

Added value laser micromachining

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One of the main concerns of everyone involved in the commercial application of lasers is how they can add value to a process, and how companies can use lasers to remain competitive in a commercial landscape that is seeing more outsourcing to low cost manufacturing bases. Traditionally lasers have been used extensively in heavy manufacturing and there are a number of well established applications in this sector. As laser sources have developed there has been a growth in the application of lasers to microtechnology, however the 'killer application' has not yet materialised. That said Excimer, Fibre and diode pumped solid state (DPSS) lasers have started to be used in the semiconductor and medical device industries, two sectors whose continued convergence may well open up new markets for laser micromachining technology. Here we show how and why lasers are used in the semiconductor industry and lessons that can be learned from that industry to allow laser developers and contract manufacturers to offer value added processes.

Semiconductor Applications

The semiconductor industry is preoccupied with ensuring the success of Moore's Law, which states that the number of transistors on a silicon chip will double every 18 months. Up until the present day this prediction has held, not through any inviolable law but through the advances in processing technology that allows an ever greater density of circuitry to be built onto the surface of a silicon chip. At its most basic semiconductor manufacturing is concerned with the adding and removing layers to create 3-D electronic structures. Since Moore made his prediction in 1968 the materials necessary to keep it on track have become more exotic, leading to more complex and expensive deposition and etching equipment, but the basic processing principles have not changed.

Semiconductor devices consist of a silicon substrate, or wafer, on top of which are built multiple layers of electronic circuitry. In order that the electronics in one layer can communicate with the electronics above or below it, interconnects are created between the layers. These interconnects are formed by chemically etching a hole and filling it with a conductive material. The holes, known as vias, can be formed at the submicron range using advanced photolithography techniques, however irrespective of the size it is a case

of adding and removing material. Given that the layers are extremely thin, semiconductor device engineers have to be able to control the depth of an etch to a high precision. They have two methods to do this:

- Controlled depth etching – The etch rates for different chemical and material combinations are either well known or easily determined. This means that it is possible to accurately control the depth of a via by simply controlling the etch time.
- Stop on layer etching – chemical etches are generally material specific, and it is possible to choose a chemical that will etch through one layer but will not etch through a lower layer. The most common of these is to use a dielectric layer such as SiO₂ as an etch stop for the plasma etching of silicon by SF₆/O₂ in the BOSCH process.

These are very powerful tools and allow semiconductor engineers to create devices composing a wide variety of materials such as metals, polymers, semiconductors and dielectrics. These are techniques which could have a direct comparison in the laser micromachining field, and are processes that would certainly allow a laser contract manufacturer to add significant value to their product offering.

Controlled Depth

Of the two etch methods used by semiconductor engineers, controlled depth etching is the easiest to realise in a laser production environment, and has already found an application in the semiconductor field. Samsung recently announced its use of laser micromachining to create through silicon vias (TSV).

In order to keep Moore's Law on track, semiconductor device designers need to find new ways of squeezing ever more transistors into a given area. One solution is to stack multiple wafers on top of each other, and use TSVs to form the interconnects between the wafers. To enable the wafers to be stacked their thickness needs to be reduced from the standard 725µm to less than 100µm. There are two possible ways to use lasers to create a TSV, in one solution a wafer can be thinned and a via can be drilled through the wafer as in Figure 1. Alternatively, a blind via can be formed in a full thickness wafer to a controlled depth and only become a TSV after the wafer is thinned.

Given the issues around handling thin wafers, it is likely that the latter solution is used by

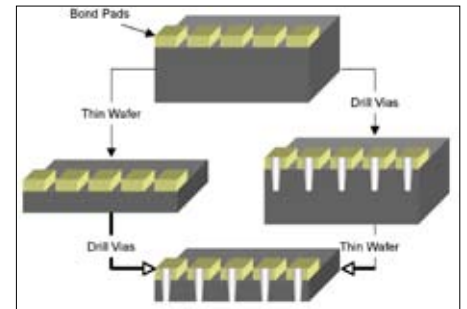


Figure 1. Different methods to produce thin wafers with laser drilled through vias. The vias can either be drilled before or after wafer thinning.

Samsung and if so this would involve controlling the depth of each via on the wafer to within ±5µm. Given that throughput would be a priority, high pulse energies would be necessary to attain a sufficient ablation rate. However as the ablation rate is a statistical average, a small number of pulses will have more variation than a large number of pulses, making it hard to control the via depth yet maintain a high throughput. The ability to manage this trade-off has allowed Samsung to reduce their device footprint by 15% and thickness by 30% making it ideal for today's smaller more slim line electronic gadgets. Additionally, as the connection goes through the wafer instead of around, it results in an approximately 30% increase in performance from reduced electrical resistance.

