Electrical Characterization and Analysis on the Via-Solder Ball Structure

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***Abstract*—With the increasing of operating frequency, parasitic parameters of packaging have significant effects on the performance of integrated circuits. Signal paths in packaging bring great transmission loss, especially discontinuous interconnections. In this paper, de-embedding methodology is used to extract S-parameter of via-solder ball structures. A typical test structure is designed, which consists of two 6-layer organic substrates that are vertically stacked by employing BGA interconnections. The results show that the insertion losses of via-solder ball with the diameter of 500μm and 600μm are below 3dB when frequency increases up to 10GHz. But for 760μm via-solder ball structure, the frequency range of 0 to -3dB insertion loss is DC to 7.5GHz. It can be seen clearly that the insertion loss increases with the increase of the diameter of solder ball. Through this work, we have a better understanding of the electrical characteristics of via-solder ball structure. And it can provide a direct reference for signal transmission path design.**

Keywords—de-embedding; via-solder ball structure; S parameter

I. INTRODUCTION

As we all know, the basic function of a package is to provide signal distribution, heat dissipation, power distribution and protection. With the increasing of operating frequencies, parasitic parameters of packaging have significant effects on the performance of integrated circuits. In order to accurately assess the capability of the signal transmission path, it is necessary to properly model the various discontinuous interconnections in packaging, including vias, solder balls, bonding wires, etc.

Smaller, lighter, faster and cheaper are realistic requirements for electronic packages nowadays. Advanced fabrication techniques and various packaging techniques play a key role in meeting these requirements. Lots of the improved technologies are proposed to reduce the parasitic parameters in packaging [1, 2]. Besides, various mature characterization methods are presented in [3-6] to model vias, bonding wires, and transmission lines in different packages. Interconnection with ball is realized as a more effective packaging alternative than traditional bonding wires. Both in reducing precious real estate on printed circuit board and improving electrical performance [7].

Ball Grid Array (BGA) packages have become a standard choice for high performance and high pin count applications. A variety of BGA packages are based on flip chip due to advantages in size scaling and performance improvement compared to wire bonding. The main discontinuous interconnections in BGA packages are vias and balls. So how to access the characterizations of these structures accurately is very important for packaging performance assessing. But as vertical interconnects, we can't obtain the S-parameters of these discontinuous structures directly by contacting micro probes. In practice, de-embedding methodology is a good choice for extracting two-port S-parameter.

In this paper, we unite via and solder ball as one typical structure (via-solder ball). De-embedding methodology is used to extract the S-parameter. The second section of this paper is about a brief introduction of the de-embedding methodology. Test structure design and results are in third section. The last section is the conclusion.

II. METHODOLOGY

In most measurement processes, we can't obtain the result of a certain structure directly. As mentioned before, micro probes usually can't contact at their two ends. De-embedding methodology is a good approach to test vias, solder balls or bonding wires. Fig. 1 shows a typical block diagram that de-embedding methodology is used to extract the characteristics of Device Under Test (DUT). The structure can be seen as three elements cascaded in a row. We can easily obtain S-parameters of part A (S_A), part B (S_B), and part M (S_M). But our target is getting the S-parameter of part DUT (S_{DUT}). T-matrix is more suitable for calculating cascaded structures, so that we convert S-parameters to T-matrixes by solving (1) firstly. Then the structure in Fig. 1 can be described in (2) by T-matrixes. So T_{DUT} can be obtained by solving (3). Eventually, the S-parameter of DUT can be obtained by converting T_{DUT} to S_{DUT}. The following section depicts the detailed de-embedding procedure for via-solder ball structure.

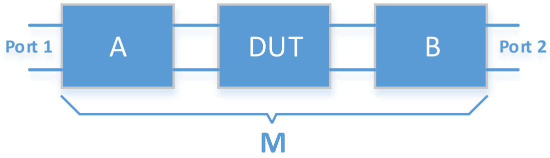

Fig. 1. A block diagram for de-embedding methodology

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \left(\frac{1}{S_{21}}\right) \begin{bmatrix} S_{12}S_{21} - S_{11}S_{22} & S_{11} \\ -S_{22} & 1 \end{bmatrix} \quad (1)$$

$$T_M = T_A T_{DUT} T_B \quad (2)$$

$$T_{DUT} = T_A^{-1} T_M T_B^{-1} \quad (3)$$

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \left(\frac{1}{T_{22}}\right) \begin{bmatrix} T_{12} & T_{11}T_{22} - T_{12}T_{21} \\ 1 & -T_{21} \end{bmatrix} \quad (4)$$

III. Experimental Design And Results

A test structure is presented in Fig. 2 for extracting S-parameter of via-solder ball structure. The structure consists of two 6-layer organic substrates (top substrate and bottom substrate) that are vertically stacked by employing BGA interconnections. Signal transmission path contains 1cm long 50ohm microstrip line on both substrates, one through via and one SnAgCu solder ball. The diameter of via is 75 μm and the height is 550 μm. In order to consider the effects of different solder ball diameter on transmission characteristics, we choose three kinds of solder ball with the diameter of 500 μm, 600 μm and 760 μm. Two samples are manufactured for each kind of solder ball, shown in Fig. 3.

