

Column Distribution Analysis and RF Characterization of High-Density Vertical Interconnections Created by Magnetically Aligned Anisotropic Conductive Adhesive

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In this paper, the property of a magnetically aligned anisotropic conductive adhesive (MA-ACA) is analyzed for RF applications with narrow-pitch I/O pads. An analytical approach to estimate the failure rate of this material is used based on an image-processing technique instead of direct experiment. This approach can predict efficiently the quality of developing MA-ACA and provide usable criteria in designing optimal pad size for vertical interconnects. In addition, the column density of the created interconnect by this approach allows for more understanding of the RF characterization of a magnetically aligned ACA and extend the application range at high frequencies.

Key words: RF packaging, anisotropic conductive adhesive, self-alignment, vertical interconnects.

1.0 Introduction

To date, various attempts have been made to achieve narrow-pitch interconnects based on conventional technologies such as solder bumping and wire-bonding [1]. However, the high density interconnect processes using the conventional technologies are complicated and expensive. Specifically, this wire-bonding technique is particularly problematic for high frequency applications because minimum loop height to connect pads is required. It causes large parasitic inductances by the long wire-bonding [2]. The bumping approach has been developed based on flip-chip packaging technology and its RF performance for integrated and mm-wave applications were studied in [3]. However, the fabrication process of the bumping approach is complicated and the performance of the interconnects is largely affected by bump height, diameter, and spacing.

As an alternative to these conventional technologies, anisotropic conductive adhesives (ACAs) have been considered for high-density I/O applications using a flip-chip bonding technique because of its low curing temperature and reasonable reliability [4], [5]. However, the assembly process is sensitive to bonding conditions such as pressure and heating temperature during the flip-chip bonding process and need to be optimized for successful assembly [6].

Previously, the RF characteristics of interconnects using a magnetically aligned ACA (MA-ACA)

on Duroid™ substrates was introduced as a novel material [7]. In this material, the conductive particles in the MA-ACA move around in response to an applied magnetic field because of their ferromagnetic property, ultimately forming columns parallel to the field lines before the polymer epoxy cures, and final-

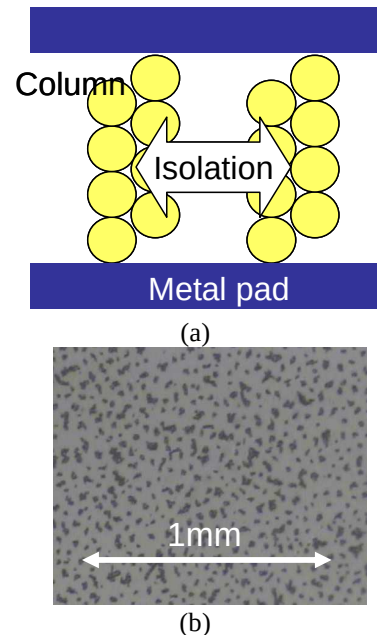


Fig. 1. (a) Schematic of Z-axis anisotropic conductive adhesive (ACA), and (c) the top view of the sample assembled with a MA-ACA.

ly locking them in place. These columns of particles create electrical interconnects vertically from one chip to another. In contrast to the conventional technologies, this epoxy includes several advantages: (1) lead-free, patterning-free for an individual pad during an assembly process, (2) low-temperature curing process ($< 160\text{ }^{\circ}\text{C}$) and (3) environmental-friendly property. Therefore, the benefits of the MA-ACA enable to make the assembly process of RF packaging much simpler.

In this study, we introduce an approach to analyze the MA-ACA using an image processing technique to predict the failure rate of created interconnects. Based on this analysis, the correlation between column density and RF characteristic are studied in assembled silicon sample with a small pad size ($30\mu\text{m} \times 80\mu\text{m}$).

2.0 Z-axis ACA properties

MA-ACA is useful for high-density and cost-critical applications because only a vertical interconnect is created without any electrical short between neighboring columns as shown in Fig. 1, which can reduce the number of step in an assembly process. When a magnetic field is induced in the gap between two substrates, the randomly dispersed conductive particles stack up as their induced magnetic dipoles attract one another forming columns in the polymer epoxy. During the curing process, induced thermal

energy causes the epoxy to cure around the columns firmly connecting the particles. In this study, two types of conductive particles were used as filler in a MA-ACA: (a) F-formulation (6.6 μm -diameter nickel core coated with gold) (b) A-formulation (23 μm -diameter graphite core coated with nickel and gold). By the analysis of the top-view images of created columns using a glass slide, the column diameter on average is found to be approximately 10 μm in F-formulation and 25 μm in A-formulation, respectively. In this work, we mainly focus on the effect of the contact resistance and the failure rate of created interconnects using two formulations in the MA-ACA.

