Microelectronics Packaging — As features get smaller, the role for lasers gets larger

DIRK MÜLLER, MICROELECTRONICS AND SOLAR MARKET SEGMENT MANAGER, RALPH DELMDAHL, PRODUCT MARKETING MANAGER, AND STEPHEN LEE MANAGER, ASIA APPLICATIONS

**Figure 1: Schematic illustrating the major differences between ultrashort pulse ultrafast processing and processing with longer pulsewidth lasers.**

**Photothermal Interaction**
- Nanosecond Pulsewidth Laser Beam
- Recast Material
- Heat Affected Zone
- Microcracks
- Surface Debris

**Photoablation**
- Picosecond Pulsewidth Laser Beam
- Atomized Vapor
- Minimal Heat Affected Zone
- No Significant Microcracks or Surface Debris
The relentless consumer demand for microelectronics products that are more compact and energy efficient, and which deliver greater functionality, translates into a need for more complex circuit packaging techniques employing ever-smaller feature sizes. While traditional mechanical methods (e.g. cutting and drilling) are well established for a variety of electronic device packaging steps, the intrinsic limitations of traditional machining include increased costs as dimensions shrink. These limitations are motivating manufacturers to transition some production steps to laser-based processes. This article provides an overview of the types of processes for which lasers are best suited, and also gives some guidance on how to select the optimum laser technology for a specific application. Finally, some specific microelectronics packaging applications are examined.

Why lasers?
Laser-based processes are well suited for applications that require feature sizes in the 10 µm to 100 µm size range, as this is commensurate with the focused spot size of most visible and near infrared wavelength laser beams. Since this is also the feature size range being increasingly required in precision fabrication tasks across a wide range of industries, interest in laser micro machining is naturally on the rise.

One significant advantage of laser processing over mechanical means is that it is entirely non-contact. This enables the production of delicate, fine features in a variety of materials, including those that are difficult to process using other methods; a standout example of this is machining diamond tools, which lasers can accomplish with ease. Furthermore, laser processing doesn’t vary with material type in the same manner that mechanical methods do. For instance, composite materials can be drilled and cut with just one laser tool, even as compositions change.

The non-contact nature of laser processing also means that the ‘tool edge’ doesn’t wear out. Thus, laser processing remains consistent over time, and largely eliminates the downtime and costs associated with mechanical tool replacement.

Another important characteristic of laser processing is that it typically only removes small volumes of material. This can be a disadvantage when an application calls for large scale, bulk material removal, and...
processes of this sort are unlikely to transition to lasers any time soon. But, the ability to remove a very thin layer of material can also be an advantage. Specifically, it enables high precision work, allowing the depth and the extent of the laser created feature to be highly controlled and repeatable.

Additionally, the lack of inertia in the laser beam can lead to significantly higher throughput than achievable with mechanical tools. For example, scanners allow laser beams to jump from one part of the work piece to another in much less than 1 millisecond. Mechanical tools can rarely be moved at these rates.

Despite all these advantages, mechanical cutting and drilling continues to dominate many applications. This is because laser based production equipment can have significantly higher initial purchase cost. However, advances in laser power, reliability and cost per photon have shifted the cost equation. And, the balance can tip even further when the total cost of ownership (including maintenance downtime, consumables, scrap and rework) are fully considered.

Understanding laser processing

‘Laser micro machining’ is a broad term, covering a wide range of different laser source types which process materials using various mechanisms. This diversity can make the job of selecting the right type of laser for one particular task seem daunting. While tool developers can often rely on the advice and experience of reputable laser process experts to navigate this landscape, it’s good to have a basic understanding of laser characteristics, and the way in which they interact with materials. Two of the most important parameters to understand in this connection are laser wavelength and pulse length.

Wavelength is significant for two main reasons. First, the minimum focused spot size that can be achieved with a laser is directly proportional to its wavelength. Thus, it’s generally easier to produce smaller features (below 50 µm) with green (typically 532 nm) or ultraviolet (typically 355 nm or 266 nm) lasers than with longer wavelength near or mid-infrared lasers.

Second, shorter wavelengths are absorbed more strongly by the vast majority of materials. This means that shorter wavelengths don’t penetrate as far into the bulk material during processing. The results of this are an ability to more precisely control the depth of the removed material, and the creation of a much smaller heat affected zone (HAZ). Specifically, this is the area surrounding the laser produced feature in which some processing related changes (such as micro cracks) have been induced.

Most precision industrial micro structuring processes are based on pulsed lasers, because pulsed operation enables laser energy to be applied in a very controlled dosage. This again helps to minimise the HAZ. Depending on process needs, an industrial laser pulse can last from milliseconds down to picoseconds ($10^{-12}$). However, shorter and
longer pulse width lasers tend to process material by substantially different means.

Many traditional applications rely on infrared and visible Q-switched lasers, which have pulse widths in the tens of nanoseconds range, and which remove material via a photothermal interaction. Here, the focused laser beam acts as a spatially confined, intense heat source. Targeted material is heated up rapidly, eventually causing it to be vaporised (essentially boiled away).

The advantage of this approach is that it enables rapid removal of relatively large amounts of target material (particularly considering the multi-kHz repetition rates at which Q-switched lasers typically operate). Furthermore, nanosecond laser technology is well established, and these sources are highly reliable and have attractive cost of ownership characteristics. However, for the most demanding tasks, peripheral HAZ damage (e.g., delamination of surface coatings or micro cracking) and/or the presence of some recast material, can present a limitation. This problem can be somewhat mitigated by employing a laser having output in the ultraviolet.

