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Laser Direct Imaging A Solution for Fine Line Imaging

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Abstract
The electronics market demands for smaller, faster, more reliable and less costly products continues to fuel major changes in printed wiring board designs. Higher layer counts, increasing circuit densities and HDI technologies have forced the PWB manufacturing industry to find new and unique methods of producing the sub 3mil lines and spaces required to meet today's design challenges. Until recently, Laser Direct Imaging (LDI) had been a viable, but cost prohibitive method of creating ultra-fine line circuitry patterns. Today, new advancements in LDI equipment, laser technology as well as the introduction of specialized photoresists have allowed LDI to emerge as a production viable process. Continuing to derail the cost drivers associated with laser direct imaging will further enable LDI processing to play a leading role in PWB manufacturing today and into the future.

Laser direct imaging for printed wiring board (PWB) applications emerged in the mid 1980's. The LDI systems offered at that time suffered from a variety of limitations, which precluded their general acceptance and use by PWB manufacturers. Chief among these were:

- Poor process cycle time - Early systems required 2-4 minutes to image one side of a PWB panel.
- Inadequate registration systems - Resulted in a lack of reliable image and side-to-side placement accuracy.
- High capital expenditure for equipment - Insufficient return on investment (ROI).
- Costly laser consumables with very short operating lives – High cost of operation.
- Absence of high sensitivity (laser definable) resist systems
- Lack of prevailing technological driver – PWB design demands could readily be imaged using conventional process techniques, and did not require laser imaging.

Since that time there have been a number of advancements in laser technology, as well as improvements in registration/accuracy systems and data handling. These have been coupled with the development of highly sensitive, laser definable photo-resists to, once again, bring laser defined imaging to the forefront of today's imaging technology.

However, one of the most important factors driving LDI technology for PWB image generation is the pace at which circuit densities are increasing. Today's PWB designs demand track width and spacing below three mils, with further reductions slated to continue to sub two mils in the very near future. Although conventional imaging techniques are able to produce these designs, the low yields associated with these methods make them cost prohibitive. New imaging methodologies must be used to deliver high-density designs at high yields. LDI has reemerged as a preferred such method.

There have been vast improvements in many aspects of laser defined imaging which have allowed its reemergence as a viable technology in today's PWB manufacturing industry. However, today's first generation LDI systems are conceptually identical to their mid-1980 counterparts, and as such, these equipment systems suffer from many of the same drawbacks associated with yesterday's LDI systems, such as long exposure time, low throughput capability and costly laser and laser consumables.

New developments, and unique equipment designs that are being incorporated into second generation LDI systems are driving the costs of both the equipment and the operation down to production usable levels. These features include:

- Automation
- Solid state laser
- Simultaneous double-sided exposure
- Laser usage efficiency
- Multi-beam optics

Automation
With fully automated panel handling and carrying systems, next generation LDI systems offer a large step in cost reduction and quality improvement by reducing or eliminating the potential for handling damage, loading orientation errors, and eliminating manpower costs. Additionally, automated systems allow for more streamlined processing, lending themselves to automatic loading from, and into other process centers. Automation also provides for a more clean imaging environment. Manual loading and unloading panels from the imaging area can bring in dust and other foreign particles, which may cause opens, as well as other repeat defects if interference with light transmittance occurs. By automating the load/unload operation, a "clean room" environment

can more easily be maintained within the imaging area, thereby reducing defects, improving yields and lowering costs.

Solid State Laser Technology

A variety of opportunities for cost savings exist within the design of the laser system itself. The gas lasers used in first generation LDI systems are more expensive to both purchase and use for a number of reasons. Gas lasers require a high degree of cooling which can be accomplished only through the use of external chilling systems. Although chiller costs vary with design and manufacturer, pricing for the systems required by LDI are typically in excess of $15,000. Solid state lasers require no external chilling systems, thereby eliminating the up-front cost as well as the maintenance required for system upkeep.

Power consumption is much greater with gas lasers than with their solid-state counterparts. Gas lasers require approximately 80kW per hour to operate, while solid-state lasers consume as little as 4kW. At typical electric costs for a plant running 24 hours/day and 6 days/week, this amounts to savings of well over $35,000 per year.

Most significant, however, is the cost and the life of the laser itself. Gas lasers are short lived, with typical life warranties ranging anywhere from 1,000 to 4,000 hours. Replacement costs for the consumable portion of gas lasers are typically $50,000 to $60,000. Solid-state lasers currently carry a minimum of 5,000 hours life guarantee, with replacement costs of the consumables ranging from $30,000 to $40,000. (See Table 1.) Additionally, solid-state laser manufacturers have projected that life warranties will extend to 10,000 hours in the next 2 years. Figure 1 shows the cost of laser use per hour as a function of the consumable replacement costs and warranties offered by the manufacturer.

