Microelectronics Reliability 78 (2017) 53–64

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

A newly developed rapid uniform thermal cycle test system for electronic components

Hajime Ikuno

Electric Packaging Lab. System & Electronics Engineering Dept. 3, Toyota Central R&D Labs., Inc., 41-1 Yokomichi, Nagakute, Aichi 480-1192, Japan

ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form 24 July 2017
Accepted 25 July 2017
Available online 6 August 2017

Keywords:
Electronic component
Solder
Thermal fatigue
New test method

ABSTRACT

Electronic components are difficult to heat or cool uniformly and rapidly because of the low heat conduction properties of the materials used in these components. The present study reports a new rapid thermal fatigue test system that circulates a temperature-controlled air shower around test samples to realize both uniform and rapid temperature control. Since the proposed test system allows multi-unit integration of multiple test chambers, the simultaneous evaluation of several samples under various test conditions can be performed efficiently. Based on the results of the temperature profile measured for a practical electronic circuit board, the proposed system is confirmed to enable the target temperature to be approached rapidly while maintaining a uniform temperature distribution. The proposed system shortens the thermal cycle period from 60 min to 12 min while generating the same degree of crack damage and the same fracture mode of solder joints.

1. Introduction

Thermal fatigue tests of metals are usually performed in cycles of a few minutes [1–6] and are used to improve the reliability of engine parts, materials, etc. On the other hand, electronic components are usually subjected to thermal fatigue tests with cycles of more than approximately 60 min [7,8]. A longer cycle time is required for electronic components because the poor thermal conductivities of the constituent materials, such as resins and ceramics, generate unusual temperature and strain distributions when they are rapidly heated or cooled. Moreover, the fracture mode may change because the ceramics used in these components have low fracture toughness and therefore fracture easily due to thermal shock.

In order to shorten the test time for such electronic components, a new technology that enables all of the low-thermal-conductivity materials of electronic components to be heated and cooled uniformly and rapidly must be developed.

Although a liquid-phase test [9] can be used to rapidly evaluate the thermal fatigue resistance of electronic components, the heating and cooling (H/C) rates are much higher (by orders of magnitude) than can be expected in practical use [9,10].

Therefore, in the present study, we attempt to develop a new method that enables rapid cooling and heating, in the same manner as the conventional standard gaseous-phase test. In addition, a multi-unit test system is developed using simple equipment in order to improve the efficiency of thermal fatigue tests.

2. Conventional system and associated challenges

A schematic diagram of the conventional thermal cycle test system is shown in Fig. 1. The conventional system uses air circulation in a gaseous-phase test [11–13]. The test system has three chambers: a test chamber (into which test specimens are placed), a hot chamber that generates high-temperature air, and a cold chamber that generates low-temperature air [11,12].

During heating, hot air is rapidly injected into the test chamber in order to rapidly heat the air and the samples in the test chamber. During cooling, precooled air is injected into the test chamber to rapidly cool the samples in the same manner. Although the temperature distribution is relatively uniform because of the slow heat transfer through the gaseous air, the response of the temperature control is not so fast because of the large heat capacity of the chambers.

In order to improve the speed of the temperature change, preheated or precooled air is rapidly injected into the test chamber. Therefore, the rate of temperature change appears to vary widely due to difference in the positions of the samples. In addition, although multiple samples can be tested simultaneously in one test chamber, the H/C rates may vary widely due to the total heat capacity of the samples.

As indicated by the temperature profile shown in Fig. 1, the air temperature changes rapidly during the initial stages of heating or cooling

E-mail address: ikuno@mosk.tytlabs.co.jp.

http://dx.doi.org/10.1016/j.microrel.2017.07.090
0026-2714/

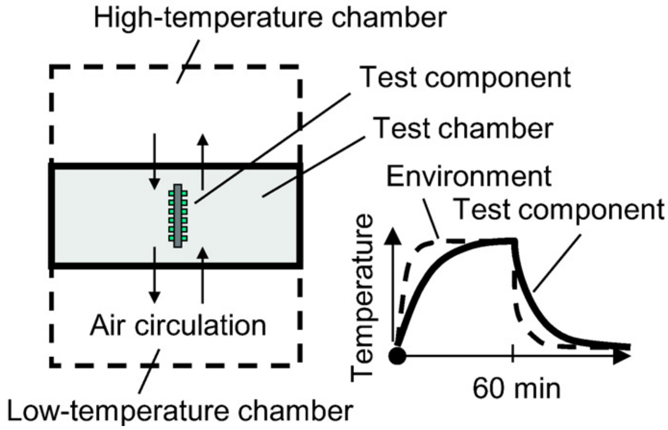

Fig. 1. Conventional thermal cycling test system.

and then begins to change slowly as the high or low target temperature is approached. Since the sample temperature changes more slowly than the air temperature, the target temperature is approached more slowly. As a result, the thermal cycle period becomes approximately 60 min.