As laser pulse width gets into the picosecond domain, an entirely different mechanism for material removal comes into play, called photo ablation. This process occurs because short laser pulse widths lead to very high peak powers (megawatts and above). These high peak fluences drive multiphoton absorption, which strips electrons from the material, which then explodes away because of Coulomb repulsion. Since photo ablation involves directly breaking the molecular or atomic bonds, which hold the material together, rather than simply heating it, it is intrinsically not a hot process. Also, when using ultrafast pulses, the laser processed material is removed in such a short timeframe that the ablated material carries away most of the energy before unwanted heat can spread into the surrounding material. Together, these effects result in significantly reduced HAZ. Plus this is a very clean process, leaving no chunks
or droplets of recast material and thereby eliminating the need for elaborate post-processing.

Another major advantage of ultrafast processing is that it is compatible with a very broad range of materials, including several high band gap materials (e.g. glass, sapphire, certain polymers). These have low linear optical absorption, and are thus difficult to machine with existing, commercially available lasers. More specifically, the technique is 'wavelength neutral', that is, nonlinear absorption can be induced even if the material is nominally transparent at the laser wavelength.

But, if ultrafast pulse laser processing is so wonderful, then why isn’t it used for everything? There are two reasons. First, material removal rates can be substantially lower than for longer pulse lasers. Second, generally speaking, laser cost increases as the pulse duration decreases. Thus, ultrafast lasers are best suited for precision applications that require relatively small amounts of volume material removal. And, they’re most cost effective when the product being processed is inherently high value (such as an integrated circuit). In this case, paying more for the laser source is justified in order to ensure that processing won’t damage the product, or produce results that are cosmetically unacceptable (as is the case in certain marking applications for consumer products).

As a result of these dynamics, picosecond lasers have yet to become commonplace in microelectronics packaging. But, thousands of such lasers have already been deployed in other manufacturing applications for mobile devices. Here they have proven to be industrial grade and suitable even for demanding, 24/7 manufacturing environments.

**Micro SD Card Singulation**

One important laser application in microelectronics packaging is micro SD card cutting. Packaged micro SD cards are typically produced on a sheet that might contain anywhere from nine to 81 units. After all card structures have been created on the sheet, the individual cards are then singulated (cut out). The shape of the finished micro SD card includes curved corners and small notches, which must be reproduced with high accuracy in order for the card to fit in the user’s device.

"Ultrafast lasers are best suited for precision applications that require relatively small amounts of volume material removal."
Furthermore, the cut edge must be smooth enough to allow easy insertion and ejection of the card.

Mechanical cutting is adequate for the straight cuts in this application, but can’t produce the tightly radiused edges or notches. Abrasive waterjet cutting is sometimes used for this purpose, but has some drawbacks. First, the cut width changes over time as the waterjet nozzle wears, leading to process inconsistency. Also, there is a significant consumables cost (abrasives, nozzles) for waterjet cutting.

Currently, the optimum laser technology for this process is the frequency doubled (532 nm), solid-state, nanosecond pulse width laser, typically operating in about the 40 W output power range. This gives the best combination of cutting speed, cut quality and service characteristics. Cutting speeds are comparable to that achieved with the waterjet, with similar cut edge quality. However, the operating costs for the laser are lower. Better edge quality could be achieved with an ultraviolet laser, but this would come at the expense of reduced cutting speed.

Today, mechanical, waterjet and laser technologies are all employed in industry. Some manufacturers singulate entirely using the laser, while others use a mix of technologies. As the cost of laser sources drop and output characteristics improve, this application will tilt further in favour of lasers.

3D packaging

So called ‘3D packaging’ is emerging as an important technology for achieving much higher density of packaged microelectronics devices than traditional methods have allowed. In 3D packaging multiple, individual ICs are stacked like a sandwich. An interstitial substrate serves as an interconnector and redistribution circuit between the dies. This substrate, called an interposer, might be constructed of silicon or glass.

Critical to the production of the interposer is the creation of small through holes, called vias, which are used to make electrical connections between the circuit components. Target via diameters are usually in the 25 µm size range.

These vias can be produced using several techniques, including etching, sand blasting, ultrasound drilling or laser ablation.

To investigate the potential for using lasers for this application, the Coherent applications laboratory laser drilled a large number of tightly spaced holes into a glass wafer. Specifically, these were 25 µm diameter holes produced in a 200–300 µm thick glass substrate, with a hole-to-hole spacing of only 50 µm. An excimer laser operating in the ultraviolet with a pulse width in the nanosecond range was utilised. This laser was chosen because its very high pulse energy enables parallel production of thousands of holes per second with a low operating cost. Plus, the excimer’s ultraviolet output ensures that the glass is not damaged in the process and micro cracks are minimised.

Figure 4 shows the entrance hole, the exit hole and the cross section of the through glass vias. A more thermal process would cause the glass to fracture. Using an excimer laser wavelength of 193 nm at higher fluences (several Joules per square centimeter) could extend this same method down to via diameters of 10 µm.

Conclusion

When it comes to supporting consumer demand for thinner, lighter devices with higher functionality, the miniaturisation of microelectronics packages is just as critical as the increasing density of integrated circuits (i.e., Moore’s Law). Mechanical methods still dominate many of the micro machining processes involved in producing these various packages and their critical components. But the packaging industry is reaching a pivot point where the physical resolution of mechanical methods is clearly struggling to keep pace with this miniaturisation. Instead the feature size is now moving into the optimum size window for high-throughput laser processing. As a result laser micro machining seems set for a period of very strong growth in the microelectronics sector.

Coherent Inc.
www.coherent.com