Table 1 - Solid State Laser Technology

	Life Warranty	Replacement Cost	Operating Cost ($/hr)
Gas Laser	**3,000 hours**	**$55,000**	**$18/hr**
Solid State Laser	**5,000 hours**	**$35,000**	**$7/hr**

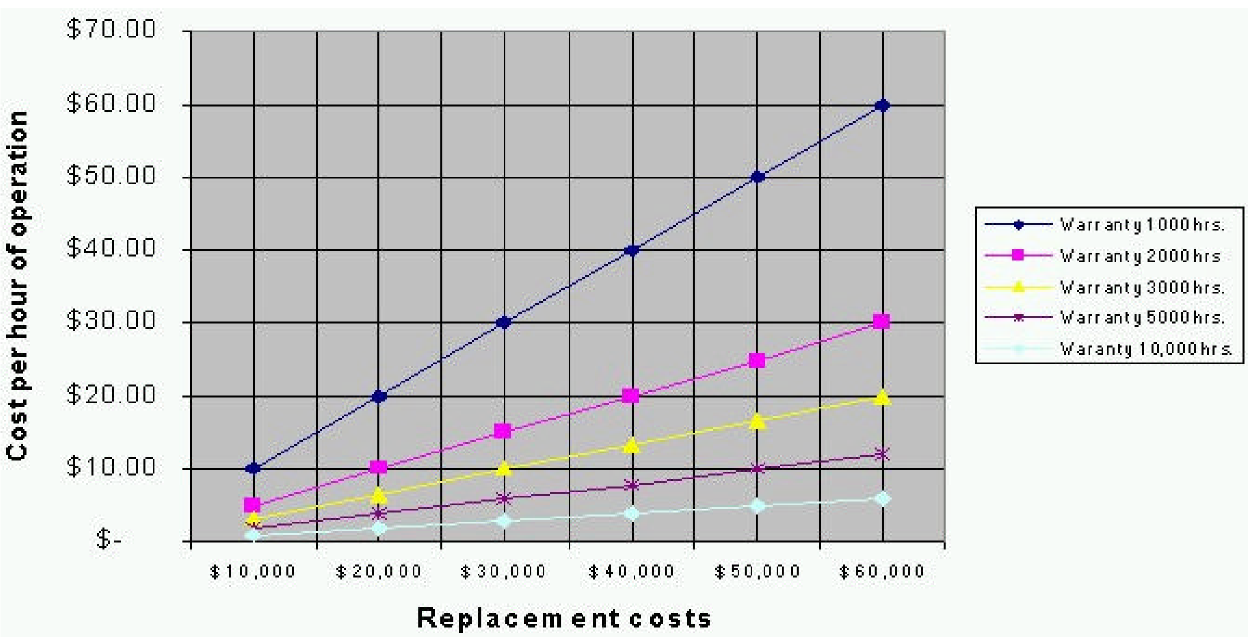

Figure 1 – Replacement Costs

As can be seen from the chart, the longer life and lower replacement costs of solid-state laser can readily translate into significant operational cost savings. The table below outlines the average life warranty and replacement cost for both gas and solid state lasers, and provides hourly operating costs for each.

A facility operating 24 hours per day, 7 days per week would realize a savings of over $100,000/year using solid-state laser technology.

Simultaneous Double-Sided Exposure

Registration, and in particular side-to-side placement of the PWB image, is crucial to yields. As feature sizes become smaller, and circuit densities increase, the registration error budget diminishes significantly. Systems that image the panel one side at a time require two separate registration processes (one for each side). Although current LDI systems use optical registration techniques, any mechanical errors in the pinning system, or any non-linear registration tooling may be doubled when the panel is "flipped" to image the second side. These registration errors are eliminated by simultaneously exposing both sides of the panel as any small errors in the registration system are the same for each side, and side-to-side registration is maintained.

Additionally, how double-sided imaging is accomplished can play a significant role in cost savings for second-generation LDI systems. Most LDI systems utilize a rotating polygon which reflects the laser light, and which subsequently sends a scanning beam to the PWB/resist surface. Because the light must reflect off of the flat face of the polygon to be usable, there are areas on the polygon, which are "dead" areas. This is where the laser light approaches and passes over a corner of the rotating polygon. During the time that the laser light is being reflected off of a polygon rotating past a facet corner, reflection is obstructed and imaging cannot occur. This amounts to as much as 50 % of the rotational time of the polygon. This means that the effective usage life of the laser is cut in half, since 50% of the time that the laser is on it cannot be used for imaging. However, by deflecting the laser light to a second polygon on the opposite side of the PWB during the first side's "dead" time, laser efficiency can effectively be doubled. Through **"laser time sharing"** each side of the panel is imaged with full laser power, and with a laser usage efficiency of well over 90%. A second look at Figure 1 can now be made with the understanding that single-sided imaging systems offer half the usage laser life as that given by the warranty, as they are used at 50% efficiency, hence the operating costs double.

Throughput Capability

In order for LDI to replace conventional imaging methods in a production environment, throughput capacity needs must be met. Typical first generation LDI systems are capable of imaging 40-60 panels/hour (both sides). This equates to less than 7,500 panels/week.

Next generation LDI systems which incorporate automation, simultaneous double-sided exposure, laser usage efficiency and multi-beam optics have proven to be able to deliver a much higher throughput capability, in excess of 100 panels/hour, or over 14,000 panels/week. Future systems will target even higher throughput capability.

Summary

Today's PWB design challenges continue to force fabricators to find new and improved methods for building printed wiring boards, while meeting cost reduction and quality improvement goals. Laser direct imaging offers a production viable method for meeting some of these challenges. Further improvements in LDI equipment design, coupled with an understanding of how to reduce the cost drivers associated with the imaging process will continue to fuel LDI's acceptance as a full production capable process.