3. Features of the proposed system

3.1. Basic concept

First, we describe the basic concept of the proposed system. Since the heat capacity per unit volume of gas represented by air is generally smaller than that of a solid or liquid, the heat transfer from the air to the sample is poor when blown directly onto the surface of the sample. As such, the temperature of the sample surface changes slowly. The slow temperature change of the sample surface prevents the occurrence of a significant temperature difference between the surface and inner part of the sample during H/C.

In conventional equipment, slow H/C simulating the actual target environment can be reproduced by this mechanism. Thus, the gaseous-phase H/C mechanism is important for preventing an increase in the temperature difference between the surface and the inner part of the sample. This basic mechanism is also incorporated into the proposed system. However, the temperature distribution over a large sample is somewhat uneven because some parts of the sample are struck by the blown air. Moreover, in the case of a large-thermal-capacity sample, significant time is required in order to realize a uniform temperature distribution over the surface by means of heat conduction. Therefore, a rapid temperature change appears to generate an abnormal temperature distribution.

In order to address these problems, air must be uniformly blown onto all parts of the samples. Therefore, how to do this was investigated in the present study. Furthermore, the air temperature is changed as a result of heat transfer when the air touches the samples, and so the temperature change at the first position to come into contact with the air is rapid. However, the temperature change is slow at the downstream side. This appears to cause large temperature differences among the samples at different positions. Fast circulation of the air and quick control of the temperature are needed in order to address this problem. As a result, the temperature difference between the upstream and downstream air is expected to be effectively reduced.

3.2. Basic structure of the proposed system

The basic structure of the proposed system is shown in Fig. 2. The proposed system uses a new mechanism called the temperature-controlled air-shower circulation system to blow the air uniformly over the entirety of large practical electronic components. The specific mechanisms of this system are described below.

Room-temperature or low-temperature compressed air is first provided. The temperature of the air is rapidly controlled by an air heater, and the air is ejected and dispersed as an air shower into the test chamber from small holes in the nozzle of the air-supply pipe attached to the outlet of the air heater. Test samples such as large circuit boards are placed in the center of the test chamber, and the air shower circulates air around the test samples, providing uniform heat transfer to the test samples. The temperature-controlled air-shower circulation system efficiently enables rapid and uniform H/C using only a small amount of air.

In addition, the test chamber has uniformly distributed slit-shaped exhaust ports, and optimally positioning the inlet nozzles and the outlet ports enables uniform airflow. Furthermore, the inner chamber walls, which are heat insulators, allow the heat of the blown air to be efficiently transferred to the test samples without heat loss.

The chamber air temperature, which is detected by a temperature sensor placed in the test chamber, is controlled to the target temperature by adjusting the output of the air heater. Since the entire chamber can be uniformly heated and cooled, simply controlling the chamber air temperature allows the sample temperature to be adjusted. Therefore, uniform and rapid H/C of the test samples is possible without attaching temperature sensors to the test samples. In contrast to the conventional system, in which the overall airflow in the chamber is generated by a fan, the proposed system ejects an air shower from the air nozzle at high speed. As a result, the air is circulated quickly. Moreover, air is rapidly discharged from the chamber after the temperature is changed by the circulating air. Accordingly, since the temperature-controlled air is constantly circulating, the temperature difference among the sample positions is extremely small.

Furthermore, since the air temperature is controlled with a high response and high accuracy, the developed system provides rapid H/C of all of the samples. Even when the temperature of the air is changed rapidly, since the heat is transferred uniformly and rapidly over the samples, all of the samples can be rapidly heated or cooled while maintaining a uniform temperature distribution.

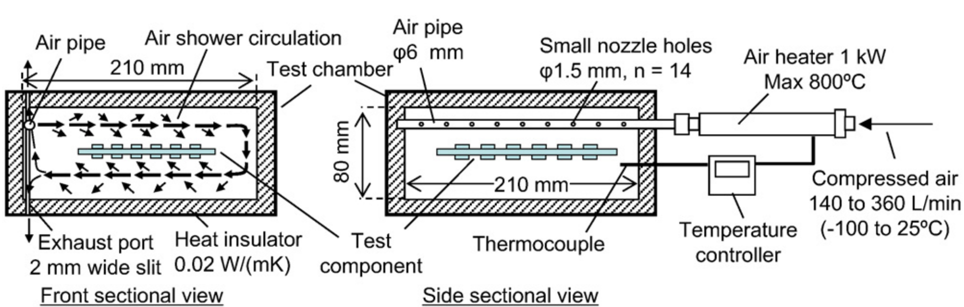

Fig. 2. Schematic diagram of the basic structure of the proposed system.