<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ablation</td>
<td>Removal of a layer of material via laser processing. Because CO₂ wavelengths are absorbed more efficiently by certain materials (plastics especially), they can be used to selectively remove one material from the surface of another—a process known as ablation. This can include removing plastic coatings, ink, paint, or thin films from other substrates.</td>
</tr>
<tr>
<td>Air Assist</td>
<td>Use of compressed gas during laser processing (this typically includes compressed air, Nitrogen, or Oxygen depending on the application). The gas can be applied co-axially (aligned with the laser beam) or at an angle via a nozzle. Air assist can help reduce flare-ups of materials during processing, remove smoke or debris from the process area, reduce the heat affected zone, or improve cut efficiency.</td>
</tr>
<tr>
<td>Astigmatism</td>
<td>Refers to beam symmetry; this means the beam cross-section reaches its narrowest width (x-direction in the diagram) and height (y-direction) at different points along the beam path (z-direction). This means that the beam cannot be focused to as small of a spot size and will likely be elliptical, reducing application quality.</td>
</tr>
</tbody>
</table>
## Asymmetry

Refers to beam symmetry; this can mean the beam has asymmetric waists or asymmetric divergence. Asymmetric waists mean that the waist diameter in the x- and y-directions are not the same, so the beam will be elliptical. Asymmetric divergence means that the $M^2$ value is not the same in the x- and y-directions, or that the beam will diverge with different behavior in each axis. The best application quality can be achieved with a beam that is as close to perfect Gaussian beam behavior as possible ($M^2 = 1$).

![Diagram of asymmetric waist sizes (diameter is different in x- and y-directions) and asymmetric divergence (different $M^2$ values for x and y).](image)

## Average Power

The power output of the laser averaged over one on/off cycle of the laser. For a CW laser running at full duty cycle (always on or 100% duty), the power output is the average power. For a pulsed laser or a CW laser running at lower duty cycle, the average power is the power in one pulse times the duty cycle. This averages the power while the laser is both on and off, the average power will therefore be lower than the peak power for pulsed lasers. The average power is what our Power Wizard measures for <250 W lasers.

![An example of peak verses average power: if the peak power is 10 W and the duty cycle is 20% (ie: the laser is on 20% of the time), then the average power over time is 10 x 0.2 = 2 W.](image)

## Beam Delivery

Any method used to deliver the beam from the laser output to the material and control the beam’s focus and placement. Examples can include fixed focus (usually turning mirrors and final focusing lens), gantry systems, galvo systems, or articulated arms (manual or robotic arms use a system of turning mirrors at each joint to direct the beam). The appropriate system is chosen based on the application itself and any speed, quality, or spot size requirements.

![An example of beam delivery: a cut head houses the final focusing lens and air assist.](image)
Beam Symmetry

Generally used qualitatively to describe how circular the beam is at its focal point. A more circular beam will improve marking, cutting, perforating, and drill quality. For example: cutting thin films with an elliptical beam will produce very narrow cuts in one direction (say the x-direction) and wider cuts in the other (the y-direction) producing inconsistent results. A circular spot size will produce consistent results despite the direction of travel, as well as circular perforation or drill holes. For more quantitative measurements of beam quality, see astigmatism, asymmetry, M², or ellipticity.

Mode burns create an imprint of the laser beam’s intensity profile in a block of acrylic. They are a qualitative way to look at the beam symmetry (the example above shows a laser with good ellipticity, or a very circular beam).

Coding

A market segment that uses CO₂ lasers to mark information on packaging. It is a fairly broad definition, and can include alphanumeric text, logos, barcodes, QR codes, etc., marked on a number of materials, including food packaging, medical packaging, plastic bottles (see ‘wavelengths’), and more. Coding is often accomplished by ablating a layer of ink from the packaging.

Coding on a package: an expiration date, serial number, and barcode were marked on the packaging by ablating a layer of colored ink.

