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Laser Marking Meets Diverse Challenges P.12

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Laser marking meets diverse challenges in fab and packaging

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The basics of laser marking are reviewed, as well as current and emerging laser technologies.

Laser marking is established at multiple points in semiconductor production and applications continue to diversify. There are several laser technologies servicing the application space. This article reviews the basics of laser marking and the current and emerging laser technologies they utilize. It is intended to give a clear sense of what applications parameters drive the choice of laser (speed, cost, resolution, etc.), and provide those developing a new application some guidance on how to select the optimum technology.

Laser marking basics

Laser marking usually entails inducing a visible color or texture change on a surface. Alternatively, although less commonly, marking sometimes involves producing a macroscopic change in surface relief (e.g. engraving). To understand what laser type is best for a specific marking application, it is useful to examine the different laser/material interactions that are generated by commonly used laser types.

Most frequently, lasers produce high contrast marks through a thermal interaction with the work piece. That is, material is heated until it undergoes a chemical reaction (e.g. oxidation) or change of crystalline structure that produces the desired color or texture change. However, the particulars of this process vary significantly between different materials and laser types.

CO_2 lasers have been employed extensively for PCB marking because they provide a fast method of producing high contrast features. However, they are rarely selected when marking at the die or package level. This is because the focused spot size scales with wavelength due to diffraction. CO_2 lasers emit the longest infrared (IR) output of any marking laser. Additionally, IR penetrates far into many materials, which can cause a substantial thermal impact on surrounding structures. Consequently, CO_2 laser marking is limited to producing relatively large features where a significant heat affected zone (HAZ) can be tolerated.

Fiber lasers, which offer high power output in the near IR, have emerged over the past few years as one of the most cost effective tools for high-speed marking. Furthermore, the internal construction of fiber lasers renders a compact footprint, facilitating their integration into marking and test handlers. Cost and space savings are further enhanced when the output of a single, high power fiber laser is split, feeding two scanner systems.

But fiber lasers have disadvantages, too. One reason for the low cost of many fiber lasers is that they are produced in high volumes with designs meant for general-purpose applications. For example, they usually produce a high quality beam with a Gaussian intensity profile. This is

FIGURE 1. PowerLine Pico 10-532 IC, a short-pulse laser for marking ultra-shallow and ultra-small features.

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advantageous for many material processing applications, but not always for laser marking. In fact, a more uniform beam intensity distribution, called a flat-top profile, is sometimes more useful since it produces marks with a sharper, more abrupt edge (rather than a smooth transition from the marked to the unmarked region). Coherent recently introduced a new type of fiber (NuBEAM Flat-Top fiber technology) which enables efficient conversion of single-mode laser beams into flat-top beam profiles, specifically to address this issue.

Other quality criteria, such as high-purity linear polarization, and stability of pulse energy and pulse width, are difficult to achieve with low-cost fiber lasers. This limits their use in more stringent or sensitive marking applications. From a practical standpoint, most fiber lasers cannot be repaired in the field, but are replaced as a whole. This leads to longer equipment downtime and increased maintenance efforts as compared to traditional marking lasers based on diode-pumped, solid-state (DPSS) technology (specifically, DPSS is used here to refer to lasers with crystal resonators).

DPSS lasers also emit in the near infrared. Generally, these lasers are more expensive than a fiber laser of the same output power level. So, infrared DPSS lasers are most commonly used in applications having technical requirements that cannot be met by fiber lasers, such as high volume production of more advanced and expensive semiconductor devices.

FIGURE 2. Standard thickness molded IC package marked with 30 W, near IR DPSS laser (PL E Air 30 D IC).

One advantage of DPSS laser technology is that it can be configured to directly produce a multi-mode beam profile which is essentially flat-top. The Coherent | Rofin PowerLine E Air 30-1064 IC is an example which has found extensive use in semiconductor marking, since it provides an efficient way to rapidly produce very high contrast marks.