Stop on layer via formation

Because laser machining is relatively non-material specific, stop on layer via formation is a harder process to carry out. The normal method is to use a stopping material that has a higher ablation threshold than the material that is being removed. This technique has been applied not only to via formation but also is used in other processes such as polymer welding. However if the use of lasers is to be economical then it will need to have a high throughput, which can only be obtained by having a high power density and fluence. A high power density is likely to lead to a non-linear regime where ablation thresholds are less of an issue and the lower level will be ablated also.

Apart from the economical reasons preventing the wide use stop on layer processing, if the process is limited by what materials can be used for the upper and lower layers, then it will not find wide acceptance by designers. Certain methods have been developed that use pre-pulses to change the ablation thresh-

olds of lower layers; however, they are limited to a few specific material combinations and cannot be transferred across a wide platform.

The ability to offer a stop on layers, would definitely be a value added process that would be applicable to many applications, but it is unlikely that a solution will be found through development of the laser material interaction alone. Blueacre Technology is working with Rideo Systems to develop solutions based on the application of novel laser processing techniques and advanced control systems to allow a greater flexibility in stop on layer processing. In particular real time end point detection and dynamic autofocusing systems are being developed to enhance machining accuracy and repeatability.

Material combinations include: metal on polymer; metal on glass; glass on polymer; and polymer on polymer. The process is not only dependent on the material type but also on the thickness of the individual layers.

Wafer Dicing

Wafer thinning in itself is not a new idea and has been much discussed with reference to producing flexible devices such as smart-cards. However thin wafers present issues for mechanical dicing saws that are used to excise the dies from the wafers. The process involves placing a wafer on an adhesive polymer tape and dicing it with a diamond coated mechanical blade. After dicing the dies are picked from the polymer tape and placed into the final package. Mechanical dicing involves rotating the blade at up to 50,000 RPM and cutting through the wafer with a feed rate of up to 100mm/s. It is a well established technique that has proved very successful for standard wafer types. However, as wafers become more complex the ability to dice them with a high throughput, high yield and low cost becomes strained.

The trend toward thinner, and therefore more fragile wafers means that mechanical saws used for wafer dicing must slow down in order to prevent breakage and maintain yield at a satisfactory level. Here lasers offer a three fold advantage. Firstly, the dicing speed

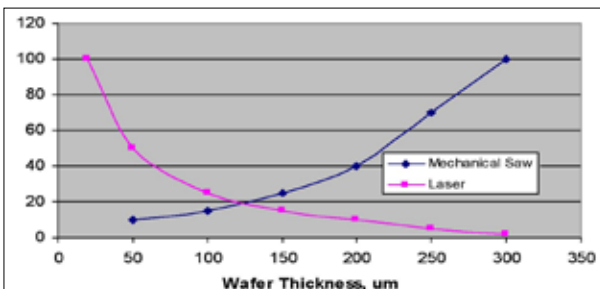


Figure 2. Comparison of wafer dicing speeds for a mechanical saw and galvanometer based laser dicing system..

	Saw	Laser
Installed Cost, \$	250,000	570,400
5 year Depreciated Cost, \$	50,000	152,080
Wafers/Month	43,572	43,572
Wafers/annum	522,864	522,864
Wafers/Hour/Saw	1.91	3.82
Operational Hours	24	24
Workdays	28	28
Wafer Yield	95.00%	98.00%
Machines	34	17
Good Wafers/month	41,393	42,701
Good Wafers/annum	496,721	512,407
Line Capacity Wafers/annum	523,676	523,676
Line Capacity	94.85%	97.85%
Blade Cost \$/annum	522,864	0
Water Usage \$/annum	340,000	0
Line Cost \$	1,700,000	2,585,360
Cost per wafer \$	5.16	5.05
Product data (Yield calculator)		
Wafer cost US\$	1000	
number of die per wafer	2627	
die cost	0.35	
Total number of die per month	123,176,044	
Yield loss calculator		
Total good die per month	117,019,142	120,714,483
Total bad die per month	6,158,902	2,463,561
Cost of bad die per month, \$	2,178,600	871,440
Yield loss cost per annum, \$	26,143,200	10,457,200
Yield Savings using laser, \$		15,685,900

Figure 3. Cost comparison between a mechanical saw and a laser dicing system. Even a small increase in yield can lead to massive savings for a fabrication line over one year..

