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X-Y SCALING COMPENSATION TECHNOLOGY FOR FINE-LINE PCB IMAGING WITH HIGH-PRECISION ALIGNMENT

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ABSTRACT

As imaging requirements continue to move towards finer resolution, accurate layer-to-layer alignment becomes an increasingly important factor that influences product yield. One of the major contributors to yield loss in fine-line products is the dimensional instability of the substrate. Large rigid substrates as well as flexible films often undergo slight dimensional changes as a result of the different PWB manufacturing process steps. In addition, the changes in the substrate dimensions are often non-isotropic. Manufacturers have been compensating for this problem by measuring the changes in the substrate and plotting new artwork that is matched to the dimensions of the processed substrate. This time-consuming and costly manufacturing practice can be eliminated through the use of the new Anamorphic X-Y Scaling technology that enables independent magnification compensation in two dimensions for laser projection exposures. In this paper, we present the results of studies conducted on laser projection imaging equipment and specifically review the performance of the X-Y scaling capability.

1. INTRODUCTION

The need for higher speeds, greater functionality, and higher densities in electronics packaging such as IC substrates and backplanes continues to place greater demands on design and manufacturing of both rigid and flexible printed circuit boards. Simultaneously, economic conditions have placed extreme pressures on fabricators to extract as much cost savings as possible out of their processes by improving yields. Fine-line photolithography and improved registration for higher yields have been identified as high-priority technical needs in the industry, not only to make HDI and microvia boards more practicable, but also to improve yields on conventional boards [1]. This need for finer lines, pads and vias, as well as more precise alignment/registration of such features, has reached a level where evolutionary improvements in traditional exposure equipment (predominantly contact printers) are no longer adequate. Responding to the need for more fundamental improvements, laser-based projection equipment has been developed and presents an effective solution for high-resolution, fine-alignment applications.

Given that laser projection imaging equipment enables non-contact patterning, it offers a substantial improvement in alignment capability (and therefore, yield) because the artwork and board can be moved independently with respect to one another and locked in place prior to exposure. In addition, the laser projection imaging equipment minimizes defect generation and propagation by placing all moving parts below the mask and board.

One of the major barriers to improving alignment has been the problem of board dimensional stability. It is well-known that boards expand or contract asymmetrically due to processing and this effect is very difficult to predict. One of the simplest techniques to compensate for this problem is to measure the board prior to exposure and plot appropriately compensated artwork. Unfortunately, this process is time-consuming and can be quite costly. For example, a 16 x 16 in. glass mask with 20 micron features can cost over $2000. Alternatively, film-based artwork, although much less-expensive to manufacture, is prone to changes in size due to temperature or humidity variations. An anamorphic X-Y scale compensation system can provide independent correction of board dimensional changes in two directions. Thus, it is clear that laser projection imaging technology, including the anamorphic X-Y scale compensation system, is an viable approach for manufacturing high-density printed circuit boards.

2. SYSTEM SPECIFICATIONS AND PERFORMANCE

In this section, we review the laser projection imaging system specifications. We then discuss some of the key system parameters that dictate performance (yield), including resolution, depth of focus and alignment in more detail. Finally, we review the recent tests performed using the scale compensation system.

2.2. LASER PROJECTION IMAGING

Laser projection imaging (LPI) systems combine the advantages of batch imaging and high resolution made possible with optical projection, and high throughput made possible with the high ultraviolet (UV) light output power of excimer lasers. An example of a system is shown in Figure 1. A detailed description of this scanning projection technology can be found elsewhere [2-4]. These systems are available in different configurations depending upon the application. For HDI substrates, the 10 micron resolution system is recommended. Its specifications are given in Figure 2. Alternatively, for optoelectronics applications, a 5 micron system has been employed [5].

Because an LPI system uses a laser beam with a large cross-section (typically 16 cm^2), it exposes millions of pixels in parallel. Also, since the excimer laser light source provides very high power output (typically 45 - 75 W of pure UV light), the stage can be scanned at very high speeds (up to 500 mm/sec). The combination of a high-power light source, a large-cross-section beam, and a high-speed scanning stage results in high throughputs, for both primary imaging and soldermask imaging with conventional resists.

Fig. 1. Laser Projection Imaging system. The system model 2100 SPE is shown from the mask loading side.

2100 SPE System Specifications	
Imaging Technique	Laser Projection Imaging
Resolution	10 microns (0.4 mil)
Projection System	1:1 magnification refractive lens
Numerical Aperture	0.025 (*f* / 20)
Depth of Focus	500 microns (20 mils)
Lens Field Size	50 mm diameter
Panel Exposure Area	18 x 24 inches
Exposure Source	XeF excimer laser
Exposure Wavelength	351 nm
Overlay Precision	± 2.5 µm (0.1 mil)
Alignment System	Automatic
Substrate Handling	Automatic
Throughput	5.0 sq. ft. / min (100 panels / hr)

Fig. 2. Model 2100 SPE system specifications.