Another useful feature of DPSS lasers, which produce pulsewidths in the nanosecond regime, is that their output is much more stable than that of fiber lasers. This makes it much easier to reliably frequency double or triple their infrared light within the laser head, giving a choice of output in the green or ultraviolet (UV). Output at these wavelengths provides two significant benefits. First, they offer additional options in matching the absorption of the material to the laser wavelength. Stronger absorption generally yields higher marking efficiency and reduced HAZ, since the laser light doesn't penetrate as far into the material. The second benefit of shorter wavelengths is the ability to focus to smaller spot sizes (because of their lower diffraction) and produce smaller, finer marks.

However, frequency multiplied DPSS lasers are generally more costly and voluminous than either fiber lasers or infrared DPSS lasers with comparable output power. Lower power translates into reduced marking speed.

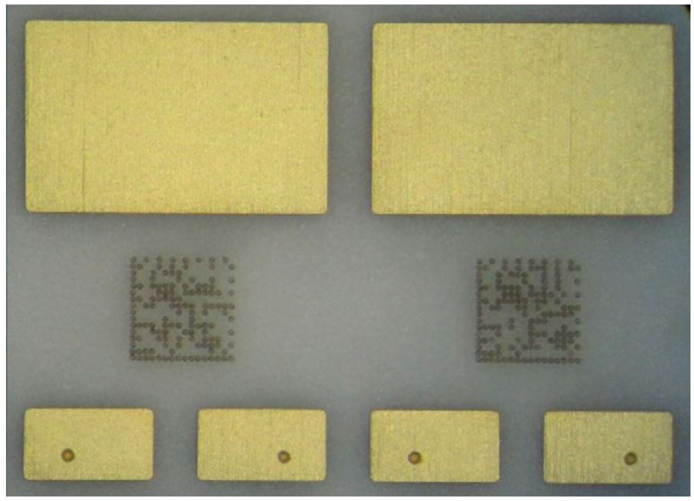

FIGURE 3. Ceramic LED substrate marked with a nanosecond pulsewidth fiber laser (PowerLine F 20 Varia IC).

Therefore, green and UV DPSS lasers are typically employed when they offer a significant advantage due to the particular absorption characteristics of the material(s) being marked.

Another emerging and important class of marking lasers has pulsewidths in the sub-nanosecond range. Due to the nature of the laser/material interaction at short pulsewidths, these lasers tend to produce the smallest possible HAZ with excellent depth control.

There are just a few products currently on the market that exploit this property. One example is the PowerLine Pico 10 from Coherent | Rofin which generates 0.5 ns laser pulses in either the near IR (8 W total power) or green (3 W total power), at pulse repetition rates between 300 kHz and 800 kHz. This combination of output characteristics makes it capable of high speed marking of a wide range of materials where mark penetration depth must necessarily be shallow because of low material thickness, or to minimize HAZ.

Laser marking today

Typically, the first consideration in choosing a laser for a specific application is matching the absorption characteristics of the material with the laser wavelength. Similarly, desired feature size is also driven by laser wavelength, as well as by the precision of the beam scanning system. Next, HAZ constraints usually determine the maximum pulsewidth which can be used (although this choice is again highly material dependent). To see how these parameters interact in practice, it's useful to review some real world applications.

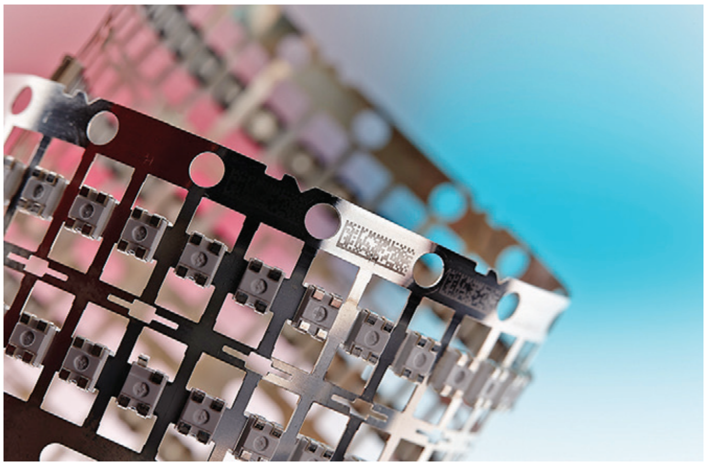

FIGURE 4. Metal ledframe marked with a near IR fiber laser (Coherent PL F 20-1064 IC).