for lasers increases as the wafer gets thinner. This is illustrated in Figure 2, where it can be seen that at a wafer thickness of 100µm the laser has a similar dicing speed as a mechanical saw. For sub 100µm wafers the laser gives a higher dicing speed, which cannot be attained by other processes. Second, as a laser is a non-contact process it puts no mechanical stress on the wafer during dicing, so wafer thickness does not affect yield; chipping on the backside of the die, one of the leading failure modes for die breakage after packaging, does not occur during the laser process. Finally, a mechanical saw blade needs to be replaced approximately every thousand meters of dicing. This is a relatively short lifetime when one considers that a 300mm diameter wafer can have up to 36m of dice lanes and a blade must be replaced every 30 wafers. Along with other issues such as high water usage, this leads to a high cost of ownership for a standard mechanical saw process when compared to a laser system. A comparison of the costs associated with mechanical and laser dicing are shown in Figure 3. As the demand for thin wafers for applications such as smart cards increases,

so will the usage of laser dicing as an alternative to existing technology.

Benefits of lasers for micromachining

Laser micromachining has both well known and well established advantages over traditional material removal technologies. Lasers provide the ability to remove materials in a non-contact and sterile environment;

and the ability to create feature sizes down to 5µm makes lasers applicable to all but the most demanding applications. Lasers are non-material specific, in that a 355nm DPSS laser that is used to machine silicon can just as easily remove polymers, metals and dielectrics. This is especially the case in applications such as via production in semiconductor devices, where a laser is used to drill through multiple stacks of thin layers. For more demanding applications both picosecond and femtosecond lasers offer the ability to tap into non-linear absorption modes, allowing a single wavelength to machine any material without excessive damage.

An area where laser micromachining has made a large impact is in the manufacture of minimally invasive medical devices such as hypotubes and cardiovascular stents. Medical device engineers were quick to develop the possibility of designing devices that make use of the capability that only lasers can offer. At the same time, engineers involved in medical diagnostics have utilised the ability of laser to form channels and modify surface characteristics to create intricate microfluidic devices that can be used in a host of analysis operations.

It is in this area of diagnostics that has seen the convergence of medical device manufacturers and semiconductor companies. The reasons for this are plentiful: firstly, medical devices, whether for diagnostics, drug delivery or monitoring, are becoming smarter. In order for a device to make decisions on when and how much drugs to deliver it must have electronic processing power, memory and even wireless connectivity, which is the expertise of semiconductor manufacturers. Secondly, semiconductor companies are device designers, who have a wealth of experience at developing products more sophisticated than any medical device. (It is worth noting that the main reason companies such as Intel have a large manufacturing presence is that they cannot guarantee the production quality if they outsource their manufacturing base.) Finally in terms of running a business, companies involved in life sciences and medical devices have seen a continuous growth in revenues over the last decade, whereas semiconductor companies have seen a number of boom and bust cycles. For CEOs who are judged solely on growth, the medical device industry is an attractive sector to be in.

With the advantages of design expertise and economies of scale it is not surprising that semiconductor companies have the edge when it comes to when developing new smart medical devices. Companies such as STMicroelectronics, Olivetti, HP, Motorola along with Intel, which has created a Digital Health Group represented at the board level,

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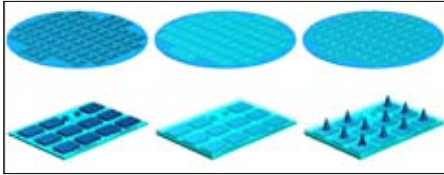


Figure 4. Fabricating integrated devices at the wafer and the device level.

are all involved in developing new markets at the interface of the medical and semiconductor sectors.

Given that lasers are already finding applications in the semiconductor and medical device industries, the convergence of the sectors may well open up new opportunities for laser micromachining.

As discussed above, the increase in complexity necessary to keep Moore's Law on track has necessitated the development of novel interconnect technology utilising cost effective laser ablation. This high level of multi-layer integration will also be necessary if microfluidic and optical diagnostic devices are to fulfil their potential, and become truly non invasive. At the present time microfluidic devices are mass produced by injection moulding, and multilayer devices are created by stacking individual layers on top of one other. This method is not suitable for the development of highly integrated devices and for this reason Blueacre Technology and other organisations have been developing approaches compatible with semiconductor device fabrication, to create devices at the wafer level, see Figure 4. These processes will create the need for new types of interconnects to transport optical, fluidic and electrical signals. Laser micromachining is well placed to offer designers the ability to machine a range of features, with high tolerances in a wide variety of biocompatible materials.