De-embedding methodology is used to extract the S-parameter of via-solder ball structures. First, we obtain the S-parameters of the entire test structure and 1cm long microstrip line. Fig. 4 is the insertion loss and the return loss of 1cm long microstrip line. The insertion loss is below 1.5dB and the return loss is below -15dB at 20GHz. Fig. 5 and Fig. 6 show the measurements of the entire test structures. The results of two samples with same solder balls agree well, which demonstrates the consistency of the samples is very good.

After getting the S-parameters of microstrip line and the entire test structure, the characteristics of via-solder ball can be extracted by solving (1), (2), (3) and (4). In this work, Agilent ADS de-embedding module is used to complete this process, which has the same principles. Fig. 7 and Fig. 8 are the characteristics of via-solder ball after de-embedding. As is shown in Fig.7, the insertion loss of via-solder ball with the diameter of 500 μm and 600 μm are below 3dB when frequency increases up to 10GHz. But for via-solder ball with the diameter of 760 μm, the frequency range of 0 to -3dB insertion loss is DC to 7.5GHz. It can be seen clearly that the insertion loss increases with the increase of the diameter of solder ball. At 10GHz, the insertion loss of via-solder ball with the diameter of 760 μm is about 2dB larger than that 600 μm ball. The reason is that signals will face a more serious discontinuous situation when transmit through a bigger solder ball. The parasitic capacitance of solder ball increases and leading to more terrible impedance mismatch and greater loss. All test results in this section are post processed by ANSYS HFSS.

