TECHNOLOGY FEATURE

Advancements in Laser Marking of Plastics

by Scott R. Sabreen, The Sabreen Group, Inc.

Advancements in direct laser marking of plastics yield unprecedented marking quality, contrast, and speed. This article presents the newest generation of laser material science and laser equipment systems. With proper application, laser marking can provide manufacturing advantages and bring value to a product's appearance and function.

Basic Principles of Laser Marking

Beam-steered Nd:YAG lasers ("YAG") at 1064nm wavelength (near infrared spectrum) are popular in the laser marking industry due to their emission wavelength, power performance and versatility. This results in faster marking speeds, higher quality, and greater production. As reference, the continuous wave (CW) CO_2 lasers operate at a wavelength of 10.6 µm (far infrared spectrum). CW CO_2 lasers generate comparatively much lower peak power and normally cannot produce high contrast markings on many plastics.

The mechanism of laser marking is to irradiate the polymer with a localized high-energy radiation source (laser). The radiant energy is then absorbed by the material and converted to thermal energy. The thermal energy induces reactions to occur in the material. Beam-steered YAG laser markers (arc lamp & diode light pumping sources) utilize mirrors that are mounted on high speed computer controlled galvanometers to direct the laser beam across the surface to be marked. Each galvanometer, one on the Y-axis and one on the X-axis, provides the beam motion within the marking field. A flat-field lens assembly focuses the laser light to achieve high power density on the substrate surface. A basic YAG laser marking configuration is shown below in Figure 1.

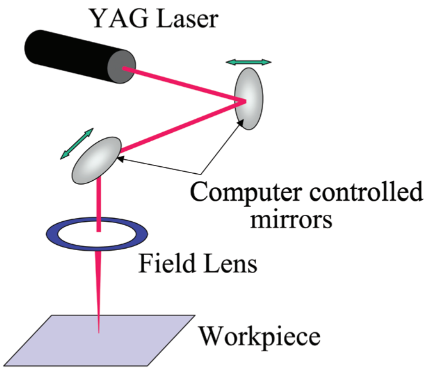


Figure 1

Laser Material Science

The material science chemistry for achieving high contrast laser marking is both art and science. Since many polymers do not possess absorption properties at 1064 nm, experts utilize additives and colorants (pigments & dyes) that enhance the absorption of laser energy yielding contrasting color changes. Contrary to popular belief, a single laser additive that solves all marking problems does not exist. Vastly different chemistries and laser parameters are used depending upon the desired marking contrast. Figure 2 shows "dark-on-light" computer keycap (left), "light-on-dark" interior automotive lever (center), and gold "color" advertising specialty product (right).

Figure 2

Three unique surface reactions are demonstrated in Figure 2. First, the charring process occurs when the energy absorbed raises the local temperature of the material surrounding the absorption site high enough to cause thermal degradation of the polymer. While this can result in burning of the polymer in the presence of oxygen, the limited supply of oxygen in the interior of the substrate results in charring of the polymer to form a black or dark-on-light marking contrast.

Second, the foaming process occurs when the local polymer temperature surrounding the absorption site is sufficiently high that the polymer generates gases via burning or evaporation. The hot gases are themselves surrounded by molten polymer and expand to form bubbles. If the energy of the laser is controlled, foaming can result in bubbles that scatter light in a way that results in white or light-on-dark marking contrast[1].

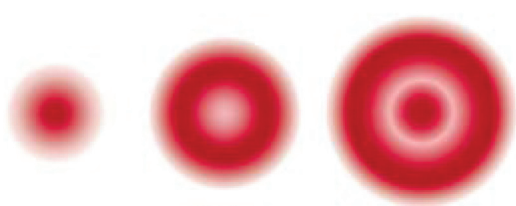
Third, laser energy is used to heat/degrade one colorant in a colorant mixture resulting in a color change. An example is a mixture of carbon black and a stable inorganic colorant. When heated, the carbon black is removed leaving behind the inorganic colorant. These mixed colorant systems are dependent on specific colorant stabilities and not all color changes are possible. Laser formulations cannot be toxic or adversely affect the product's appearance, physical properties, or functional properties.