Continuous Wave (CW)

These lasers produce a continuous beam of light when run at full duty cycle; therefore their peak power is about equal to their top average power. CW lasers are useful for marking, engraving, creating smooth cuts on certain materials like acrylic, and creating grayscale images. Synrad’s 48-series, v- and vi-series, ti-Series, f201, and i401 lasers are all CW lasers.

Synrad CW lasers include the 48-series, v- and vi-series, ti-series, f201, and i401 lasers.
**Converting**

Material processing historically done via die cutting, now can be performed with a laser. Typically these are thin materials on a roll (thin films, paper, cardstock, labels, fabric, etc.), that are cut into shapes as the material passes below the laser at high speeds. “Converting” encompasses a broad market space and can include packaging, labels, display or polarizer films, textiles, paper, and more.

**Cut Head**

This device houses the focusing lens and gas jet manifold for laser processing on an XY-gantry system or fixed-focus system. Although these devices can be used for marking or engraving materials, as the name implies, the primary purpose of a cut head is to provide coaxial air assist during cutting and drilling processes.

**Cutting**

Plastics, natural materials (paper, wood, etc.), textiles, and certain thin metals can all be cut with a CO₂ laser. The cut quality will depend on the material’s composition, thickness, and absorption of the CO₂ wavelength. These same properties are therefore used to determine the appropriate laser for cutting, which may include pulsed verses CW lasers, alternative wavelengths, and beam delivery.

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Depth of Focus
(Depth of Field)

When a laser is focused, it first converges to a focal point (or focal plane), then diverges afterward in an hourglass shape as shown. The depth of focus is the distance above and below the focal plane where there is still enough power density to achieve good laser processing results. Depending on the process (cutting verses marking) and the material type and thickness, different spot sizes and depth of focus parameters become necessary. For example: cutting thick acrylic would require a longer depth of focus to provide a consistent, clean cut edge (see the image above under ‘cutting’).

Drilling

Creating small holes (roughly the diameter of the focused spot size) in a material. Pulsed lasers are often used for this process because they more efficiently deliver energy into the material, creating a tight hole with minimal heat affected zone. Drilling is usually performed with a fixed-focus or gantry system, and is often used for ceramics or plastics.

Duty Cycle

The percent of on time in the PWM command signal sent to the laser is the duty cycle. A 50% duty cycle would command the laser to fire for half of the cycle time, while a 100% duty cycle is essentially CW output or always on. Frequency determines the cycle time, so combining frequency and duty cycle allows us to control the pulse length of the laser. Rise/fall times will impact the optical output of the laser in response to the command signal, since there is some delay in reaching maximum power or returning to minimum.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipticity</td>
<td>Refers to beam symmetry; this is a measure of how round the beam is in both near field and far. Near field, ellipticity is a ratio of the beam diameter in the y-direction with the diameter in the x-direction (so a perfectly circular beam would have an ellipticity of 1). Far field ellipticity looks at how the beam diverges in each axis, so the ratio is beam divergence in the y-direction to that of the x-direction. A circular beam produces the best application results, with consistent performance in any processing direction and circular perforation or drill holes.</td>
<td></td>
</tr>
<tr>
<td>Engraving</td>
<td>Creating depth into the surface of a material. This can be useful for marking materials (often plastics) that do not change color when absorbing CO₂ laser light, since it creates a shadowed effect in the engraved area that provides contrast. It can create deep marks more resistant to wear for serialization or coding. It can also be used to create 3D relief in materials like wood.</td>
<td></td>
</tr>
<tr>
<td>Fall Time</td>
<td>Rise/fall times are the times during a pulse required for a laser output to go from 0 W up to the maximum pulse power (rise time) and then return to 0 (fall time). Typical times range from 75-150 μsec depending on the laser model. These times need to be as fast as possible for best results during high speed marking, engraving, perforating, or scribing.</td>
<td></td>
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</tbody>
</table>
Field Size

The area a scan head can operate in while maintaining consistent quality. The dimensions scale based on the focusing setup. The smallest field size will also have the smallest spot size (more power density and greater detail) and a shorter working distance (the distance between the scan head and the focal plane). Selecting a scan head and focusing lens usually involves balancing the necessary spot size verses the desired field size.