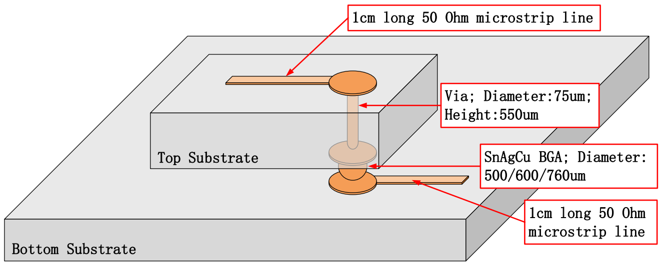

Fig. 2. Test structure for via-solder ball de-embedding

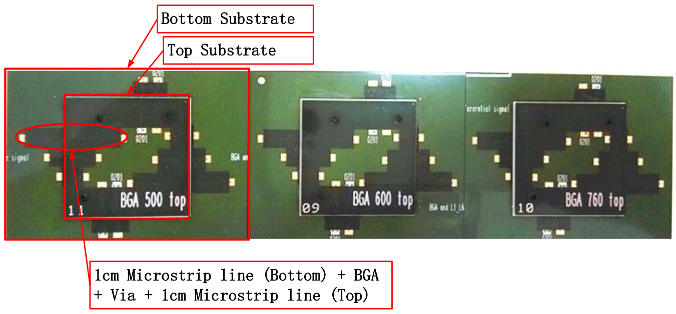

Fig. 3. Photo of test samples

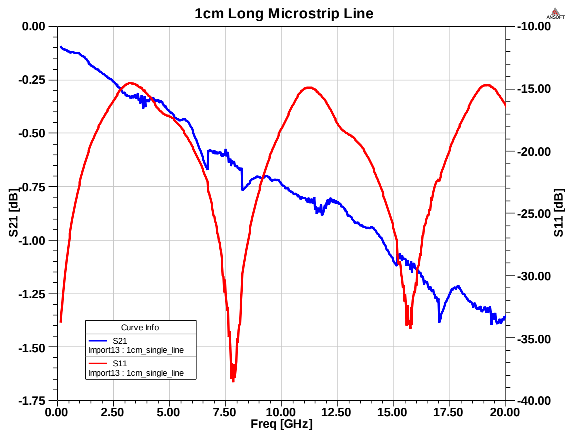

Fig. 4. Insertion loss and return loss of 1cm long microstrip line

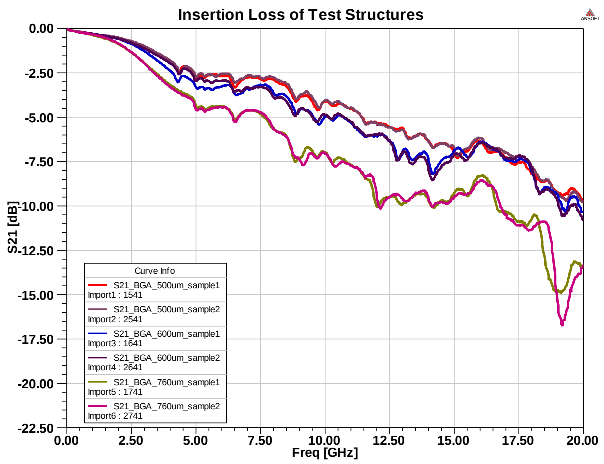

Fig. 5. Insertion loss of test samples with different diameter of BGA

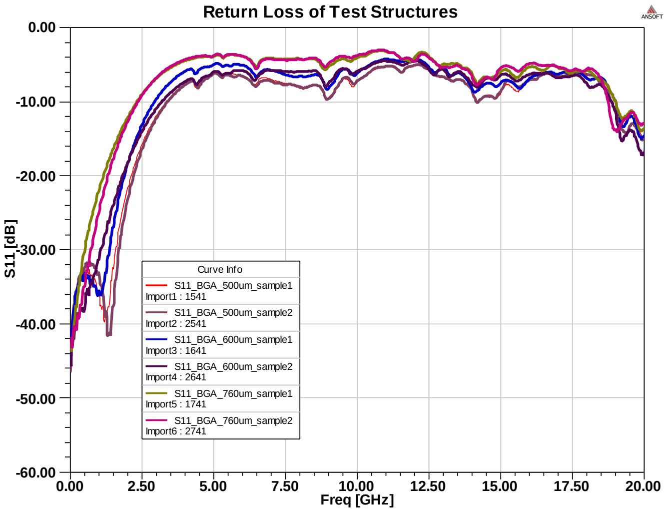

Fig. 6. Return loss of test samples with different diameter of BGA

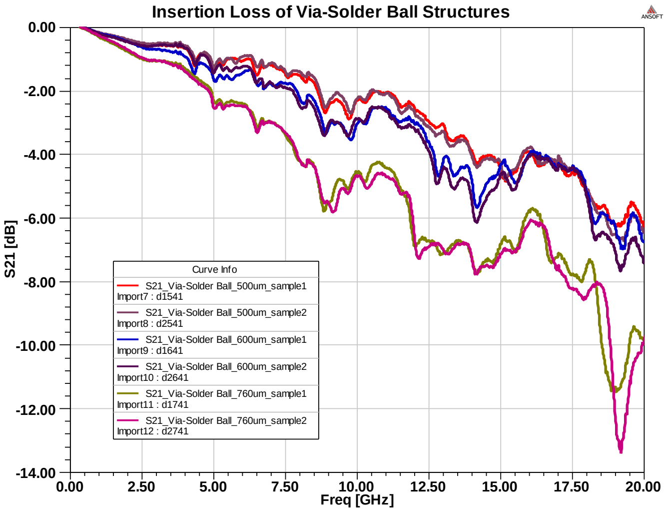

Fig. 7. Insertion loss of via-solder ball structures

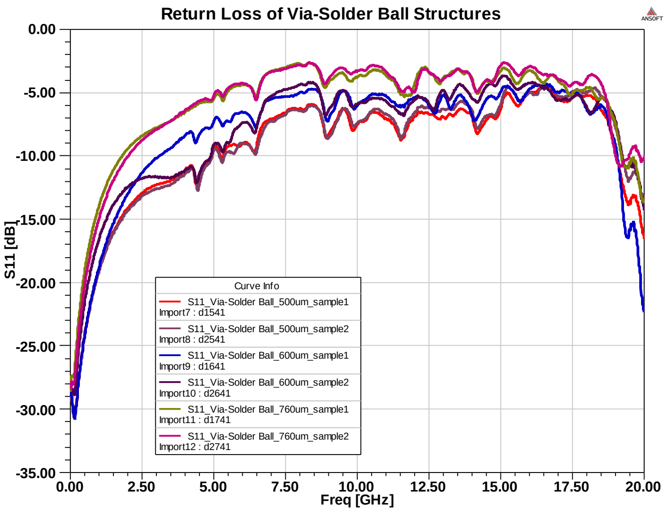

Fig. 8. Return loss of via-solder ball structures

IV. CONCLUSION

We use de-embedding methodology to extract S-parameter of via-solder ball structure. Based on a typical de-embedding test structure, Vector Network Analyzer and Agilent ADS are used to accomplish this work. Finally, we obtain the characteristics of via-solder ball structures with different ball diameters. By comparing the influence of ball diameter, it can be seen clearly that the insertion loss increases with the increase of diameter of solder ball. Through this work, we have a better understanding of the electrical characteristics of via-solder ball structure. And it can provide a direct reference for signal transmission path design. In future work, individual de-embedding structures for via and solder ball will be designed, respectively. More parameters of vias and solder balls will be considered. Besides, accurate broadband equivalent circuit model will be constructed to make it becoming a more general and direct guidance for packaging design.

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