3.0 Prediction of the Failure Rate

A novel image-processing technique is used to aid in obtaining the statistical features of created columns in MA-ACAs. Fig. 2 shows an imaging process flow from acquiring an original image to calculation of the failure rate of test samples. Top-view photographs of samples are taken after assembly by using a Z-axis ACA with either 10 or 25 μm -diameter columns. In the first step, photographed images are converted from grayscale images to black and white (B/W) images using a threshold gray value, which is set in 8-bit depth scale. Next, a column mapping process is carried to decide if a column is assigned to the size of

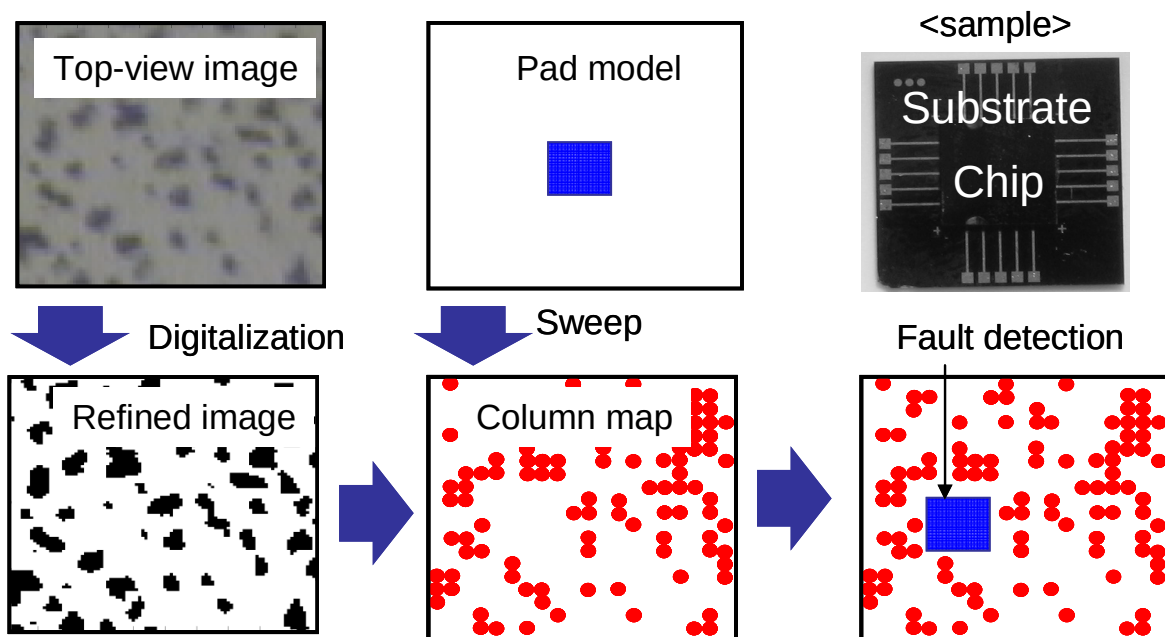
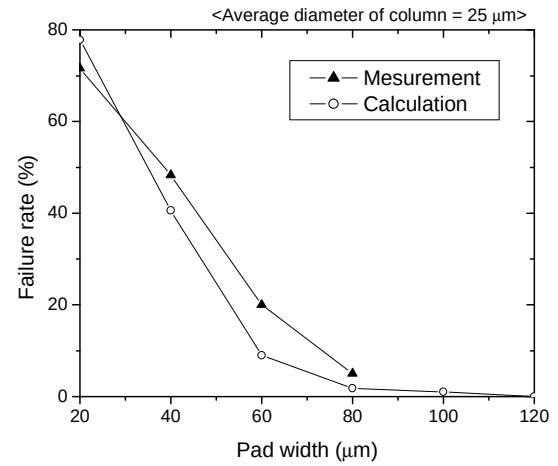


Fig. 2. Image processing flow for the calculation of failure rate in a MA-ACA.