Fixed-Focus

One method of beam delivery: fixed focus is the simplest optical setup, usually including a turning mirror, final focusing lens, and air assist nozzle. The laser and beam delivery are both stationary and the material moves into position beneath. This setup is useful because the optical path length does not change, so a small, consistent spot size is achievable. This can be useful for detailed drilling, perforating, scribing, or cutting, usually on flat surfaces.

Frequency

This is the frequency of the pulse width modulation (PWM) command sent to control the laser (i.e.: how often the laser is being commanded to fire). Together with the duty cycle, these parameters control the pulse length (the length of time the laser is on; pulse length = duty cycle divided by frequency). Low frequencies (<10 kHz) allow the entire pulse shape to form (including the rise time up to full power and the fall time back to 0) and can be useful for cutting challenging materials like polycarbonate or for scribing or perforating—each benefit from high peak power pulses. Higher frequencies (>10 kHz) blend the pulses together, creating a quasi-CW mode for pulsed lasers. At high speeds, the frequency must be monitored to use the appropriate pulse spacing so pulses either overlap (cutting/marking) or are separated (perforating/scribing).
<table>
<thead>
<tr>
<th><strong>Galvanometer</strong> (Galvo)</th>
<th>“Galvo” is used both to refer to a beam delivery system using mirror galvanometers to steer the laser (see also ‘scan head’) or more correctly to the mirrors themselves. A mirror galvanometer is an electromechanical system that deflects a beam of light in response to an electrical signal. These devices allow for high speed, accurate beam delivery and are often use for coding or converting applications.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gantry</strong> (XY-Gantry)</td>
<td>One method of beam delivery: XY-gantries use “flying optics” (meaning that the optical mirrors and focusing lens is moving, but the laser itself is stationary) to move the laser beam around the work area. The optics mounted on a gantry system provides motion in two directions: x and y. This motion system can be operated similar to an ink-jet printer (quick back and forth motion in the x-direction, slow advancement in the y-direction) which is called raster-motion. Additionally they can operate in vector-motion, which is a combination of x- and y-motion used to create outlined shapes (similar to an etch-a-sketch) or straight-line motion.</td>
</tr>
<tr>
<td><strong>Gaussian</strong></td>
<td>The Gaussian function (a bell curve) describes the ideal energy density profile for CO₂ laser beams—the beam has the greatest intensity at the center, symmetrically tapering off farther away from center. The closer a beam is to the ideal Gaussian profile, the smaller it can be focused (up to a point, when the beam becomes diffraction-limited). This leads to greater power density for improved processing speeds. A circularly symmetric beam shape also improves application quality—creating consistent marks or cuts in any direction.</td>
</tr>
<tr>
<td>Glossary of Industry Terms</td>
<td>Synrad® is a registered trademark of Novanta Corporation. ©2018 Novanta Corporation. All rights reserved.</td>
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<tr>
<td><strong>Heat Affected Zone (HAZ)</strong></td>
<td>The area around a cut affected by the cutting process. Excess heat absorbed by the material during processing can cause melting (forming a raised melt lip at the cut edge) or discoloration. Using pulsed lasers, alternative wavelengths, air assist, or higher wattage lasers are all common methods of reducing the heat affected zone.</td>
</tr>
<tr>
<td><strong>Kerf</strong></td>
<td>The width of material removed by the laser during a cutting process, usually slightly larger than the spot size. This can also refer to the taper that occurs between the top of the cut and the bottom, and customers may specify what width or angle is acceptable for their application. It is necessary to balance the spot size with the depth of focus to achieve the right kerf width and taper for an application.</td>
</tr>
<tr>
<td><strong>K</strong> (Beam Quality; see also M²)</td>
<td>A measurement of beam quality: the K value indicates how well the beam can be focused to a small spot size. This increases power density for greater processing speeds or higher detail. K represents the degree of variation from an ideal Gaussian beam. An ideal beam would have a K of 1; most Synrad lasers have K values ≥0.83. M² is also commonly used in the industry, where K=(1/M²) for the TEM00 (Gaussian) mode.</td>
</tr>
<tr>
<td><img src="image" alt="10.6 µm HAZ" /></td>
<td>The HAZ for the same material (PET film) cut on the left with a 10.6 µm laser and on the right with a 9.3 µm laser.</td>
</tr>
<tr>
<td><img src="image" alt="Kerf" /></td>
<td>Dieboard cutting applications require both extremely consistent kerf width and taper to allow the blades to be accurately fitted and secured to the board.</td>
</tr>
<tr>
<td>A look at M² calculation: comparing the real beam with the behavior of an ideal Gaussian.</td>
<td>K = ( \frac{\lambda}{\theta W_{0}\pi} )</td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td><strong>Kiss-Cut</strong> <em>(Selective Cut)</em></td>
<td>A kiss-cut or selective cut is one that only penetrates one layer of material, stopping before it penetrates the substrate or backing material. This is the style of cutting used for labels (though it can be applied to other applications as well): the label itself is kiss-cut, leaving the backing material intact. This style of cutting requires a laser with good power density stability (i.e.: requiring both consistent power and spot size over time).</td>
</tr>
<tr>
<td><strong>M²</strong> <em>(Mode Quality or Beam Quality Factor)</em></td>
<td>A measurement of beam quality: the M² value indicates how well the beam can be focused to a small spot size, which allows greater power density for increased processing speeds or higher detail. M² value is the degree of variation from the ideal Gaussian beam. It is the ratio of the laser’s actual beam parameter product (the laser beam’s divergence half-angle times the radius at its narrowest point) to that of a perfect Gaussian. An ideal beam would have an M² of 1; most Synrad lasers have an M² of ≤1.2.</td>
</tr>
<tr>
<td><strong>Marking</strong></td>
<td>Laser processing that alters the surface of the material. This generally involves a contrasting color change, but the industry may also include light ablation or engraving under the banner of “marking”. Applications can include marking alphanumeric text, logos, images, diagrams, or barcodes.</td>
</tr>
</tbody>
</table>
### Marking Head

