Laser Based Direct Exposure to Photo Materials Used in Advanced Semiconductor Packaging

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Laser based direct write exposure tool for advanced semiconductor packaging has been introduced into the market. The tool has unique features compared to existing high-pressure mercury lamp based exposure tools. The tool does not require any masks or reticles because it equips with state-of-the-art light valve called Grating Light Valve (GLV) along with high power laser unit producing wavelength of 355 nm. Minimum resolution that the tool is able to draw is 2μm lines/spaces with overlay accuracy of equal to or less than 1μm at average plus 3σ, that satisfies most advanced packaging requirement as of today. In the paper, we will introduce the advantage of this type of exposure tool in the market and discuss about technical challenges.

Keywords: Photoresist, Laser direct imaging, Photo sensitive insulation dielectric, Grating light valve (GLV), RDL

1. Introduction

Exposure tools commonly used in photolithography process as of today for advanced semiconductor packaging are steppers and aligners. Since those tools are exposure equipment based on masks and reticles, they have technical difficulties because substrates in advanced packaging usually tend to have non-linear distortion. For examples, semiconductor dies embedded in the mold substrates have positioning shift in X, Y direction and theta rotation independently and randomly on the mold. Usually one exposure mask has plural of die data, however if each die moves and/or rotates independently in random manner, it will be impossible to align to every die in mask.

At the same time, advanced packaging industry is facing to have more I/Os and more number of re-distribution layers (RDL) in limited module size. There are a strong demand for generating 2μm copper RDL lines and spaces for packaging modules.

At SCREEN Semiconductor Solutions, we have developed direct imaging tool with intention to solve technical issues mentioned above [1].

This exposure tool equips with high power laser unit along with unique light valve called Grating Light Valve (GLV) [2].

The exposure tool also has been carefully designed to satisfy market’s demand such as minimum resolution and throughput.

In the paper, we will introduce the advantage of this type of exposure tools in the market and discuss about technical challenges.

2. Technology background

In the semiconductor manufacturing processes, most exposure equipment has been mask-based tools such as steppers and scanners. On the other hand, last ten years direct imaging tools have become very common in printed circuit board (PCB) manufacturing process. Because PCB substrates are flexible, substrates tend to have distortion or deformation. Exposure tools must have flexibility in exposure figures in order to compensate this deformation of the substrate. Thus, demand for direct imaging exposure tools has been more popular in PCB market.

There are similar substrates used in the semiconductor packaging process, when dies are cut from the wafer into individual ones and then
those dies will be embedded and constructed onto mold base substrates. Substrates used in advanced semiconductor packaging are more flexible than silicon wafer, demand for exposure equipment become similar to that of PCB.

In Fig. 1, several advanced packaging methods are shown.

![Fig. 1. Several methods in semiconductor packaging.](image)

There are technologies commonly used within advanced packaging. They are; 1) Copper plating re-distribution layering technique that will replace traditional wire-bonding technique, and 2) Generating photosensitive dielectric layer with vias to connect between top and bottom layers.

These two main techniques both require photolithography equipment and photo materials and they are key process technologies for advanced packaging.

Figure 2 shows typical multi-layer formation process used in advanced semiconductor packaging.

![Fig. 2. Typical multi-layer formation process for advanced packaging.](image)

3. Introductions of lithography equipment

At SCREEN Semiconductor Solutions, a laser based i-line exposure tool has been developed and released into the semiconductor advanced packaging market [3-5]. Table 1 shows summary of specifications in terms of optical features.

![Table 1. Specification of direct imaging tool for advanced semiconductor packaging.](image)

4. Experimental

As discussed, in the advanced semiconductor packaging area, minimum of 2 μm copper RDL shall be created through plating technology. The minimum resolution of the exposure tool is 2 μm which most R&D sites currently are targeting this resolution. Figure 3 shows the comparison between plating technology and wet-etching technology when generating copper lines on substrate. Plating technology has an advantage in generating more fine patterns such as 2 μm, because cross section of copper lines are determined by photoresist cross section shape. With wet etching method, side etching will make copper cross section having taper with sidewall.

![Fig. 3. Comparison of two major methods for Cu based RDL.](image)

In Fig. 4, cross section of 2 μm photoresist pattern is shown (Thickness of the photoresist is 5 μm).
Figure 5 shows the basic optical configuration of the direct imaging tool. Unlike steppers or scanners, the tool does not require any masks or reticles that hold exposure patterns. Instead of masks or reticles, the tool equips with the light valve called Grating Light Valve (GLV). The device has more than 8,000 sets of light valves or ribbons that are independently controlled with very fast speed to make both bright status and dark status on the substrate surface. All the optics are rigidly fixed on a firm frame and exposure chuck which hold wafer/substrate to be exposed will be moved underneath of the projection lens.

Figure 6 shows the major difference of the exposure ethics between stepper and direct imaging tool. Steppers usually use ultra-high pressure mercury lamp as a light source. Typical intensity on the substrate surface with a stepper is around 1 W/cm². If the photo material requires 100 mJ/cm² for the given process, the stepper tool will have to expose 100 milli seconds.

In case of laser based direct imaging tool, intensity of laser on substrate surface is 4 digit stronger than steppers. In compensation, exposure time will become very short time like 10 μseconds to obtain 100 mJ/cm².

These differences in intensity and exposure time sometimes create lithography result different. Since exposure time of the direct imaging tool is very short, some photo materials do not catch up its chemical reaction. Figure 7 indicates the phenomena. We have used negative tone dry film with around 100-μm thick. The exposure dose has been applied by laser based direct imaging tool to the dry film that was laminated onto the wafer. Three pictures in the upper side, exposure dose had been applied with combination of higher intensity and shorter exposure time. Three pictures in the bottom, combination of relatively lower intensity and longer time have been applied. Upper one and lower one have the same exposure dose where intensity x time equals to the same value. It was found that photoreaction did not completely go down to the bottom of the substrate in upper pictures. After we have extended exposure time up to around the double value, the cross section of the dry film became straight.
We have concluded how the phenomena occur shown in Fig. 8. With negative tone photo materials, the exposure will be done on to the part where film must be remained. If the exposure time is very short, majority of the energy will be consumed in upper part of the photo material. In addition, the exposure will be finished before the photoreaction reaches to the bottom of the photo material. Thus, photo material remains as non-exposed status. In the next process step at developing, bottom part near the via hole will be developed.

To prevent this phenomenon, the tool will have to increase exposure time and at the same time, the tool will have to decrease the intensity to keep the same exposure dose.

Speaking about productivity, typical throughput of the direct imaging tool is in inverse proportion to exposure dose as shown in Fig. 9. It is mandatory to keep lower dose to maintain higher throughput when the exposure tool has the same intensity.

5. Summary and conclusion

Exposure tools in semiconductor packaging have been traditionally are steppers. Direct imaging tool shall be new candidate because they have advantage in exposing patterns on to flexible substrates with having distortion.

Optical performance of the tool are meeting requirement of the semiconductor advanced packaging in regards to resolution and overly accuracy.

The direct imaging tool has unique characteristic of having higher intensity and shorter exposure time. For some photo materials, the tool will have to decrease its intensity and increase the exposure time to obtain expected cross section profile.

However, this usually ends up lower productivity.

The direct imaging tool would like to have higher sensitivity photo materials having faster photoreaction.

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References