I. Introduction

Only until recently, Laser Direct Imaging (LDI) technology has received conceivable recognition within the printed circuits board industry. Especially in those fabrication sites involving production of small lot, pilot run, quick turn-around, as well as high density and high layer count multi-layer products. A rough estimate indicates the number of LDI systems installed worldwide is approaching 120 up to end of 2003.

In fact, LDI technology has been developed for quite a while, but in those days, the benefits of laser direct imaging process were not significant when compared to the conventional imaging process.

One of the reasons why LDI process was not gaining sufficient popularity is associated with its comparatively high running costs. Such costs consist of material costs on special Dry Film Resist (DFR), and LDI consumable parts such as laser light source. The sensitivity of DFR for LDI system is in general higher than that of the conventional DFR. Owing to the relatively small production volume, the price of LDI DFR is in general higher than the conventional one. On top of that, the laser sources employed on LDI systems (e.g. Ar+ laser, Solid State Laser and Laser Diode) inevitably incurred higher running cost as compared to the UV light source found on conventional exposure systems.

As technology advances into the areas of high density, high layer count multi-layer, sequential build-up PCBs, and as product lifecycle renews rapidly, production volume goes smaller and smaller, those costs related benefits of conventional imaging technology are losing their ground. With its unique features and its fine line imaging capability, LDI out-performs conventional imaging processes in both areas of quality performance and cost performance. Further discussions on the benefits of LDI will be given in the following passage.

II. Light Sources and DFR for Direct Imaging system

Listed below are various generations of light sources employed on LDI systems in chorological order:

1. Ar+ Laser   (Spectrum: Blue - F line)
2. Ar+ Laser   (Spectrum: UV - I line)
3. Solid State Laser   (Spectrum: UV - I line)
4. Laser Diode    (Spectrum: Violet - H line)

Items (1) and (2) belong to the group of Gas Laser, while items (3) and (4) are classified as Laser
Diode. Typical lifetime of Gas Laser ranges from 2,500 to 3,000 hours, whereas that of Laser Diode normally lies between 5,000 to 10,000 hours. One special feature that distinguishes Laser Diode from other laser sources is that it will only be energized (or switched on) by the time the LDI system starts to plot. On the contrary, Gas laser will be energized whenever LDI system power is ON. With such intrinsic difference in the mode of operation, there is no surprise that typical Laser Diode is having as much as 3 times the lifetime of Gas / Solid State laser.

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Ar+ laser Blue</th>
<th>Ar+ laser UV</th>
<th>Solid State laser</th>
<th>Laser Diode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime hours</td>
<td>2,500 to 3,000</td>
<td>2,500 to 3,000</td>
<td>5,000 to 10,000</td>
<td>15,000 to 30,000</td>
</tr>
</tbody>
</table>

Table 1: Lifetime of Lasers

DFR nowadays available for LDI application can be classified into two categories: one operates at F line in the visible blue light spectrum; whereas the other operates at I & H lines in the UV spectrum. In general, LDI DFR is having higher exposure sensitivity than conventional DFR. Typical sensitivity of LDI DFR lies around 10mj/cm², but some LDI DFR may go lower than 10mj/cm².

Up till now, several major conventional DFR manufacturers have been supplying LDI DFR to meet the high sensitivity requirements. When selecting a LDI DFR to cope with specific product requirements, one should determine the appropriate resist thickness, the applicable line width & spacing, as well as the compatibility of developing, plating, etching and stripping processes.

III. Features of LDI system

Process Innovation by LDI system:

1) Flexible Manufacturing Process that gives rise to Delivery Lead-time Reduction

LDI system constitutes “on-demand process” by eliminating the necessity of a physical image transfer media - the photo-tool. The processes of photo-tool generation (including film plotting, developing, fixing, rinsing and stabilization) in the conventional manufacturing process now become things of the past.
Set-up time for exposure will be reduced significantly by simply sending plot data to the LDI system. Flexible Manufacturing Management system is thus constituted as a result of shortened delivery lead-time plus the elimination of photo-tool inspection, touch-up, storage and maintenance.

2) Yield Improvement

Those defects inevitably associated with conventional exposure process, resulting from contact printing and image transfer with photo-tool, are now eliminated by this photo-tool-less LDI process. Repeatable defects caused by scratches and foreign materials on the artwork no longer come into play.

On top of the above defects, another type of defects commonly found in conventional process are caused by layer-to-layer mis-registration. One typical example is the annular ring break-out on outer-layer circuitry. All these defects will contribute to potential failure on finished PCB.