Used interchangeably with ‘scan head’; a method of beam delivery that involves galvanometer (galvo) mirrors quickly steering the laser beam across a material. One of the fastest methods of beam delivery, especially when compared to a gantry system, but is constrained by spot size and field size. As the name implies, primarily used for marking, but can also cut thin materials like labels, plastic films, or thin fabrics. Often found on production lines for applications in the coding and converting markets.

![Synrad’s FH Flyer marking head. The spot size and field size are controlled by changing the focusing lens at the bottom of the unit.](image)

### Mark on the Fly (MOTF or Tracking Mode)

The scan head processes material or parts that move past it on a conveyor or a roll-to-roll system. This is used for manufacturing in coding and converting applications. A sensor will trigger the scan head to execute its file (cutting, marking, perforating, etc.), and can be used to change jobs on the fly. The versatility of applications and quick change between jobs is a huge benefit over traditional mechanical operations. The conveyor or material motion speed is determined by how quickly the scan head/laser subassembly can complete the desired job.

![Coding bottles and packaging is a common MOTF application. Information like serial numbers and dates are easily updated, improving production.](image)

### Peak Power

The maximum power output of a laser. For a CW laser, the peak power is about equal to the average power. For pulsed lasers, the peak power is about equal to the average power divided by the duty cycle. High peak power can be useful for reducing HAZ on sensitive materials, piercing thin material surfaces quickly (for perforating or scribing), and penetrating material surfaces that require higher power density (like certain metals).

![An example of peak verses average power: if the average power is 2 W and the duty cycle is 20% (ie: the laser is on 20% of the time), then the peak power is approximately 2 ÷ 0.2 = 10 W.](image)
**Perforation**

A series of small holes, penetrating completely through a material or only partially penetrating. Typically, a pulsed laser with fast rise/fall times and high peak power create distinct circular perforation holes for high speed processing. In the food packaging industry, perforation is used for vegetable bags or easy open packages; it can also be used to create ventilation holes in athletic fabrics, or for perforating paper for easy-tear.

