High frequency measurement and characterization of ACF flip chip interconnects

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Abstract

Microwave model and high-frequency measurement of the ACF flip-chip interconnection was investigated using a microwave network analysis. S-parameters of on-chip and substrate were separately measured in the frequency range of 200 MHz to 20 GHz using a microwave network analyzer HP8510 and cascade probe. And the cascade transmission matrix conversion was performed. The same measurements and conversion techniques were conducted on the assembled test chip and substrate at the same frequency range. Then impedance values in ACF flip-chip interconnection were extracted from cascade transmission matrix. ACF flip chip interconnection has only below 0.1nH, and very stable up to 13 GHz. Over the 13 GHz, there was significant loss because of epoxy capacitance of ACF. However, the addition of SiO_2 filler to the ACF lowered the dielectric constant of the ACF materials resulting in an increase of resonance frequency up to 15 GHz.

High frequency behavior of metal Au stud bumps was investigated. The resonance frequency of the metal stud bump interconnects is higher than that of ACF flip-chip interconnects and is not observed at the microwave frequency band.

The extracted model parameters of adhesive flip chip interconnects were analyzed with the considerations of the characteristics of material and the design guideline of ACA flip chip for high frequency applications was provided.

1. Introduction

These days, rapidly increasing demand for wireless communications and radar systems has resulted in much attention to the microwave/millimeter wave region as new frequency resources. Therefore, Flip chip interconnection becomes popular for microwave and millimeter wave packaging applications.

Conductive adhesive have been considered as promising interconnect materials for flip chip interconnects because of several advantages such as good electrical performance, low-temperature assembly, high-density interconnection, low cost, and fluxless bonding, which eliminates the need for cleaning.

In spite of these merits of flip chip package for microwave and millimeter-wave applications, their use has been limited. This is partly because the accurate characterization and modeling of adhesive flip chip to enable electrical circuit design has been considered difficult.

Recently, performances of high-speed circuits are limited by package interconnect discontinuity due to large inductance and resistance in the high frequency range [1]. Transition in a flip chip package involves the use of metallic bumps to transmit the signal between chip and substrate. These bumps represent the main discontinuity to the signal propagation on the line which results in partial loss, reflection and possibly distortion of the signal. Since these factors alter device parameters, accurate analysis and modeling of the package interconnects should be performed.

Several high frequency properties of conductive adhesive interconnections have been already investigated [2], [3].

In this study, new material system to improve high frequency properties of ACF flip chip technique has been developed and investigated using extracted impedance parameter.

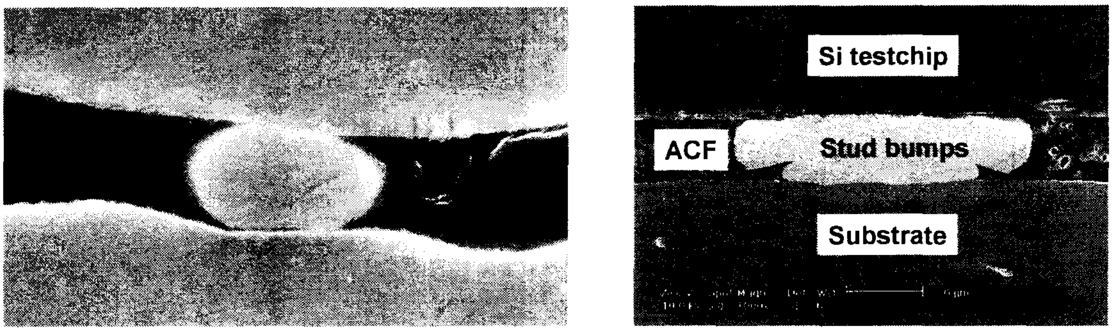
2. Experimantal

2.1. Testchip, interconnect materials

To extract the impedance parameter of interconnects, the test chip with 20μm width microstrip and 100μm × 100μm bumping pad was fabricated using a 1-poly and 3-metal 0.6 μm Si process. The microstrip structures were fabricated with Inverted Embedded Microstrip (IEM) structure to minimize parasitics due to orientation and ground impedance.