Epoxy-based molding compounds

The most commonly used molding compounds absorb very well in the near IR. Specifically, the near IR laser transforms the usually black molding compound into a gray/white powder, yielding high contrast marks. Plus, many IC packages have mold compound caps thick enough to easily tolerate a marking depth of 30 μm to 50 μm. As a result, many marking systems based on near IR lasers, both fiber and DPSS, are currently in use.

However, some semiconductor devices with small form factor have only thin mold compound caps to protect wire bonded silicon dies, and a marking depth of only 10 μm or less is required. Increasingly, green lasers are used for this type of shallow marking because of a stronger absorption at this wavelength by the epoxy matrix.

Ceramics

The process window when marking ceramics, such as used in packaging power semiconductors, high-brightness LEDs, RF devices, saw filters or MEMS sensors, is relatively narrow. Accurate focus and high pulse energy are critical to ensure reliable marking results, and ideally, the laser marker should have the capability to adjust the focus of the laser beam onto the ceramic surface in real time, in order to compensate for package height variations. Because of their more reliable interaction with ceramic materials, DPSS lasers based on Nd:YAG, which offer high pulse energies and relatively long pulses, are often still used for marking ceramic lids and substrates. Coherent | Rofin has also developed a special fiber laser (the PowerLine F 20 Varia IC), which offers adjustable pulse widths up to 200 ns, specifically to improve process windows for marking applications of this type.

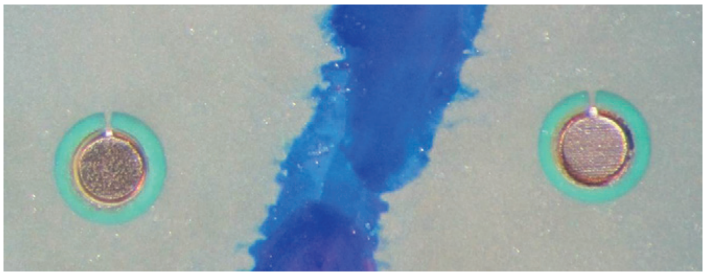

FIGURE 5. a) Gold pad marked on flexible IC substrate

FIGURE 5. **b)** IC substrate marked white

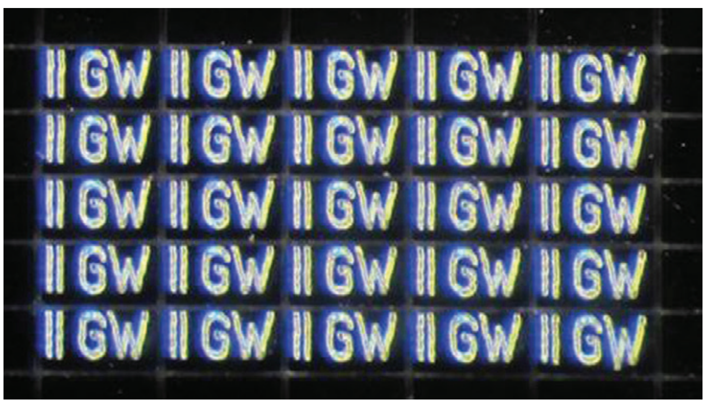

FIGURE 5. c) backside of silicon wafer marked with characters <150 μm in height

The ceramic substrates used with high-power LEDs often require tiny marks to identify individual devices. IR lasers are the preferred lasers for marking these ceramic substrates, providing their spot size is not too big for the layout to be marked. For very small marking features a green laser or UV laser is often required.