Perforation is often used for easy-open food pouches. It can also be used to encourage airflow through vegetable packages, increasing shelf life.

**Polarization**

Polarization describes the orientation of the electric field with respect to the direction the laser is propagating. Light is an electromagnetic wave with an electric field that oscillates perpendicularly to its direction of motion. This includes different types of polarization:

- **Random** - the electric field does not have a defined, repeatable path
- **Linear** - the electric field oscillates in a single plane with respect to the laser beam’s path, usually vertical, horizontal, or 45°
- **Circular** - when the electric field describes a circle around the path of the beam
- **Elliptical** - when the electric field describes an ellipse around the beam path

Certain materials can be sensitive to polarization, displaying different cut characteristics based on the polarization of the beam with respect to the direction of cut motion. Polarization is also important for beam delivery components like optical isolators, which prevent back reflections from damaging the laser when cutting reflective materials like metals.

Top: the electric field oscillates perpendicularly to the direction the laser beam travels (linear polarization in this case). Below: A) Random polarization, B) Vertical, linear polarization, C) Circular polarization.
Power Density

A measure of power per unit area, generally referring to the density of laser power contained in the spot size. For example, a 100 W laser with a 110 µm focused spot size has a power density of 1.05 MW/cm². Higher power densities allow laser energy to couple into the material more efficiently, reducing HAZ or increasing processing speeds. The ability to focus a laser to a smaller spot size is related to the M² value (i.e., a better M² value—as close to 1 as possible—will allow the laser to be focused to a smaller spot size).

Power Stability

Consistency of a laser’s power output over time. For Synrad, this is a percentage calculated by:

\[
\% \text{ Power Stability} = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}} \times 100
\]

Greater power stability leads to greater consistency in processing—so mark color, cutting depth, feature profile, or HAZ would be consistent over time. That said, there are caveats: power stability does not include the timeframe of the power swings. So even a laser with good power stability (<±5%) may show inconsistent marking or cutting results if the power swings happen quickly enough for the eye to see. The common example of this is banding behavior during marking. Another note is power stability is not the only parameter affecting the final appearance of the application. Any change in spot size or shape also has an impact on power density, and affect the final application.
### Pulsed Laser

A laser whose output is a series of pulses rather than a continuous wave (CW). Pulsed lasers have higher peak power but are duty cycle limited (usually <50% duty), which is beneficial for certain applications. High peak power delivers energy more efficiently, which can reduce HAZ, pierce thin material surfaces more quickly (helpful for perforating/scrubbing), and provide high enough power density to pierce challenging materials like metals. Pulsed lasers can also operate in quasi-CW mode, where the frequency is raised enough that the pulses bleed together (due to limitations imposed by rise and fall times), allowing them to cut and mark similar to a CW laser.

![Comparison of a CW laser operating at high duty cycle with a duty cycle limited pulsed laser.](image)

### Pulse Width Modulation (PWM)

The input signal that controls our lasers contains a series of pulses that (combined with the rise/fall time of the laser) determine how the laser fires. The percent of on time in the signal is the duty cycle (so a 50% duty cycle would command the laser to fire half the time, while a 100% duty cycle is essentially CW output or always on). Combining duty cycle with frequency allows us to control the pulse length of the laser. This is the reason our pulsed lasers are duty cycle limited and have fast rise/fall times—it allows for a brief, high-peak power pulse that can be useful in certain applications.

![An example PWM signal (bottom) and the optical output of the laser in response (top).](image)

### Raster (Bitmap)

Motion similar to an ink-jet printer: quick back-and-forth motion in the x-axis, line-by-line advancement in the y-axis to fill in a shape. This is the motion scan heads and gantries use for filled text, logos, images, and barcodes. Because the motion must cover the entire mark or engraving, it is typically a slower process than vector marking.