Silver Halide Film is widely used as the photo-tool in conventional image transfer process. Due to temperature & humidity variations in the ambient environment, the photo-tool is actually undergoing continuous dimensional changes, which involve non-linear and irreversible materials shrinkage or expansion. Such dimensional changes are complex and are difficult to predict. The inevitable dimensional changes are tackled in conventional process by employing numerous trial-and-error tests before compromised, or so called “acceptable”, compensational scaling factors are derived.

On the contrary, the overall registration and alignment, no matter they are between drilled holes and pads or among different layers, will be improved significantly by the unique real time scaling & compensation function available on LDI system. Actual and real-time compensation is achieved directly on the production panel, no more uncertainties or compromise.
3) Cost reduction

With LDI, the tooling costs involving materials, labor, maintenance and storage of photo-tool will be permanently removed from the book of account. The LDI process itself can easily be integrating into the Automatic Material Handling System with minimum setup time. Besides, integration into the Automatic Process Control System is just another step away. All these benefits will certainly give rise to further reductions in operation costs.
It has already been mentioned that the cost of LDI DFR is in general higher than conventional DFR. However when total cost concept is applied to calculate the total operation costs, then the total costs are found to be dependent on the complexity of the products as well as the production volume. Summing up, with simple calculation, there is no surprise to arrive at the conclusion that LDI process is actually more economical than conventional process when we move towards areas of high density, high layer count multi-layer, sequential build-up, and when production volume diminishes as product lifecycle renews rapidly.

4) Fine Line Imaging

Pentax developed her first photo plotter in 1973, and the first Pentax laser photo plotter was introduced into the market in 1986. Accumulating over 30 years of research & development efforts and experiences, Pentax now introduces the latest fine line LDI system, DI-2080. This LDI system is capable of imaging line width and spacing down to 15 µm.

![Picture 1: 15 microns Line Width and Spacing](image)

Typical LDI systems have seen limitations on laser beam spot size, thus they are incapable of achieving high resolution. The minimum line width and spacing supported by conventional laser scanning technology is around 40 to 50 microns, whereas Pentax has already achieved a figure of 15 micron on her new imaging system.
Examples on the benefits and possibilities opened up by applying LDI system are listed below:

a) Yield Improvement
   • precise pattern registration and dimensional compensation
   • eliminate defects on associated with photo-tool
b) Delivery Lead-time Reduction
   • zero setup time by plotting directly from data
quick response to engineering design changes by data modification only

c) Fine Line & High Density
- overcome dust & particles problems during physical image transfer processes that contributes to small defects
- higher resolution and higher imaging quality achievable

IV. Future Development of LDI

1) Exposure Energy

Meanwhile, the exposure energy generated by LDI system is in general lower than that from conventional exposure machine. That is the reason why another type of higher sensitivity dry film resist (DFR) is required for LDI system. Such exposure energy property makes DFR system for LDI not as popular as the conventional DFR currently in mass production. Besides, subsequent PCB manufacturing processes, e.g. etching, plating & stripping, may inevitably need certain process parameters adjustment to adapt to DFR for LDI.

LDI systems require higher energy light source before they are fully compatible with the conventional DFR. One of the solutions for the demand on higher energy, may be accomplished by the continuous research and development on Laser Diode technology. Currently, Laser Diode is one of the key components in the escalating electronics market. With plenty of R&D efforts now undergoing, we are quite optimistic to foresee higher energy Laser Diodes coming up soon.

2) Throughput

Not only LDI system, but also all manufacturing systems share the common goal in maximizing throughput. On LDI system, speed and accuracy seems to be contradictory to each other. With the current technology advancement in high precision motion systems, accuracy has already been achieved at a substantial level. Our new imaging technology employs a flexible configuration capable of improving throughput while maintaining accuracy at the same time.
Figure 6 Flexible DI modules

- The suitable DI models can be designed with different number of Optical Engines for each Applications, Imaging Area and Throughput.

Nevertheless, throughput on LDI system depends on the co-relation between LDI exposure energy and DFR sensitivity. Increase in either exposure energy or sensitivity, or both, will improve the throughput of LDI eventually. Other remaining issues on throughput will go to the speed and accuracy of alignment, as well as the efficiency of material handling inside the LDI system.

3) Solder Resist
Direct Imaging has already been employed in Solder Resist application, and Solder Resist specifically for LDI system with I line spectrum is being supplied in the current market. Also, the Solder Resist for H line spectrum is available in the market shortly. As LDI establishes its foundation on Solder Resist application, there are still possibilities to improve upon the existing throughput, and to strike for price reduction on special Solder Resist as this process becomes more popular.

Entering the 21st century, as product life cycle shortens, with production volume keeps on decreasing, we have seen changes in the manufacturing technology that favor LDI. As LDI technology continues to advance with this ever-changing market, Pentax holds the belief that LDI will become a critical innovation in PCB manufacturing technology that contributes to the high technology industries.

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