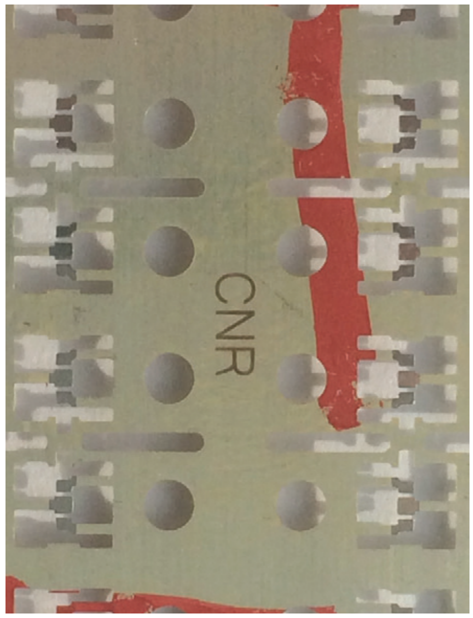

FIGURE 5. d) leadframe mark

Organic substrates

IC substrates or interposers are marked during production with traceable data matrix codes. The thin green solder resist layer on top of the substrate has to carry the mark, and care has to be taken that the copper underneath the solder resist is not exposed. Moreover, data matrix codes can be quite small, with cell sizes of only 125 μm or even less. Since the spot size of the focused laser beam must thus be much smaller than the cell size, the final spot diameter must be significantly less than 100 μm.

Defective IC substrates often are identified by marking large features (e.g., a cross) into the solder resist layer. Although the part is defective, the properties of the mark are still important. This is because it has to be reliably recognized by subsequent processing tools, and also, because any delamination of the solder resist layer might cause problems during succeeding processes.

IC strips have gold pads along their periphery which are used to identify parts found to be defective after die attach and wire bonding. For defective parts, the gold pad is marked by converting its color from gold to black or to dark grey.

Ideally, it is desirable to have one laser marker that can accomplish all three of these marking applications tasks. The green DPSS laser has become the standard laser marker for these applications, with UV lasers occasionally employed for high-end substrates.

Semiconductors

The growing demand for flip-chip devices, wafer-level packaging and defective die identification drives the need for direct marking of silicon, GaAs, GaN/sapphire or other semiconductors. Silicon is partially transparent in the near IR, and lasers at this wavelength are used whenever deep marks into silicon are required, such as placing wafer IDs near the wafer edge. Near IR laser markers are also selected for marking molded fan-out wafer level packaging wafers.

However, for marking either flip-chips or the backside of wafers, green lasers are preferred because of the strong absorption of this wavelength in silicon. Wafer backside marking requires only very shallow marks and the shallow laser penetration avoids potential damage to the circuitry on the reverse side of the flip-chip or wafer. The need for shallow marking also minimizes the laser power requirement. For example, Coherent | Rofin provides a 6 W green laser (the PowerLine E 12 SHG IC) that is well suited for wafer backside marking, and can also mark the wafer through the tape whenever the wafer is mounted on a film frame.

Metals

Near IR lasers are widely used for marking the metal lids used with microprocessors and other high power consumption ICs.

Leadframes, which are plated with tin, silver or gold, are marked either before or after plating. Since leadframes are used for cost sensitive devices, capital investment is critical, and economical fiber lasers are often chosen for this reason.

Laser marking tomorrow

As packages get thinner and smaller, they will require shallower, higher resolution marks. Sub-nanosecond lasers are the most promising method for producing these types of marks, and are compatible with a wide range of materials. The diverse capabilities of this technology are shown in **Figure 5,** which depicts marking results on four different materials using a sub-nanosecond laser (Coherent | Rofin PowerLine Pico 10-532 IC).

The first image is a flexible IC substrate; very thin solder resist layers and metal coatings make it important that the laser does not cause delamination. Here, the circular gold pad has been converted to black without delamination. In the next image, an IC substrate has been given a white mark, again without delaminating the solder resist.

The third image shows very small characters (< 150 μm) marked on the backside of a silicon wafer containing hundred thousands of tiny discrete semiconductor devices. Producing marks of this resolution through the film would be difficult to accomplish with a nanosecond pulsewidth laser.

The final image is a copper leadframe coated with thin silver film. Here, the goal is to produce a shallow mark with high contrast without engraving the underlying material, which has been accomplished with the sub-nanosecond laser.

Conclusion

Semiconductor fabrication and packaging represent challenging marking applications, often requiring small, fine marks produced without a significant effect on surrounding material. An overall trend towards smaller and thinner device geometries will drive increased use of higher precision laser tools, such as those utilizing green and UV nanosecond lasers, and even sub-nanosecond lasers, while cost-sensitive applications will continue to utilize inexpensive fiber lasers. ◈