Laser Ablation in the Interconnect Industry

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Abstract
The last 10 years have seen the rise of lasers used in the interconnect industry to a point where their use is almost becoming 'main stream'. As line width and spacing requirements become smaller, lasers will play an ever increasing role in the manufacture of interconnect devices. There is currently a gap between lithography processes on the small side and 'traditional' etch/mechanical methods on the large side which lasers fill quite nicely. Within these bounds, lasers are poised to be the dominant manufacturing technology for many processes.

Introduction
There are currently thousands of lasers used in the interconnect industry throughout the world. CO_2 lasers, which are fast and relatively inexpensive, represent the majority. There are also a large number of frequency tripled Nd:YAG lasers being used to etch copper and to drill vias too small for the CO_2 laser. Fundamental frequency lasers are used for stencil making and frequency doubled lasers are sometimes also used for via drilling. Finally, excimer lasers are used for work requiring the finest resolution and the most critical dimensional tolerances. This presentation will review the current state of laser technology and also discuss upcoming and future applications.

Lasers Used Currently in the Industry
As stated, the CO_2 laser is used primarily to remove dielectric material. Since Cu is very reflective at the 10 micron wavelength of CO_2 laser output, it is not generally used on Cu. There is a method, pioneered by Hitachi, whereby holes can be put in Cu, but the Cu must first be pre-treated with an absorbing film in order to induce absorption and thereby thermally remove the underlying Cu. This method is only useful however on very thin Cu, less 18 than microns at least and in most cases even less than this. In no case is the rapid drilling of vias possible at via diameters less than 75 microns, and usually the number is 100 microns or more. Also, the primary interaction of the CO_2 laser wavelength with materials is via a thermal interaction, so there may be charring or burning seen with some dielectrics. This can be minimized in two fashions. First, broadband CO_2 lasers emit all vibration-rotation lines around 10 microns. It turns out though that most dielectrics absorb better around 9.5 microns, and the rest of the broadband output only contributes heat to the process. This effect can be minimized using a properly designed laser with only a very narrow band output around 9.5 microns. This significantly increases the absorption of available photons and thereby increases processing cleanliness and efficiency. The second way to control processing efficiency is to optimize the duty cycle, or more specifically shorten the pulse length. Shorter pulse lengths with a given laser power output result in higher peak powers. High peak power is extremely helpful in achieving clean processing results. New short pulse, q-switched lasers look like an interesting option for future devices.

Some of the drawbacks of using the CO_2 laser other than the minimum via diameter and the inability to process Cu directly are the residual or residue and the problems with processing glass filled material. Glass filled material, which still accounts for a majority of the dielectric used in the industry, is problematic for any laser, but especially for the CO_2 laser, because of the difference in fluence or energy density on target required to ablate the two materials. Glass is relatively transparent to the 10 micron wavelength and requires a high fluence to ablate it. Most dielectrics only require fluences much lower than the glass. These factors combine to sometimes cause problems with leaving glass ends in the vias, or with barrel effects or undercutting. Since the wavelength is 10 microns and Cu is very reflective, it is basically impossible to remove the last minute layer of dielectric material from the bottom pads, making a post laser processing step a requirement. This is usually accomplished with a vigorous chemical wash or a light plasma etch. In the case of drilling thin Cu with a conformal coating applied, a post laser step is necessary to remove the coating and condition the holes.

Nd:YAG lasers come in many different wavelengths starting at the fundamental, around 1 micron output. This laser has fairly high power output and couples well with metals. Fundamental frequency lasers are used extensively for stencil making, as shown in Figure 1:

The 1 micron wavelength does not couple well with dielectrics though, so this wavelength is not used for microvia drilling. For microvia drilling, the frequency tripled YAG laser with an output at 355 nm wavelength is normally used (although some work has been done at the 532 nm doubled wavelength). This laser has a very high pulse repetition rate and is usually used in conjunction with a galvanometer scanning field. Because of the short wavelength, very small spot sizes can be achieved on target even with large scan fields. Laser tools using tripled YAG lasers generally have a minimum spot size of 25 microns or less. The UV output couples well with metals, like Cu, and most dielectrics. There are two drawbacks of using the 355 nm laser. The first is that it requires more care to control the end point and not go through the catch pad as the UV light will etch the underlying copper at high enough laser fluence. The other drawback is that the etching process is slow compared to the CO_2 laser, especially on the dielectric. It is for this reason that dual laser systems are currently being used to a large extent, where a CO_2 laser is used for the dielectric while the 355 nm laser is used for the copper. In this way, fairly fast processing speeds can be achieved. Also, in principle the 355 nm laser should be capable of leaving a clean enough copper surface for subsequent plating without use of aggressive cleaning post lasering. Frequency quadrupled lasers (266 nm wavelength) are capable of the cleanest processing and the smallest feature sizes, but are more expensive to operate than 355 nm lasers and are currently generally used only in specialty applications, perhaps with some exotic materials that do not show good absorption at 355 nm. Figure 2 shows examples of polyimide cut with (a) the 355 nm laser and (b) the 266 nm laser (c) the 9 micron CO_2 laser. The processing times for this device were 400 ms, 18 seconds and 12 seconds respectively.