To investigate the low-k filler addition effect on high frequency behavior of ACF, two kinds of anisotropic conductive films with different filler system, (1) Ni particle (conductive particle) only and (2) Ni particle (conductive particle) + Low-k SiO_2 particle (non-conductive particle), were formulated. As shown in Fig. 1 (a), electrical connection of adhesive flip chip interconnects is achieved by the deformation of conductive particles.

To investigate the high frequency behavior of stud bumps, metallic stud bumps were formed on the Al pads of the test chip. Fig. 1 (b) shows cross-sectional SEM images of stud bump after adhesive flip chip bonding.



(a) (b)

Fig. 1. Cross-section images of various adhesive flip chip interconnects for high frequency test

2.2. S-parameter measurement and impedance parameter extraction procedure

The S-parameters of the test chip and test PCB were measured using HP8510 network analyzer and cascade probe tip in the frequency range 200 MHz 20 GHz. Also, S-parameter of flip chip bonded device was measured. From these measured S-parameters, impedance parameter model of flip chip interconnect was investigated based on a microwave network analysis.

The extraction procedure is shown in Fig. 2. Consequently, the high frequency transmissions characteristics of the flip chip interconnect were acquired. Total ABCD parameters of the measurement can be easily determined from the measured S-parameters as shown in the following Eq. (1), (2), (3) and (4).

$$A = \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}} \qquad (1)$$

$$B = Z_o \frac{(1+S_{11})(1-S_{22}) - S_{12}S_{21}}{2S_{21}} \qquad (2)$$

$$C = \frac{1}{Z_o} \frac{(1-S_{11})(1-S_{22}) - S_{12}S_{21}}{2S_{21}} \qquad (3)$$

$$D = \frac{(1-S_{11})(1+S_{22}) + S_{12}S_{21}}{2S_{21}} \qquad (4)$$

Then, with the extracted ABCD parameters of the total test specimen (A_T, B_T, C_T, and D_T), the CPW on the PCB (A_p, B_p, C_p, and D_p), and the Inverted Embedded Microstrip (IEM) line on the silicon substrate (A_o, B_o, C_o and D_o), the de-embedded Z_1 and Z_2 parameters of the flip chip interconnect were calculated.

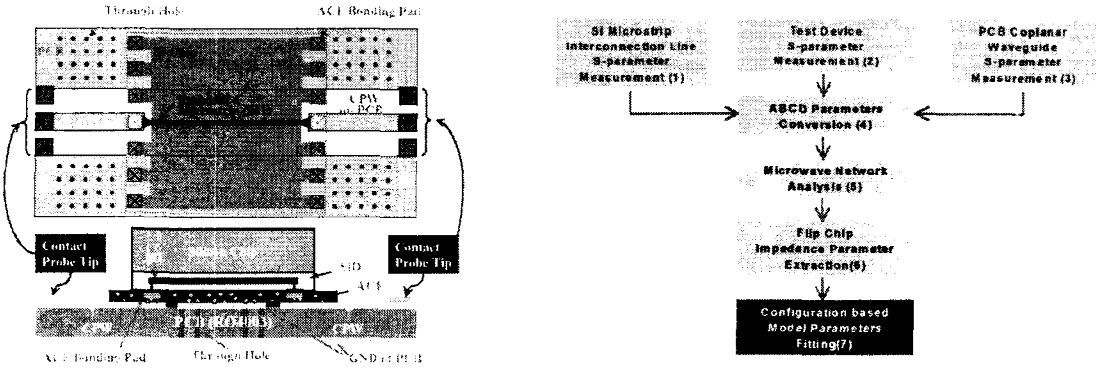
Negligible ground impedance and quasi-TEM wave transmission through the microstrip line was assumed. Then the cascade transmission matrix conversion was performed to determine impedance Z_1 and Z_2 as following (Eq.(5)).