What can laser micromachining do to meet these challenges? It is important to realise that the laser source is only one of many components in a machine and has to operate in parallel with the vision system, the beam delivery unit and part handling. Some of the most important advances in the last five years have been the following:

CAD/CAM

At a simple level the ability to use a galvanometer to direct write a pattern based on a CAD file has opened up a host of new applications in the field on microelectronics and semiconductor processing. Initially used for prototyping and small production runs, it is now well established on the production floor. Advanced CAD/CAM techniques that allocate specific processing parameters within an individual CAD layer and control parallel motion

of the galvanometer and stages, are also being developed.

Trochoidal Cutting

When a laser cuts a line in a material the width of the line is determined by the diameter of the laser spot at focus. In order to cut lines, which are wider than the spot diameter, it is necessary to cut two parallel lines as shown in Figure 5. The process is not efficient in that the area bounded by the region where the laser lines overlap is machined twice. This not only increases the machining time but because the overlap area is machined twice, the channel will be deeper at the overlap. This problem can be eliminated by implementing trochoidal (combined linear and circular motion) laser beam scanning. This has allowed an improvement in not only throughput but also quality.

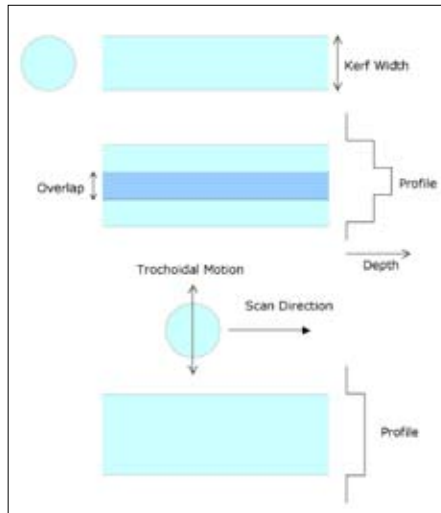


Figure 5. Trochoidal cutting using advanced galvanometer scanning has had a large effect on both cut quality and throughput.

Controllable Pulse Energy

The new range of DPSS lasers allow the laser energy and repetition rate to be directly controlled from pulse to pulse. By controlling the energy of the laser pulse, it is possible to increase or decrease the amount of material removed from any one location. In addition, as ablation only occurs if the pulse energy is greater than the material bond energy, by lowering the energy it is possible to prevent the laser from machining certain materials in a sample while machining other materials. This selective material removal is an important step forward in laser machining and is only possible by integrating a laser with pulse-to-pulse control, CAD/CAM facilities, and a high precision galvanometer system.

An example of the above selective technique is illustrated in Figure 6a where a fluidic device has two layers, one on top of the other separated by a spacer. The upper and lower channels are connected by two interconnect-

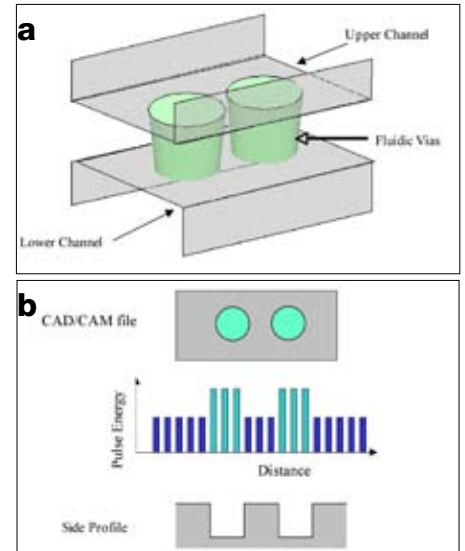


Figure 6. Fluidic vias: (a) fluidic device with two layers connected by laser drilled fluidic vias; (b) CAD/CAM file utilising pulse to pulse energy control to enable position specific machining parameters capable of drilling two fluidic vias.

ing vias, which can be used to enable fluid to flow between one layer and the other. Using CAD/CAM it is possible to create a direct writing file that maps a process to a specific location. In the example illustrated in Figure 6b there are two processes that have different pulse energy and pulse overlap. There is a low power step to remove the material to the standard depth and a higher energy step to remove the material to the lower depth.

Conclusion

There is no doubt that laser micromachining is beginning to create a number of niche markets, most notably in the medical device and semiconductor markets. However in order to make a larger impact it will be necessary to combine simple fixed beam laser micromachining with more advanced process control. As with any developing market it will not be enough to increase capability and wait for the orders to come in. It is going to be necessary to engage and educate the customer as to how advances in laser micromachining can enable them to develop new products and enter new markets.

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