A Method of the Measurement of Moisture in IC Packages Using Microwaves

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A Method of the Measurement of Moisture in IC Packages Using Microwaves

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***Abstract*—A new method to measure the moisture content of integrated circuit (IC) packages is demonstrated. The moisture contained in the encapsulant resin was determined by using microwaves. The microwave signal was transmitted into the encapsulant resin and reflected at the surface of the chip pad. The amplitude and phase of the reflection coefficient of the microwave signal, which varied with the moisture content of the encapsulant resin, were measured in order to determine the moisture content. A preliminary experiment was carried out, and the calibration equation was developed. The present technique indicates the possibility of determining the moisture content directly without drying and weighing IC packages.**

***Index Terms*—Calibration equation, IC packages, microwaves, reflection coefficient, resin moisture.**

I. INTRODUCTION

WITH THE development of integrated circuit (IC) technology, IC chips are constantly growing in size to increase the level of integration, and the plastic encapsulant is required to be as small as possible in order to raise the density of surface mount components. Therefore, delaminations that mostly occur at the interface of chip pad and encapsulant resin have become one of the most important factors to affect the reliability of IC packages. During the soldering process, a high stress is caused within the package as a result of the large thermal expansion mismatch between the dissimilar materials within the package. At the same time, the evaporation of the moisture absorbed from the ambient by the encapsulant resin causes a pressure between the resin and the chip pad. These two factors sometimes cause delamination in IC packages [1]–[3]. The delamination will grow until the interface is fully delaminated and then leads to cracks at the sides of the chip pad. In addition, moisture diffusion within IC packages can lead to their catastrophic failure due to corrosion. Therefore, it is important to understand the diffusion behavior of moisture in the encapsulant resin, and the contribution of moisture content to the delamination of IC packages. As examples, the level of moisture absorption in the molding compound was determined for various environmental conditions [4] and the speed of moisture diffusion was also evaluated [5]. Concerning the study of moisture that affects the reliability of IC packages, the basic issue is the measurement of the moisture content in the encapsulant resin. In the present paper, a new method to measure the moisture absorbed in IC packages by using microwaves is studied.

Most standard methods of determining moisture content requires weighing a sample, in some cases drying it for several days (up to several weeks), and reweighing. Moreover, in the using of weighing method, the resin weight is usually replaced by the package weight because the weights of the chip and lead frame are commonly not known; therefore the measured moisture content is affected by the weights of the chip and lead frame. The primary advantage of the microwave method over the standard weighing method is that the moisture content can be determined directly from a wet material without drying and weighing it. Microwave has previously been used to determine the moisture content of grains [6], [7]. However, conventional microwave moisture measurement, which is based on a transmission technique using two sensors, cannot be used for IC packages containing a chip pad made of metallic material. Recently, the authors have developed a microwave imaging technique by using an open-ended coaxial line sensor to detect delamination in IC packages [8]. A sensor the same as that used above is used in the present experiment. It can effectively transmit and receive microwave with a relatively high spatial resolution [9]. The amplitude and phase of the reflection coefficient are used to determine the moisture content.

II. BASIC DEFINITIONS AND PRINCIPLES

The moisture content, M, of an encapsulant resin expressed as a percentage, is defined as

$$M = \frac{m_w}{m_w + m_d} \times 100 \quad (1)$$

that is, as the ratio of the weight of the contained water, m_w, to the weight of the wet resin, where m_d is the weight of the resin when dry.

The principle of the technique described here is based on the interaction of a microwave signal with IC packages. An open-ended coaxial line sensor is used as a source of microwave signal that is transmitted into the package, where the backside of the package is placed against the sensor. Then, the microwave signal is reflected at the surface of the chip pad, where delamination mostly takes place.