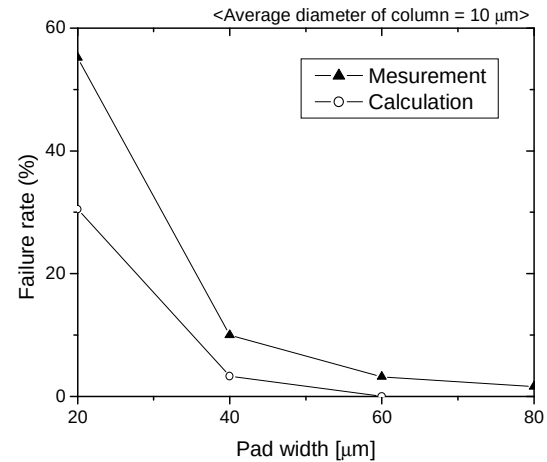
a unit block containing a single column in B/W images. In this column map creation, a threshold is set to decide whether or not a unit block, already assigned with the dimension as large as average column diameter (10 or 25 μm), is processed as a column in a comparison with the contrast ratio of a B/W image. Last, virtual pads with various dimensions are created for the calculation of a failure rate. The process counts how many columns there are in pad's boundary while the pad sweeps around in the column map. There are two assumptions in this approach: (1) each column is strongly connected between the top and bottom pads, and (2) the position of columns in a contact pad does not affect the resistance of interconnects. Finally, when a vacant place is detected, it is regarded as a failed interconnect.

To obtain the experimental DC resistance of interconnects created by a MA-ACA, test samples using a high resistivity silicon substrate ($\epsilon_r=11.5$ and $\tan\delta=0.005$) are designed with four cases of overlap area, ranging from $20\mu\text{m} \times 20\mu\text{m}$ to $80\mu\text{m} \times 80\mu\text{m}$ by a $20\mu\text{m} \times 20\mu\text{m}$ increase. The fabrication and assembly processes of the sample are as follows: (1) 50 nm-thickness Ti and 2 μm -thickness Au metals are deposited on a silicon wafer with high resistivity ($\rho>10,000\ \Omega\cdot\text{cm}$). (2) After a lithography and development process, the deposited metals are etched in order by the corresponding etchants, (3) the etched samples are cut into individual samples by a dicing saw, (4) fabricated samples are assembled with the MA-ACA by a flip-chip bonding machine (FINEPLACER from FINETECH GmbH & Co), and (5) the MA-ACA is cured in a magnetic curing oven. The right upper side in Fig. 2 shows an assembled silicon sample with a MA-ACA.

Fig. 3 shows the comparison between the experimental and calculated results. The calculated failure rate increases drastically at $40\mu\text{m} \times 40\mu\text{m}$ through $60\mu\text{m} \times 60\mu\text{m}$ pad dimension in both MA-ACAs with 10 and 25 μm -diameter conductive particles. In comparison, the difference in a failure rate calculated by the images of MA-ACA from the experimental result is less than 4.12 % in the Z-axis ACA with 25 μm -diameter columns and less than 24.7 % in the Z-axis ACA with 10 μm -diameter columns. Overall, the calculated result agrees more with the experimental results in 25 μm -diameter columns. This is because the portion of the samples which were void is 2.67% in the MA-ACA with 10 μm -diameter columns and 0.46% in the MA-ACA with 25 μm -diameter columns. It is observed that the presence of voids in the MA-ACA largely affect a failure rate of interconnects.



(a)



(b)

Fig. 3. Measurement result of silicon samples: (a) comparison with the calculation result in samples with 25 and (b) 10 μm -diameter columns.

Therefore, this result indicates that the column distribution with fewer voids is more close to the ideal column distribution with equal spacing, and the failure rate of this case can be more predictable.

4.0 RF Characterization

To characterize the RF performance of a MA-ACA, samples are fabricated using a silicon substrate. The signal of fabricated CPW is 80 μm wide and the gap between signal and ground is 90 μm wide for 50 Ω impedance on 500 μm thick substrate. Fabrication and assembly process is the same as in the previous