2.3. PROJECTION IMAGING PERFORMANCE

We note that fine resolution with large depth of focus is very important for the exposure of printed circuit boards. During production, boards can exhibit significant thickness variation both board-to-board and within a single board. In addition, any variation in the mask flatness serves to reduce the available depth of focus. The resolution and large depth of focus of the laser projection imaging system come from the diffraction-limited, doubly-telecentric projection lens. The lens discussed below has a resolution of 10 microns and a depth of focus of approximately 500 microns. The depth of focus then increases linearly for coarser resolution features (That is, the depth of focus is approximately 1.0 mm for 20 micron features). The performance of this lens can be approximated by the following first-order equations:

$$\text{Resolution} = 0.7(\lambda/\text{NA})$$

$$\text{DOF} = \lambda/(\text{NA})^2$$

where λ is the wavelength of light and NA is the numerical aperture of the lens. It is noted that these equations only apply to this class of lenses. Other lens types cannot deliver this large a depth of focus at 10 micron resolution.

Examples of imaging results from a laser projection imaging system are shown in Fig. 3. Figure 3(a) shows scanning electron micrographs of 25 micron (1.0 mil) wide lines and spaces obtained with MacDermid LF 106 dry-film resist. Figure 3(b) shows scanning electron micrographs of 20 micron (0.8 mil) wide lines and spaces obtained with Shipley Laminar ProPlate 7313 dry-film resist. The 15 micron (0.6 mil)-thick negative-acting resists were laminated on standard FR4 boards. All processing conditions used, including lamination, exposure dose, and development parameters, were typical for these resists and as specified by the supplier. Figure 3(c) presents LPI results obtained in a liquid photoresist. The resist used was AZ-Clariant 9260, coated to a thickness of 13 microns (0.52 mil) on an FR4 board. All processing conditions, as above with the dry-film resist, were standard and as specified by the supplier. The figure shows an SEM of 10 micron (0.4 mil)-wide lines and spaces.

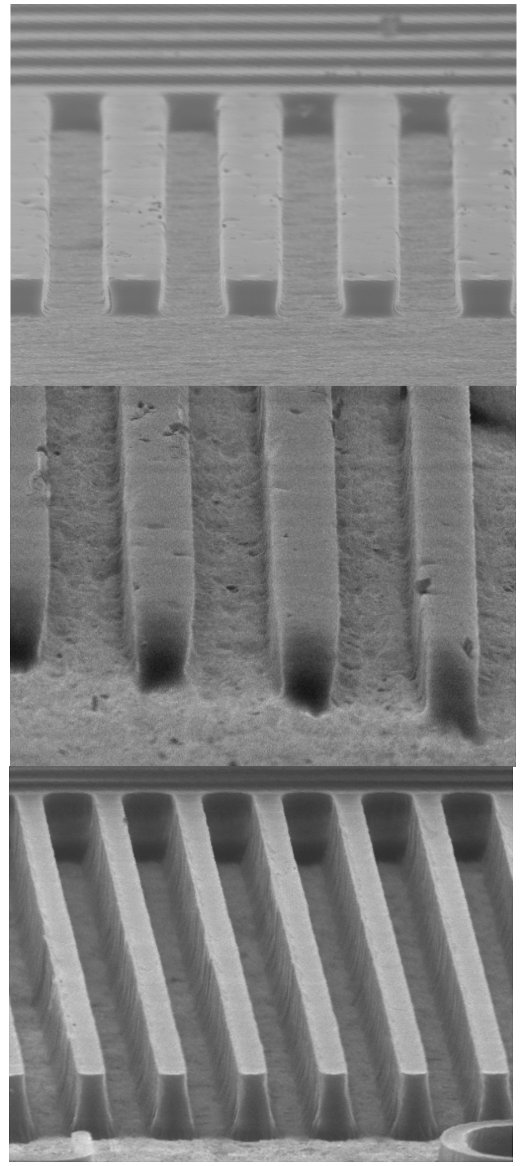

Fig. 3. Exposures made with an LPI system in dry-film and liquid resists. (a) 25 µm (1.5 mil) lines and spaces imaged in 15 µm (0.6 mil)-thick MacDermid LF 106 negative dry-film resist. (b) 20 µm (0.8 mil) lines and spaces imaged in 13 µm (0.5 mil)-thick Shipley Laminar ProPlate 7313 negative dry-film resist. (c) 10 µm (0.4 mil) lines and spaces imaged in 13 µm (0.5 mil)-thickAZ-Clariant 9260 positive liquid resist.