The microwave signals interacting with IC packages depend upon the relative permittivity (dielectric properties) of the encapsulant resin, and the standoff distance and operating frequency of the measurement. Since the relative permittivity of

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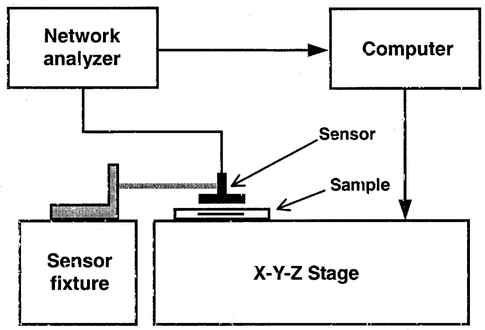

Fig. 1. Configuration of the microwave measurement system.

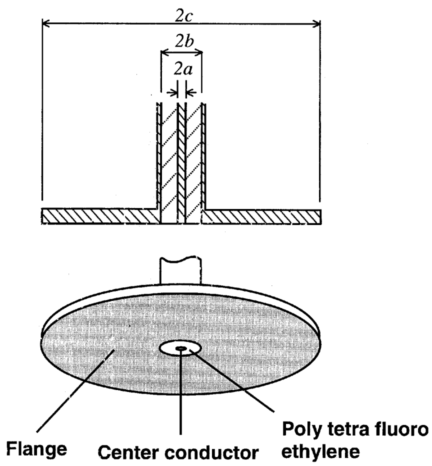

Fig. 2. Configuration of the open-ended coaxial line sensor.

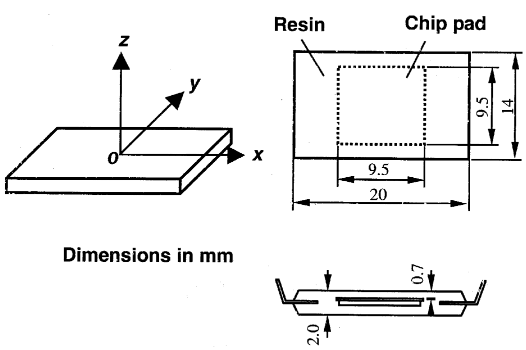

Fig. 3. Geometry of the package sample.

water differs significantly from that of the encapsulant resin, it is possible to separate the effects on the microwave signal of water and the dry material in the moist resin. Therefore, when the standoff distance and operating frequency are fixed, any changes in the amplitude and phase of the reflection coefficient, which are also known as insertion loss and phase shift respectively, are only due to the dry basis encapsulant resin and the moisture in the wet resin. Relative to the amplitude and phase measured in the absence of the test resin, the presence of the test resin introduces an insertion loss in decibel, ΔA, and a phase shift in degrees, $\Delta\phi$. These two quantities may be expressed as

$$\Delta A = \Phi_1(m_w, m_d) \tag{2}$$

and

$$\Delta\phi = \Phi_2(m_w, m_d) \tag{3}$$

TABLE I
PACKAGE SAMPLES EXPOSED TO THE SAME ENVIRONMENTAL CONDITIONS FOR DIFFERENT EXPOSED TIME

Sample pair number	1	2	3	4
Environmental conditions	–	303K/ 60% RH	303K/ 60% RH	303K/ 60% RH
Exposure time, hours	0	48	96	144
Dry weight, mN	67.5788	67.5534	67.3348	67.5269
Wet weight, mN	–	67.5730	67.3603	67.5622
Moisture content, %	0	0.0526	0.0688	0.0947

TABLE II
PACKAGE SAMPLES EXPOSED TO DIFFERENT ENVIRONMENTAL CONDITIONS FOR THE SAME EXPOSED TIME

Sample pair number	5	6	7
Environmental conditions	303K/ 60% RH	358K/ 60% RH	358K/ 85% RH
Exposure time, hours	168	168	168
Dry weight, mN	67.5592	67.3799	67.4750
Wet weight, mN	67.5867	67.4485	67.5955
Moisture content, %	0.0737	0.1846	0.3229

where Φ_1 and Φ_2 are functions of m_w and m_d. It may generally be possible from (1) to (3) to express the moisture content as a function, Ψ, of the two measured parameters ΔA and $\Delta\phi$ as

$$M = \Psi(\Delta A, \Delta\phi). \tag{4}$$

The moisture content can therefore be determined experimentally from only the measured microwave reflection parameters.

