temperature controller, the local temperature can be adjusted slightly and this contributes to more accurate case temperature of the tested devices.

V. SUMMARY

Aiming at the problem of potential thermal runaway under burn-in test, this paper proposes a closed-loop temperature controlled system. And its feasibility is proved by simulation and experimental results. This temperature controlled system is especially suitable for high-power devices. Because of proposed temperature controlled system, thermal runaway can be avoided and this will lead to reduction the cost of burn-in test.

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REFERENCES

- [1] G. vollertsen,R.-P, “Burn-in”, Integrated Reliability Workshop Final Report, 1999, IEEE International,pp.167-173.
- [2] Forster, J., “Single chip test and burn-in”, Electronic Components and Technology Conference,2000. 2000,pp.810-814.
- [3] A.Vassighi, O. Semenov, and M. Sachdev, “CMOS IC technology scaling and its impact on burn-in”, Device and Materials Reliability, IEEE Transactions on, Vol.4, pp.208-221, June 2004.
- [4] A. Agarwal, et, al, “Leakage in Nano-Scale Technologies: Mechanism, Impact and Design Considerations”, Proc. 41st Design Automation Conference,2004, pp. 6-11. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
- [5] J. Forster, C. Lopez, “Junction temperature during burn-in: How variable is it and how can we control it?”, Semiconductor thermal measurement and management symposium,2007, Twenty third annual IEEE, 2007,pp. 168-173.
- [6] P. Tadayon, “Thermal challenges during microprocessor testing”, Intel Technol, pp. 1-8, <http://developer.intel.com/technology/itj/archive.htm>.