Electrical Performance of Micro-assembled Beads under Different Temperatures and Loadings

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Abstract—Micro-assembly is an efficient tool to build electrical connections with metallic micro-beads. This process uses patterned photoresist AZ1512 as an adhesion for micro-bead arrangement. The assembled beads is immobilized with underfill embedment (ZYMET 2821). This method allows arbitrary geometric pattern designs. All of these processes can be completed below 150°C. This paper characterizes the electrical performance of these densely-arranged anisotropic conductive tunnels under different temperatures and stresses loading. Experiment results suggest that using photoresist to assemble micro conductive beads with underfill immobilization can yield stable performance.

Keywords-assembly; micro-assembly; micro beads; vertical conductive channel; underfill.

I. INTRODUCTION

In recent years, 3D flip-chip packaging becomes an important technology to integrate miniaturized systems. Overall, the packaging scheme can involve high density electrical interconnections between chips and integral circuits or between vertical conductive channels and through silicon vias (TSV) [1, 2]. Through the vertical conductive path, the transmission and processing speed of the microelectronic device can be improved [3]. Anisotropic conductive film (ACF) bonding is one of the well knowing technologies for building vertical conductive paths. It is widely used in flat panel displays, chip packaging and ACF wafer-level packaging [4]. However, it is well known that the thermo-mechanical reliability of these vertical conductive paths is depended on the thermo-mechanical properties of ACF. Many researchers have conducted some useful research [5-6] in this area. Instead of using ACF, we presented a photolithography based micro-conductive-bead assembly method our previous research [7]. It can provide miniaturized and densely packed conductive paths. The assembled micro-conductive-beads have to be permanently immobilized and electrically connected to the binding sites for practical applications. In this paper, we arrange the micro-scaled conductive beads on the lithographic patterns and inject the underfill into the gap between chips; it can immobilize the beads and help the conductive chip to against the mechanical stress and moisture. The effect of the mechanical stress and temperature variation of electrical conductivity was also investigated. In the following sections, we first discuss the materials, experimental procedures and methods. Then, we present the test results and conclusions.

II. MATERIALS AND EXPERIMENT PROCEDURES

A. Materials

3 μm micro-composite conductive beads are selected for building anisotropic conductive electrical channels. The beads consist of a 0.025 μm gold-nickel metal layer and an encapsulated benzoguanamine resin core.

AZ1512 is used to define the require patterns for micro-beads assembly by photolithography process. It is a widely used positive photoresist for micro-fabrication.

ZYMET X2821 is an encapsulation underfill materials, it can be quickly cured under low temperature. In this paper, it is used to immobilize the conductive beads and to hold the assembled chip. It can also protect the connections from damages.

<table>
<thead>
<tr>
<th>TABLE I.</th>
<th>WL-CSP AND BGA UNDERFILL ENCAPSULANT</th>
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<tbody>
<tr>
<td>Type</td>
<td>ZYMET X2821(underfill)</td>
</tr>
<tr>
<td>Viscosity, 25°C</td>
<td>500 (cps)</td>
</tr>
<tr>
<td>Cure conditions</td>
<td>150°C, 1minutes</td>
</tr>
<tr>
<td>CTE</td>
<td>36ppm/°C</td>
</tr>
<tr>
<td>Tg, (TMA)</td>
<td>135°C</td>
</tr>
<tr>
<td>Shear storage modulus</td>
<td>3GPa</td>
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</tbody>
</table>

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<tr>
<th>TABLE II.</th>
<th>BEADS COEFFICIENT OF THERMAL EXPANSION</th>
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<tbody>
<tr>
<td>Layer</td>
<td>Coefficient of Thermal Expansion</td>
</tr>
<tr>
<td>Au</td>
<td>14.2 ppm/°C</td>
</tr>
<tr>
<td>Ni</td>
<td>13 ppm/°C</td>
</tr>
<tr>
<td>Micro conductive beads</td>
<td>45 ppm/°C</td>
</tr>
</tbody>
</table>

B. Micro-assembly Process

To achieve densely packed electrical connections between chip and substrate, the procedures for micro conductive beads assembly and underfill process are listed in Fig. 1. A similar process of micro conductive beads assembly has been published in our previous research [7]. This process is start from an oxidized and aluminum deposited 4” wafer. AZ1512 is spin coated on Si wafer to pattern the aluminum. Depends on the applications, after lithography, developing and etching process, one can create desired patterns on the photoresist and aluminum for micro conductive beads assembly. The beads are spread densely and evenly on the photoresist patterns.
The Hotplate heating makes the photoresist soften at 120°C. It can increase sticking force between beads and patterns. Micro-conductive beads are selectively immobilized on the photoresist patterns. After gently washed redundant beads away with deionized water, we injected underfill into the chip’s gap and heated it up to 150°C for 1 minute to bond and to immobilize the combinations.