$$\begin{bmatrix} A_{p1} & B_{p1} \\ C_{p1} & D_{p1} \end{bmatrix}^{-1} \begin{bmatrix} A_T & B_T \\ C_T & D_T \end{bmatrix} \begin{bmatrix} A_{p2} & B_{p2} \\ C_{p2} & D_{p2} \end{bmatrix}^{-1} = \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} A_o & B_o \\ C_o & D_o \end{bmatrix} \begin{bmatrix} 1 & Z_2 \\ 0 & 1 \end{bmatrix} \qquad (5)$$

Finally, the flip chip interconnection impedance Z_1 and Z_2 can be calculated with an assumption of reciprocity of the microwave network analysis as shown in Eq. (6) and (7).

$$Z_1 = \frac{1}{C_o}\left[K_{p1}K_{p2}\left\{D_{p2}(D_{p1}A_T - B_{p1}C_T) - C_{p2}(D_{p1}B_T - B_{p1}D_T)\right\} - A_o\right] \qquad (6)$$

$$Z_2 = \frac{1}{C_o}\left[K_{p1}K_{p2}\left\{A_{p2}(A_{p1}D_T - C_{p1}B_T) - B_{p2}(A_{p1}C_T - C_{p1}A_T)\right\} - D_o\right] \qquad (7)$$



(a) (b)

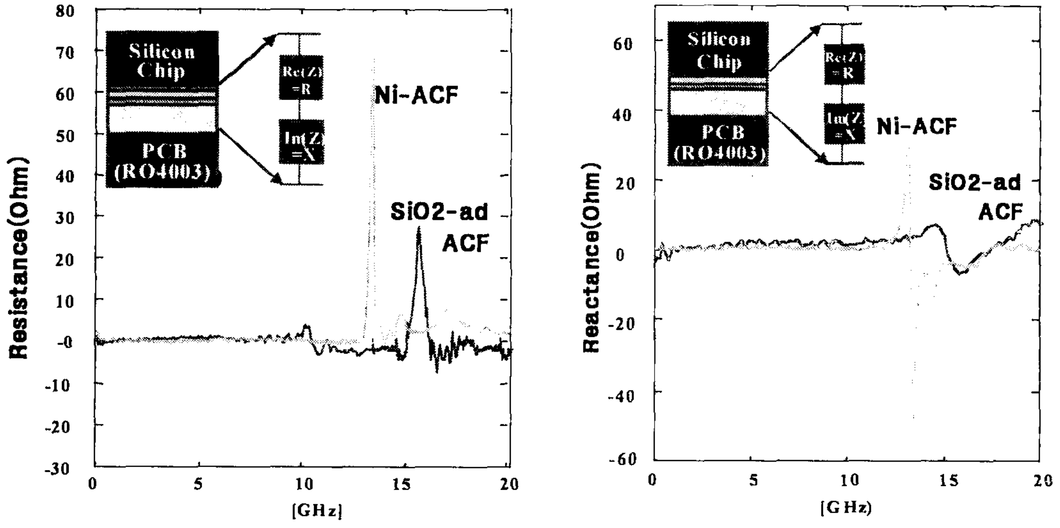
Fig. 2. (a) Configuration of test PCB and chip, (b) Extraction procedure of impedance parameter

3. Results and Discussion

3.1 Low-k filler addition effect on ACF

Effects of low-k filler (SiO_2) addition on high frequency behavior of ACF were investigated. Interconnect capacitance of the ACF joint formed between the CPW of PCB and the test chip pad is relatively high due to the high dielectric constant of the epoxy resin and the large area & small gap of the parallel metal plate structure, compared to the solder ball flip-chip structure. Consequently, the resonance frequency of the ACF flip-chip interconnect is lower than that of the solder ball flip-chip interconnect. The resonance frequency was found around 13 GHz for the conventional Ni ball ACF [4], [5].

The extracted impedance model parameters of 100μm × 100μm bonding pad for Ni ball ACF including SiO_2 filler were presented in Fig. 3. Interestingly, the Ni ball ACF including SiO_2 filler has resonance frequency slightly higher than the conventional Ni ball ACF. Up to 10GHz, resistance value of Ni ball ACF with SiO_2 filler is dominated by the skin effect loss of the conductive system. Above 10GHz, the conductive loss of polymer matrix becomes dominant. Then SiO_2 filler reduce the capacitive coupling & the conductive loss of polymer matrix by lowering the dielectric constant of ACF. Therefore, Ni ball ACF including SiO_2 filler exhibited the resonance phenomena around 15GHz. This difference is originated from dielectric constant change of polymer matrix.