Unlike the lasers discussed so far, the excimer laser is not a single mode laser where the beam can be focused to a very narrow waist. The excimer laser is very highly multi-mode, and the beam is large and has a reasonably homogeneous energy distribution. Therefore, it is not used in a focused configuration, but in an imaging mode where a mask is imaged onto a target. As such, the obtainable resolution is on the order of microns for micromachining purposes (sub micron for lithography applications). Excimer lasers are used where the smallest spot size is needed or where the cleanest processing is required. Figure 3 shows a circuit excised using the excimer laser. Excimer lasers are generally not used where cost considerations outweigh technical considerations, but there are some very clever imaging techniques that make the excimer sometimes cost competitive with other technologies. One in particular is the writing of fine line circuits using a large field mask imaging technique. The majority of work is done at 248 nm wavelength, but shorter wavelength 193 nm and 157 nm lasers are available for more challenging applications.

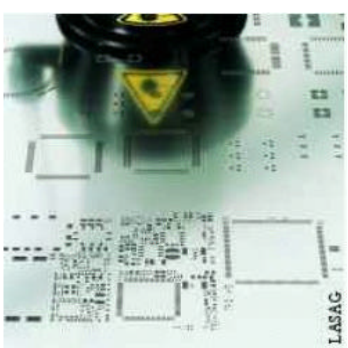

Figure 1 - Stencil Making

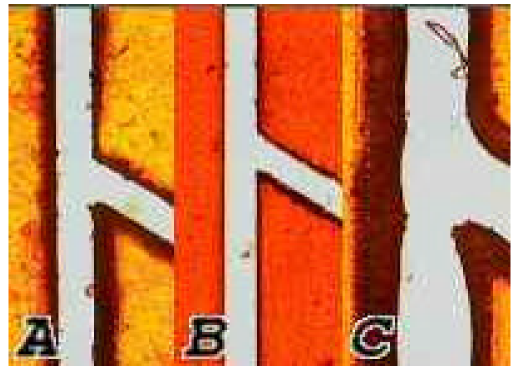

Figure 2 - Polyimide Cuts

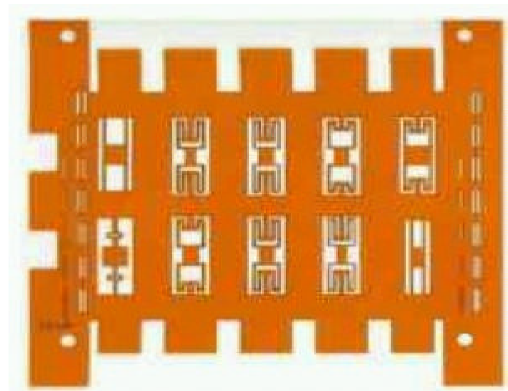

Figure 3 - Excimer Machining

Current Applications

By far the most visible application is the drilling of microvias for interconnects. Thousands of lasers, primarily in Asia and to some extent in Europe, are used. The majority are CO_2. Generally, lasers start to become cost effective as via sizes are less than 10 mils diameter (250 microns). Most of the microvias in high volume production are in the 5 to 10 mil diameter range, but a good volume of work is currently being done down to about 3 mils diameter. We have seen vias down to 0.5 mil diameter in very low volume, low yield types of devices, but commercial work in this range is a few years away. Nevertheless, the industry is certainly moving in this direction and as the required via sizes become smaller, lasers will play an ever increasing role in interconnect production.

Stencil screen cutting is done on thin SS sheets using a fixed beam or flying head delivery system and a very robust stage designed to handle the acceleration changes of a large format table when making complicated patterns requiring a large number of openings. This technology will continue to be used for the near term, but new laser cut polymer stencils (Figure 4) will eventually probably replace the SS films as feature sizes decrease.

The flexible circuit industry, in the US at least, seems to be in better shape than the rigid board industry and lasers are used for several applications on flex. The first is microvia drilling as described above. The second is routing circuits. Lasers can be used to excise the entire circuit or portions thereof. Lasers can also be used for single sided and double sided exposure of trace fingers or pads. Figure 5 shows a split screen with dielectric material coating the pads on the left and with the pads exposed on the right. Notice the lack of damage around the exposed pads.