III. EXPERIMENTAL PROCEDURE

The configuration of the microwave measurement system is shown in Fig. 1. A network analyzer (HP8510) was used to generate a continuous wave signal fed to the coaxial line sensor and to measure the amplitude and phase of the reflection coefficient at the sensor aperture. A computer was used to record the data output from the network analyzer and synchronize the stage translation in the $x-, y-$ and z-directions. Fig. 2 shows the configuration of the open-ended coaxial sensor having inner and outer radii of $a = 0.46$ and $b = 1.50$ mm, respectively. A flat metallic flange with radius $c = 14.50$ mm is attached to the end of the coaxial line. In the experiment, the sample was placed in the near field of the aperture, and the backside of the package faced toward the sensor.

Seven pairs of samples of 14 IC packages were prepared. They were formed by epoxy resin filled with 79.9 wt% of silica powder and then cured for 2 h at 448 K, and post-baked for 8 h at 448 K. The dimensions of the sample are shown in Fig. 3. The size of the chip pad is 9.5×9.5 mm with resin 0.7 mm thick above the chip pad. To introduce moisture into the resin, six pairs of the packages were exposed to a range of different

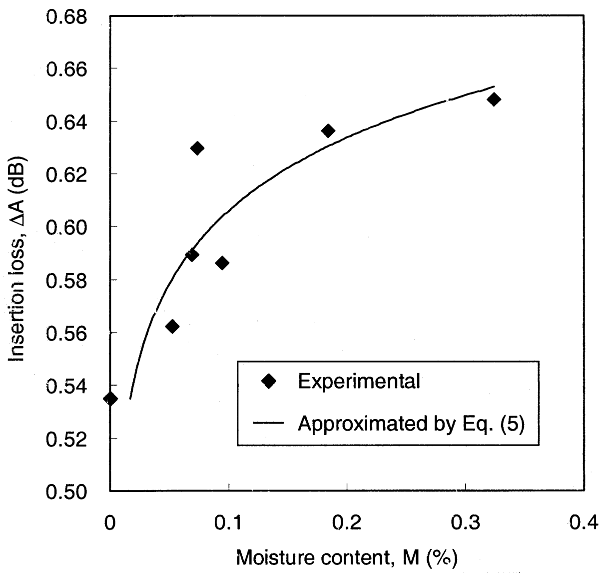

Fig. 4. Relationship of measured insertion loss with the moisture content.

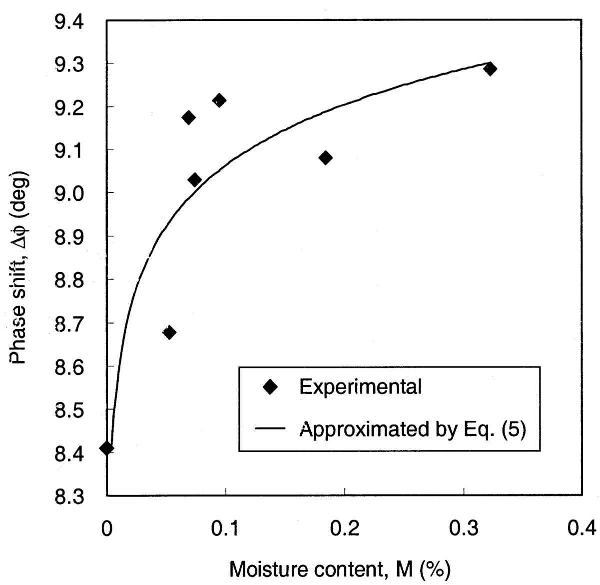

Fig. 5. Relationship of measured phase shift with the moisture content.

environmental conditions as shown in Tables I and II. Table I shows the samples exposed to the same environmental conditions but for different times and Table II lists those with the same exposure time but with different environmental conditions. The moisture contents were tested in advance using the standard weighing method. In the calculation of resin weights, the total weight, 30.2771 mN, of the chip and lead frame was deducted from the weights of packages. Another pair of packages was kept free of moisture. The encapsulant resin is assumed to be homogeneous, isotropic and nonmagnetic.