(a) (b)

Fig. 3. Impedance parameters of the ACF flip-chip interconnect including SiO_2 extracted from S-parameter measurement and network analysis. (a) Resistance(R), (b) Reactance (X)

3.2 High frequency behavior of stud bumps

High frequency behavior of Au stud bumps was investigated.

Fig. 4 shows the impedance parameters of Au stud-bump interconnect extracted from the s-parameter measurement.

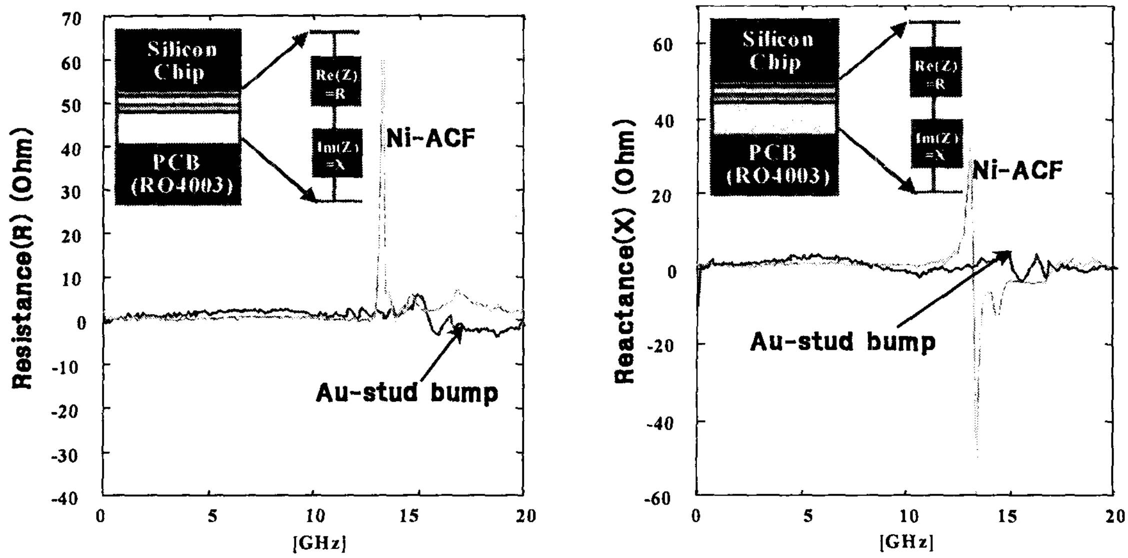
As depicted in Fig. 8, in contrast to Ni ball ACF, Au-stud bump interconnects did not exhibit resonant phenomena up to 20GHz.

This means that Au stud bumps maintain the constant impedance in microwave frequency range. Capacitive coupling of the Au-stud bump joint formed between the CPW and the test chip pad is relatively low due to the large gap of the epoxy resin and the small area in the parallel pad structure, compared to the ACF flip-chip structure.

Consequently, the resonance frequency of the Au-stud bump interconnects is higher than that of ACF flip-chip interconnects and is not observed at the microwave frequency band.

When compared with ACF interconnects, stud bumps interconnects have no resonance phenomena and stable impedance value at microwave frequency range. It is considered that better microwave frequency property of stud bump is originated from the reduced capacitive coupling of stud bumps. Coupling effects are composed of electromagnetic interactions between

PCB pad and metal bump (chip-substrate proximity effect) or between conducting media (inter-conducting system effect). Therefore, ACF interconnect include coupling phenomena caused both by chip-substrate proximity effect and by inter-conducting system effect. In case of stud bumps, coupling effect caused by chip-substrate proximity effect becomes small due to larger gap and coupling effect by inter-conducting system does not occurred.



(a) (b)

Fig. 4. Impedance parameters of the Au-stud bump interconnect extracted from S-parameter measurement and network analysis. (a) Resistance(R), (b) Reactance(X)

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