Fig. 2 shows the immobilized micro-conductive bead on the photoresist. The diameter of the micro conductive beads is around 3µm. The micro conductive beads are selectively immobilized on the patterned region. This immobilization process does not require external force fields. It is a cost and time efficient process.

The bead distributions on the patterns are random in nature; however, they are confined to predetermined area. To ensure a good encapsulation process, the designed pattern should have topologically opened cavity geometry to spread the underfill.

This study is focus on the electrical performance of micro-assembled beads under different temperatures and loadings. The simplified bead assembly region is prepared to ensure the applicable array arrangement, which provides improved filling results on the curing, velocity and encapsulant distributions for capillary-driven by dispensing. Fig. 3 shows an assembled combination of top and bottom chip with sandwiched conductive beads, underfill and photoresist.

III. EXPERIMENTAL SETUP AND MEASUREMENT

Unlike traditional soldering processes, the electrical connections are not built by chemical bonding or phase transition. There are only physical contacts between electric pads and micro-conductive beads. That means contact sliding gap deformation and stress variation may cause the resistance change. Measurements have been made of the electrical conductive performance of the assembled conductive beads, namely its resistance at different temperature, compressive stress and shear stress. The experiment setups of these tests are shown in Fig. 4.
The assembled chip is placed on a hot plate; the electrodes are connected to a digital multimeter (Agilent 34410A) to measure the resistance. The setup is installed in a sealed chamber which provides a closed environment and good temperature uniformity. The heating rate of this setup is around 29°C/min and the cooling rate is around 4°C/min. As shown in Fig. 5, the resistance measurement range is setup from 25 to 150°C, the data are automatically collected by a computer.

Contact resistance measurement results corresponding to the thermal cycle is shown in Fig. 6, the contact resistance between 3μm Ni/Au coated Benzoguanamine resin beads and bonding pads are increased after temperature increased from 27 to 148°C. Photoresist above reflow temperature was thermally and mechanically less stable above 110°C; however, been embedded in the underfill, photoresist reflow did not show any significant impact to resistance.

There are various explanations on what causes the resistance variation (Fig. 6) during the thermal cycle, the most possible explanation being Matthiessen’s rule and the coefficient of thermal expansion differences among the photoresist, micro metallic beads and the underfill.

B. Electrical resistance of this connection under different compressive loadings

The sample was tested under compressive loadings (Fig. 7). The loadings are gradually increased from 0 to 800kN/m². Then it is gradually decreased back to 0kN/m² to form an enclosed loop.

The assembled connection had low contact resistance at the initial stage. When the pressure force is gradually applied to the assembly, compressive loading pressure would promote contact stress redistribution which increases the resistance of the electric assembly. However, the data measured within the linear elastic deformation loop are steady and repeatable.

C. Electrical resistance of this connection at different shear stresses

To precede the resistance investigation under shear stress loading, an assembled chip is installed onto a testing platform with a force gauge. The shear stress was continuously loaded to the assembled chips until the catastrophic damage occurred.

The value of contact resistance, measured correspond to the shear loading, is shown in Fig. 8. The experiment results suggest that shear stress may cause significant degradation on the contact resistance. It can cause physical detaching and delaminating which leads to mechanical and electrical failure.

The composite metallic beads aging caused by high temperature can lead further degradation of the contacts. High bonding and reflow temperatures above 200°C are not recommended for reliability issue.

![Temperature curve](image-url)
IV. CONCLUSION AND SUMMARY

Micro-assembly is an efficient tool to build electrical connections with metallic microbeads. This process uses patterned photosensitive AZ1512 as an adhesion for micro-bead adhesion. This method allows arbitrary geometric pattern designs. All of these processes can be completed below 150°C.

This paper characterizes the electrical performance of this densely-arranged anisotropic conductive tunnels under different temperatures and stresses. Experiment results suggest that using photosensitive to assemble conductive beads with underfill embossment (XYNET 2021) can yield stable performance with appropriate shear stress protection.

The results indicate that the micro-bead assembly with the underfill encapsulation method developed in this study is adequate for micro conductive beads assembly in flip chip bonding process.

ACKNOWLEDGMENT

The authors would also like to thank National Chiao Tung University, and the Nano Facility Center at National Chianghua University of Education, for providing the fabrication facility. This work is supported by National Science Council, NSC 100-2221-E-018-015 and NSC-98-2221-E-018-012-MY2.

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