![Raster motion is used to fill solid shapes, text, or images during marking or engraving applications.](image)
| **Rise Time** | Rise/fall times are the times during a pulse required for a laser output to go from 0 W up to the maximum pulse power (rise time) and then return to 0 (fall time). Typical times range from 75-150 µsec depending on the laser model. These times need to be as fast as possible for best results during high speed marking, engraving, perforating, or scribing. |
| **Scan Head** | Used interchangeably with 'marking head', this method of beam delivery involves galvanometer (galvo) mirrors quickly steering the laser beam across a material. One of the fastest methods of beam delivery when compared to a gantry system, but is constrained by spot size and field size. Primarily used for marking, but can also cut thin materials like labels, plastic films, or thin fabrics. Often found on production lines for applications in the coding and converting markets. |
| **Scribing** | Creating a series of deep, narrow holes into the surface of a material, usually for segmenting the material. On materials like ceramics that do not cut well, a pulsed laser scribes lines where the material snaps into smaller pieces. The high peak power and fast rise/fall time of pulsed lasers creates cleaner, deeper scribes into the material. |
Spot Size

The diameter of the laser beam when focused to its smallest point. The spot size will vary depending on the beam quality ($M^2$ value), the size of the beam entering a focusing lens, and the lens itself. Smaller spot sizes have higher power density and can achieve greater detail, but have less depth of field (i.e.: the laser diverges more quickly from the focal point) and can therefore not be used on uneven surfaces or for cutting thick materials. Large spot sizes will have greater depth of field, but the reduced power density makes them unsuitable for cutting. These parameters have to balance for a successful application.

Standalone Mode

Allows the scan head to operate independently of a computer. In standalone mode, a job file is uploaded to the head and can be triggered by an external signal. This mode is typically fastest for vector marking or cutting, since there is no communication delay between the computer and scan head. It is also the mode typically used in manufacturing.

Tethered Mode

The scan head is connected to a computer, which is controlling the application process. This is possible using Synrad’s WinMark Pro software, which allows users to import or create designs, then optimize laser and scan head settings to achieve the desired application result. Tethered mode is most useful for testing a new application process or material, since it is easy to iterate and optimize settings. These settings can be chosen to enable almost any process, including marking, cutting, engraving, or perforating.
### Tracking Mode

Automating the scan head to process material or parts that move past it on a conveyor or a roll-to-roll system. This mode is used for manufacturing in coding and converting applications. A sensor will trigger the scan head to execute its file (cutting, marking, perforating, etc.), and can be used to change jobs on the fly. The versatility of applications and quick change between jobs is a huge benefit over traditional mechanical operations. The tracking speed (conveyor or material motion speed) is determined by how quickly the scan head/laser subassembly can complete the desired job.

![Coding bottles and packaging is a common tracking application. Information like serial numbers and dates are easily updated improving production.](image)

### Vector

Motion that can follow any path across a material, as opposed to the back-and-forth motion of a raster mark. Vector motion is generated by some combination of x- and y-axis movement, similar to an etch-a-sketch. Typically, vector motion is more efficient than raster, and used for marking, cutting, perforating, scribing, or welding.

![Vector motion can follow any path across the material and is often used for marking and cutting.](image)

### Wavelength

The available CO₂ wavelengths are 10.6 µm, 10.2 µm, and 9.3 µm; with 10.6 µm the most commonly used. Certain materials absorb the alternate wavelengths better: polyethylene terephthalate (PET) is the classic example for good 9.3 µm absorption, while polypropylene (PP) absorbs 10.2 µm more efficiently. Choosing the correct wavelength for the application can provide better processing speeds and/or cleaner results (either better marks or reduced HAZ in cuts). Note that other lasers operate at different (often much shorter) wavelengths, impacting the types of materials they can interact with.

![An absorption curve for PET: the vertical lines indicate absorption at 9.3 µm (green line), 10.2 and 10.6 µm (red lines). The higher absorption of 9.3 µm wavelength improves application processing speed and quality.](image)