The depth of focus of this system is shown in Figure 4. In addition to addressing the above-mentioned issues associated with board thickness and flatness variations, a large depth of focus serves to eliminate the problems associated with off-contact imaging.

2.4. ALIGNMENT SYSTEM

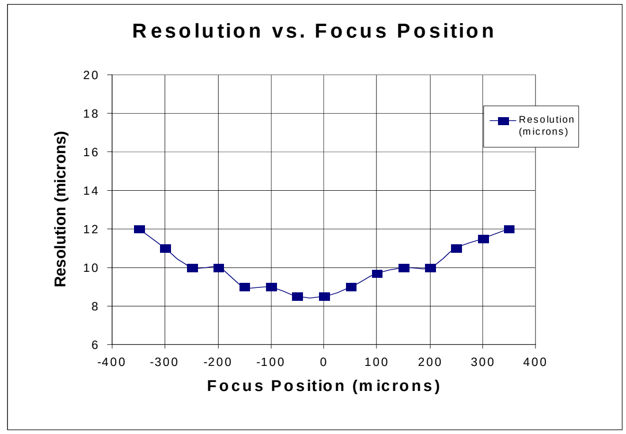

Fig. 4. Graph of resolution versus focus position showing excellent resolution over the entire range of 500 microns.

The laser projection imaging system incorporates a high-precision, optical alignment system which is designed to be able to align the mask and panel rapidly and automatically to within a specified alignment tolerance. Such an alignment capability is necessary for layer-to-layer alignment in a multilayer circuit and for front-to-back alignment in a dual-sided panel. It is a rule of thumb that a suitable value for the alignment specification should be ~ 25% of the minimum feature size. Thus, for example, the 10-µm-resolution system has an alignment precision of ± 2.5 µm, whereas a 5-µm-resolution system has an alignment precision of ± 1 µm. The automatic alignment system consists of an optical metrology system and a fine positioning system. The optical metrology system is used to determine the relative locations of the mask and substrate with respect to the projection system. Depending upon the desired resolution of the measurement, the optical metrology system incorporates some or all of the following subsystems: CCD cameras, pattern recognition software, confocal microscope(s), and/or a laser-based interferometric system. The position information for the mask and substrate is processed by the system computer and sent to a Fine Positioning and Alignment System (FiPAS), which imparts a relative x-y-θ correction in the position of the substrate with respect to the mask, bringing the two in the desired alignment.

Since the mask and panel can be moved independently and locked immediately prior to exposure, the laser projection imaging equipment offers a substantial advantage over contact printers. In one recent study conducted jointly with a printed circuit board fabricator (which did not include the X-Y scale compensation technology), the alignment of this machine was shown to provide a factor of 3 reduction in yield losses when compared with their existing equipment.

2.5. SCALING COMPENSATION

In discussing the needs for scale compensation with printed circuit board fabricators, we have determined that rigid board dimensions can vary by up to 2000 ppm (0.002). This error translates into a variation in distance of up to 1.2 mm for a 460 x 610 mm board! Flexible printed circuits can often exhibit even greater dimensional variation. As discussed in the introduction, compensation for this board variation using scaled masks is costly and time-consuming. As a stopgap, some companies have used a binned scaling approach (e.g. plot masks in increments of a nominal scale factor, such as 200 ppm) in an attempt to limit the number of masks used and limit costs. In this example, in the worst case, a panel could be imaged and have a scale factor that is off from nominal by 100 ppm. This translates to approximately 60 microns over a full-size board. As alignment requirements become tighter, however, the number and cost of masks required for the binned scaling approach only increases. It is clear that a longer-term solution is needed.

In recognition of this need for scale compensation, we have developed an X-Y scaling compensation technology and integrated it with the laser projection imaging system. In this configuration, the board dimensional variations are measured automatically when it is loaded into the machine. These variations are determined according to the separations of fiducial marks on the board, which are then compared to fiducials on the mask. The system then compensates for these variations by varying the magnification of the scanning projection system.

We first tested this scale compensation system by making exposures and comparing the input scale to the actual scale after exposure. We designed a special mask having fiducials set up in a repeating pattern that is distributed over the entire area, as shown in Figure 5. We measured the fiducial separations on the mask using an in-house optical coordinate measurement system. The accuracy of this measurement system is ± 1 μm. We then used this mask to make exposures on a 5 inch silicon wafer. The silicon wafer was used instead of FR4 because of its low thermal expansion coefficient (2 ppm/°C). The results from this test are shown in Figures 6 and 7. Figure 6 shows the measured versus programmed symmetric scale compensation over the range of -1000 ppm to +500 ppm. Figure 7 shows the residual difference between the programmed scale compensation and the actual scale of the exposure. We note that a 20 ppm error corresponds to 2 micron of shift over 100 mm.