Again, because of the thin nature of the material involved and the small sizes of features required, I foresee a large increase in the use of lasers in the flex industry worldwide, but near term in the US.

To me, one of the most interesting uses of lasers is one for which they were not originally intended. This is for the repair of circuit boards or flex. The most common problem is solder mask being put in the wrong places. We have saved thousands and thousands of boards that would otherwise have been scrapped because lasers can easily remove this unwanted mask cost effectively. Figure 6 shows rings of solder mask precisely removed with the CO_2 laser.

Sometimes, customers even design this ‘flaw’ into their product where masking techniques may not be effective. Usually though, somebody just makes a mistake which is then laser repaired. While the majority of repair applications involve removal of dielectric, some require the precise removal of Cu shorts. This can be accomplished using a UV laser source.

Possibly the most exciting new area of application is in the precise trimming of embedded passive devices to within a very narrow band of values. This application seems to be getting most of the current ‘buzz’ and several companies are racing to take market share.

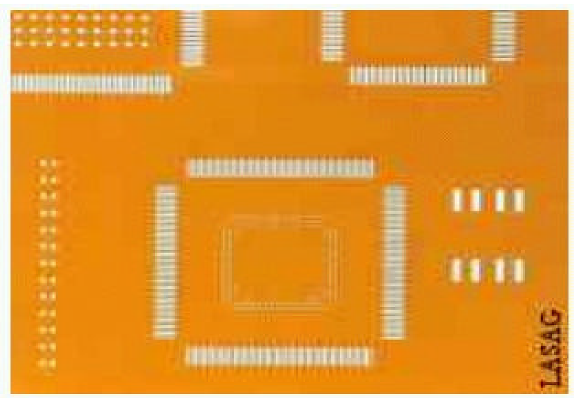

Figure 4 - Polymer Stencils

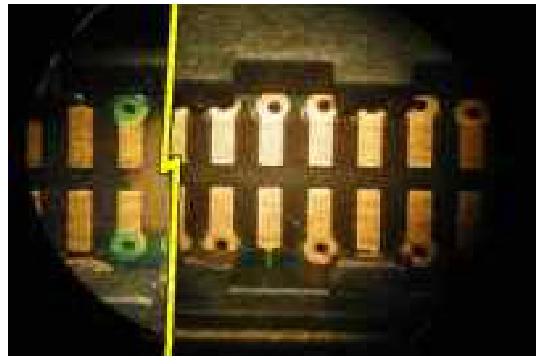

Figure 5 – Flex Conductor Exposure

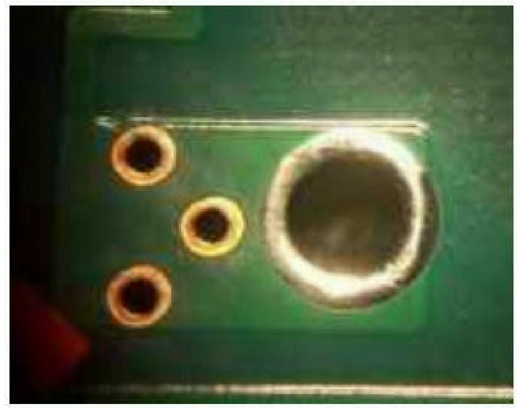

Figure 6 - PCB Repair

Figure 7 - Glass Drilling

New Lasers and Applications

I have already mentioned the q-switched CO_2 laser and the 266 nm solid-state laser above. One other area or potential application of the 266 nm laser is in glass processing. Superior results can be obtained in materials like glass over the 355 nm laser because the absorption of the material is much better. In addition, several companies are working on very short pulse lasers with temporal outputs less than one micron, and in some cases in the femtosecond regime. This short pulse output give extremely clean processing results even on difficult to work with material like glass. Figure 7 shows glass drilled with a nanosecond pulse length laser (b) and a femtosecond pulse length laser (a).

When pulses are in the fs regime, they are pretty much wavelength independent also. Unfortunately, these lasers are not yet mainstream as they are too slow and costly. I expect significant advances in the next few years though and it is possible that very short pulse lasers may find a niche in some areas of interconnect manufacturing. Finally, new diode laser sources will find increasing uses on interconnect boards, especially as the industry matures more toward *optical* interconnects and away from *electrical* interconnects.

Conclusion

There is no doubt that lasers will become even more embedded in the manufacturing process of interconnect devices as the devices require smaller features and as the industry moves toward optical interconnects and embedded components. New laser sources will be developed over the next several years, which will open up even newer application areas. Also, new engineering advances will make current lasers more usable, faster and cheaper to operate. The next few years will be an exciting time for the laser industry and also for those in the interconnect industry who embrace this enabling technology.