Selective Heating of Microbumps Using Microwave for Low Strain Heterogeneous Chip Stack Integration

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1. Introduction

3D-LSI has high capability to support next generation electronics[1, 2]. We have been developing micro interconnection technology to realize chip level stacking of Si LSIs and the success of 20 μm-pitch bonding with Au cone bump[3, 4] and solder electrode[5] are demonstrated.

On the other hand, integration of dissimilar materials causes inaccurate placing of the chips and/or generation of extra strain under pressure and heating up during the bonding. For example, III-V compounds which are major materials of opto-electronic devices are softer than Si and have larger thermal expansion coefficients than Si as listed in Table 1.

In this study, we investigate major cause of strain generation when either a GaAs or InP chip is stacked on a Si chip using mechanical simulation. The simulation results suggest that it is important to reduce bonding temperature to minimize strain. As a possible candidate, we investigate application of microwave to selectively heat bumps between chips. Experimental results demonstrate the feasibility of this new method.

Table1. Properties of materials[6]

<table>
<thead>
<tr>
<th></th>
<th>Young’s module (GPa)</th>
<th>CTE (×10^-6/K)</th>
<th>Fragility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si[100]</td>
<td>130 (300K)</td>
<td>3×10^-6/K</td>
<td>robust</td>
</tr>
<tr>
<td>GaAs[100]</td>
<td>86 (300K)</td>
<td>5.7×10^-6/K</td>
<td>fragile</td>
</tr>
<tr>
<td>InP[100]</td>
<td>61 (300K)</td>
<td>4.5×10^-6/K</td>
<td>fragile</td>
</tr>
</tbody>
</table>

2. Simulation of Strain

We have carried out mechanical simulation by ‘CoventorWare’ simulator to estimate mechanical strain generated in the chips. The model is shown in Figure 1. Either GaAs or InP chip is bonded to a Si chip by using a Au bump array. The size of Au bump is 10 μm. The Au bump array is located near the center of the chip. In the simulation, the pressure or temperature are individually applied on the surface of top chip. The pressure varies from 0 to 1 g/mm². Temperature was changed from 300K to 500K. We extracted the data along the dashed line in Fig. 1. Figure 2 shows the maximum value of strain generated in each chip when the pressure is applied and temperature was changed. It is clearly to see that temperature is the main factor that affects strain. During the bonding of Au cone bump and solder electrode, both chips will be heated up to a temperature higher than 500K which is the melting point of SnAg solder.

3. Theoretical Consideration on Microwave Heating

The most useful way to minimize strain in bonding heterogeneous chips is selective heating of bumps while keeping semiconductor chips unheated. Two candidates appear feasible: induction heating and dielectric heating. Li et al.[7] had developed a induction heating equipment to deal with Ø700 μm Sn96.5Ag3.5 ball in bonding of FPGA chip on a board. Habib et al.[8] tried to reflow Ø25~45 μm Sn96.5Ag3.5,Cu85.5 powders but they encountered difficulty in melting solder because of the following reason.

Induction heating needs alternating electric field to generate eddy current in the object. When AC current flows in the object, its density distribution obeys the well-known 'skin effect'. The skin depth d could be calculated by equation (1)[9], where \( \rho \), \( \mu \), \( f \) represent resistivity of the conductor, absolute magnetic permeability of the conductor and frequency of the current.

\[
d = \frac{\sqrt{\pi f \mu}}{\rho}
\]

(1)

\[
k = a / d
\]

(2)

It is easy to notice that the skin depth is inverse proportion to the root of frequency, which means that higher frequency is necessary when treating with smaller object. Another effective way to determine the appropriate frequency is to calculate factor \( k \) in equation (2)[9] where \( a \) is diameter or thickness of object. When \( k<1 \) the eddy current would not be generated or produce insufficient power to heat up object. Li et al. used 300 kHz AC current with a \( k \) value of 1.6 which is an acceptable experiment condition.

The same condition did not work for the study of Habib et al. because of the diameter of solder powder was far smaller than the skin depth at the frequency used.

For the sake of achieve smaller skin depth below 10 μm, to induce current in a microbump, microwave of 2.45GHz becomes of practical candidate because it gives a skin depth of 5 μm.

4. Experiment

Experimental study to investigate possibility of melting solder microbumps by applying microwave was carried out according to the following process:

1). Chips with Au cone bump and chips with Sn96.5Ag3.5 solder electrodes were respectively fabricated by photolithography and electro-plating; 2). Solder reflowing was carried out with flux, followed by flux removal with solvents (Fig. 3); 3). The two chips were temporarily bonded
with the conditions of 0.25 gf/bump / 150°C / 20 sec; 4). The resistance of all connections was carried out by daisy-chain method; 5). 2.45 GHz microwave of 750W was applied for 1 min using a commercial microwave oven; 6). Tested the daisy chain resistance, again; 7). After peeling off bonded chips, observation of bonded surface was carried out using 3D laser microscope.

Figure 4 shows cumulative resistance vs. number of connection obtained from daisy chain test. Owing to the concentration of stress at the top end of the cone bump, the daisy chain showed a good connection even at the temporary bonding step although bonding strength is not sufficient. After microwave application, resistance remained unchanged and a low level of about 140~150 mΩ/bump was observed. Figure 5 shows microscopic images of the surface of cone bump observed by peeling off the bonded chips before and after microwave application. We can see on the surface of the microwave applied bump a residue of solder bump remains, which indicates that the solder bump is heated up by the application of microwave.

4. Conclusions

Selective heating of microbumps to reduce strain generated during bonding of heterogeneous chips has been proposed. The use of microwave is expected to heat bumps whose diameter is a few tens of micrometer or below. Preliminary experiment showed the feasibility of the microwave application to heat up solder microbumps.

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References