For the microwave measurements, the operating frequency was 20 GHz. The standoff distance, from the sensor to the surface of the sample, was 0.2 mm. Here, all the samples were considered to have the same thickness of resin above the chip pad. For calculating the insertion loss and phase shift, the measurement for the case of the absence of the encapsulate resin layer was carried out by placing a lead frame without encapsulant,

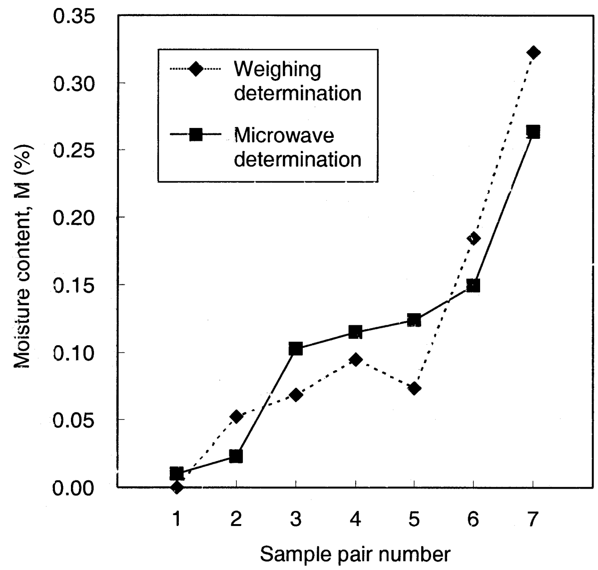

Fig. 6. Measured moisture content for different samples.

with a standoff distance $0.9 (= 0.7 + 0.2)$ mm. In other words, the same distance between the sensor aperture and the chip pad was held in both cases of the encapsulant resin being absent and present.

IV. Results

The experimental results from the microwave moisture measurement are shown in Figs. 4 and 5, respectively. In Figs. 4 and 5, the average value of the data measured from a pair of packages is shown as a single data point. Fig. 4 shows the relationship between the measured insertion loss and the moisture content, and the relationship between the phase shift and the moisture content is shown in Fig. 5. The insertion loss and the phase shift are observed to be approximately in logarithmic relationships with the moisture content in the examined range. For determining the moisture content from the microwave measurements, a calibration equation is needed. Based on the experimental results, the relationship of the moisture content with the measured insertion loss and phase shift can be expressed as

$$M = 1.3 \times 10^{-8} e^{25\Delta A} + 2.1 \times 10^{-21} e^{4.9\Delta\phi}. \quad (5)$$

The moisture contents determined by microwave and the weighing method are shown in Fig. 6 for different samples, where pairs 1 to 5 experienced different moisture absorption time with the same environmental conditions and pairs 5 to 7 the same absorption times for different environmental conditions. The moisture content determined by the microwave method agrees with that based on the standard weighing method.

It is noted that even if the conditions of moisture absorption are different from those examined in the present paper, (5) could be used for measuring the moisture content, provided the present package is concerned and the moisture content is in the examined range. For a kind of encapsulant resin, once a calibration equation is made as demonstrated in the present paper, it is possible to determine the moisture content directly by using microwaves.

V. Conclusion

A method to determine the moisture content in IC packages by using microwaves was demonstrated. It offers the possibility of measuring the moisture content directly without drying and weighing of IC packages. Therefore, the technique may be used in an on-line environment.

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