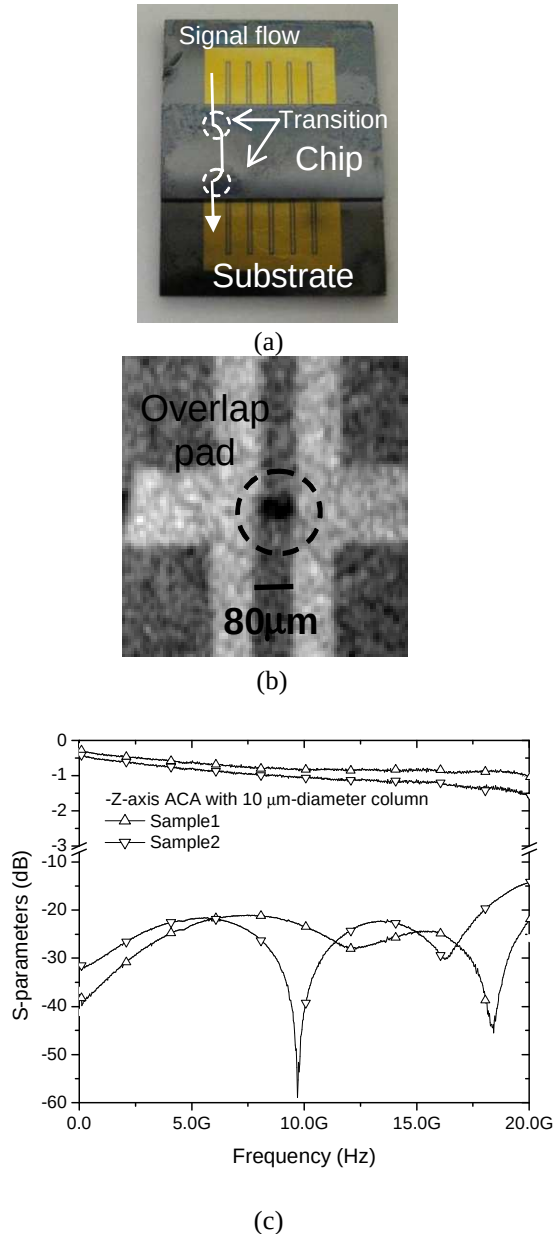


Fig. 4. Measurement result of silicon CPW samples: (a) photograph of an assembled sample (dashed circle: vertical transition), (b) X-ray photograph of a sample with 30 μm -overlap area (dashed circle: overlap area), (c) S-parameters of silicon CPW samples.

section for the DC resistance samples. As shown in Fig. 4 (a), a signal flows through CPWs on bottom and top silicon substrates. In this signal path, there are two vertical transitions, each created by a Z-axis ACA with 10 μm -diameter columns. In order to investigate the effect of column density on RF performance in a silicon sample with extremely small contact area, samples with approximately 30 μm x 80 μm contact area are assembled. The contact length is

verified by an X-ray photographed image shown in Fig. 4 (b).

Based on the analysis of column distribution using the image processing technique, we can determine the expected DC resistance of interconnects in these silicon samples with 30 μm x 80 μm pad. The insertion loss of a silicon sample at 100 MHz is measured to be 0.28 dB (sample 1) and 0.42 dB (sample 2), which correspond to 1.65 Ω and 2.5 Ω in the transition regions. Next, we calculate the number of columns in the contact area. The column spacing is found to be 37 μm distance from the top-view image analysis. Thus, the 30 μm x 80 μm pad size of silicon samples is expected to have 5 conductive columns on average. To calculate the resistance of interconnects, we use the measured DC resistance of a single column on average (15.4 Ω), which was found in the smallest pads (20 μm x 20 μm) of DC resistance tests. The total calculated resistance (5 parallel columns) is 3.07 Ω . However, the measured resistances are 1.65 Ω and 2.5 Ω in silicon samples, which correspond to approximately 9 (sample 1) and 6 (sample 2) columns in the pad. Thus, the difference of this column density causes the 0.25 dB/transition loss difference between two samples at 20 GHz.

Finally, from the analysis based on the column distribution, the number of columns in a contact area can be predicted and this result can be helpful to optimize the RF characteristics of interconnects created by the MA-ACA for narrow-pitch I/O applications.

5.0 Conclusion

The failure rate of interconnects built by MA-ACAs were studied for small pads (less than 100 μm x 100 μm). From silicon samples assembled by MA-ACAs with both 10 and 25 μm -diameter columns, the distribution of DC resistances were measured as a function of pad dimension. The effect of RF characteristics by column density was also explored. Consequently, the failure rate of MA-ACA interconnects using a proposed image processing technique is helpful to efficiently design I/O pad of interconnects for RF packaging.

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