The next step in our experiments is to vary the X and Y magnification independently. At the time of writing, the results from the anamorphic scale compensation were still being compiled.

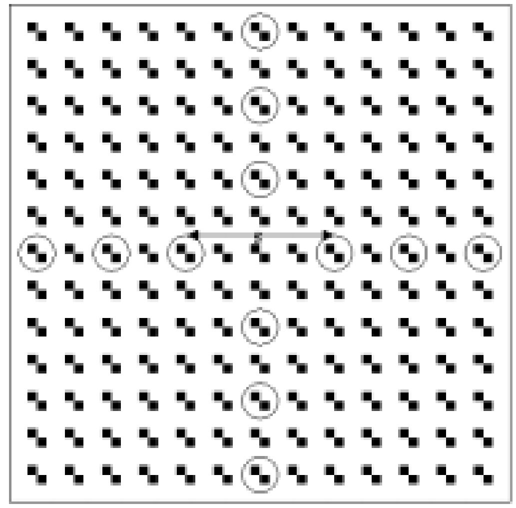

Fig. 5. Schematic of mask used in scaling compensation system testing. A repeating pattern of fiducials was distributed over the entire mask. The circled fiducials represent some of the sample measurement locations.

3. SUMMARY

As imaging requirements continue to move towards finer resolution, accurate layer-to-layer alignment becomes an increasingly important factor that influences product yield. Laser projection imaging equipment has been developed to provide high-resolution exposure capabilities with fine alignment at high throughput. These systems also deliver such fine resolution with a large depth of focus.

One of the major contributors to yield loss in fine-line products is the dimensional instability of the substrate. An X-Y scaling technology for laser projection imaging system has been demonstrated to compensate for this dimensional variation. This technology will significantly enhance product yields and is becoming essential as design rules are tightened.

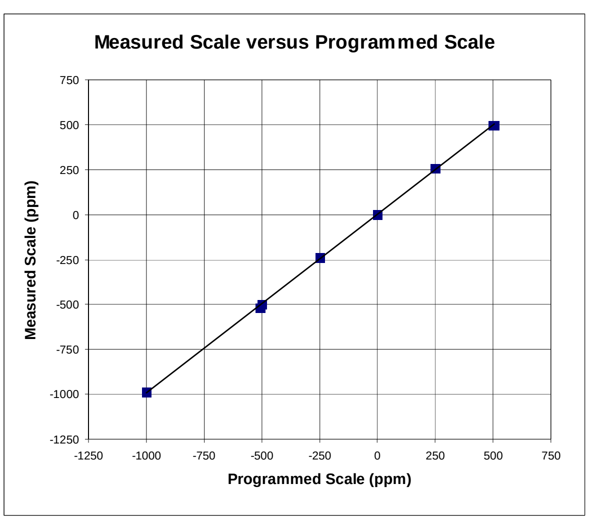

Fig. 6. Graph of scaling compensation results showing correspondence between programmed scale change and actual scale of exposures.

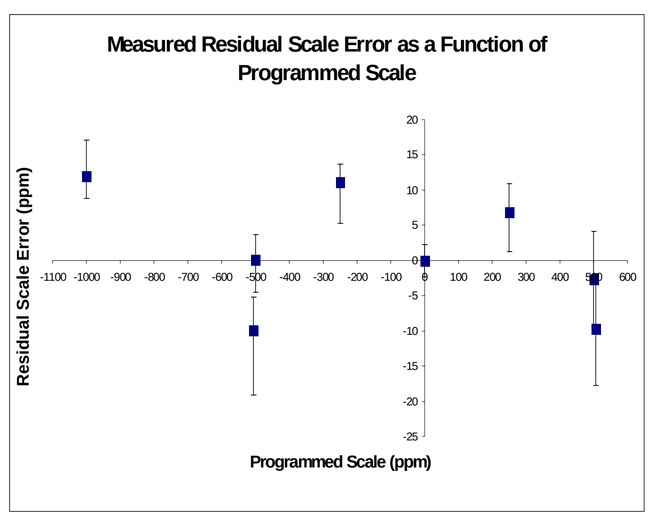

Fig. 7. Graph of scaling compensation results showing residual errors between programmed scale change and actual scale of exposures.

4. REFERENCES

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