A recent advancement is Mark-it™ Laser Marking Pigment by BASF Corporation (formally Engelhard Corporation). This additive product is an antimony-doped tin oxide pigment that is easily dispersed in polymers. Mark-it™ pigment is the first to receive U.S. Food and Drug Administration (FDA) approval for use in YAG laser marking processes to generate dark markings (light markings also are achievable by incorporating additional additives). The product has FDA approval for use at loadings up to 0.5 percent in polyolefins that contact food under conditions A-H of 21 CFR 178.3297 Colorants for Polymers[2].

Laser Marking Equipment Systems

All beam-steered YAG lasers are not created equal. The hardware and software components a laser manufacturer incorporates into its systems makes significant differences in marking quality, speed and versatility. When procuring laser systems, it is important to remember there is not a single universal solution. Each application is unique relative to the plastic substrate composition and color, marking quality, speed, laser efficiency, contrast (dark-on-light, light-on-dark, or color), and total system costs.

Beam quality output mode refers to the energy distribution within the laser beam and is critical to marking performance. Lasers can be supplied by manufacturers as multimode (MM), TEM00 (Transverse Electromagnetic Mode) or anything in between including Low-Order Mode (LOM). These output modes relate to factors including the beam divergence and power distribution across the diameter of the laser beam. A TEM00 laser beam can be focused to the smallest size spot that the focusing optics permit and the energy distribution in a TEM00 laser beam is most intense at its center and tapers off uniformly from its center to its edges. TEM00 laser output provides the highest beam quality. Multi-Mode (MM) laser output provides the poorest beam quality. Reference Figure 3. Low-order and TEM00 mode lasers are particularly well suited for high speed vector marking of single-stroke alphanumerics, filled true-type fonts, and complex graphics because of their ability to achieve a small focused spot with very high power densities, resulting in a very narrow line with well defined edges that can be drawn quickly. Most plastics applications are optimal using near TEM00 or TEM00 laser beams.



TEM_{00} Highest beam quality | Low order mode | Multi-mode Poorest beam quality (Hot spots)

Figure 3

Power density is a function of focused laser spot size (laser power per unit area, watts/cm2). This is different than the raw output power of the laser. Focused laser spot size for any given focal length lens and laser wavelength is a function of laser beam divergence which is controlled by laser configuration, mode selecting aperture size and upcollimator (beam expander) magnification. Pulse repetition rate (via acousto-optic Q-switch) and peak power density are critical parameters in forming the mark and achieving the optimal contrast and speed. High peak power at low frequency increases the surface temperature rapidly, vaporizing the material while conducting minimal heat into the substrate. As the pulse repetition increases, a lower peak power produces minimal vaporization but creates more heat. Beam velocity (speed of the laser beam across the work surface) is also a critical factor.

Two types of solid-state beam-steered YAG lasers are traditionally used for marking plastics – lamp and diode-pumped systems (referred to as "lamp/YAG" and "diode/YAG"). Major differences exist between these two laser types. Both lamp/YAG and diode/YAG can potentially yield acceptable marking results relative to marking contrast and speed. Table 1 provides comparative data (page 38) for lamp/YAG and diode/YAG lasers ranging from low to high power and configured for multimode (MM) to TEM00 beam quality modes.

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For a direct comparison of diode/YAG versus lamp/YAG, it is important to evaluate near equivalent lasers for a specific application, e.g., 100-Watt. Using a 100-Watt laser as a basis, diode/YAG lasers are inherently more efficient than lamp/YAG in terms of output beam power as a fraction of input electrical power. Diode/YAG lasers rely on a bank of laser diodes as the optical "pump" source for the YAG laser rod, rather than a krypton arc lamp. Laser diodes are more sensitive than arc lamps to electrical noise so greater circuit protection is required. Contrary to common perception, both high-powered diode and lamp pumped lasers require a cooling system, although diode systems can use smaller cooling units but require greater temperature control. Low power diode/YAG systems are sometimes air-cooled. Diode/YAG lasers can produce TEM00 beam output quality, resulting in higher peak power and subsequent fast marking. Both lamp/YAG and diode/YAG systems can produce TEM00 beam output quality, or near TEM00 outputs, with proper apertures and collimation to produce similar spot sizes.

Lifetimes of laser-diode bank versus arc lamps are an important consideration. Most commonly advertised lifetime of laser diodes operating in Q-switch mode are in the range of 10,000 hours, although the actual lifetime is dependent upon a variety of factors and can vary significantly. When replacing a bank of diodes, the laser head is returned to the factory and the replacement cost can be in the range of $12,000 to $15,000. In contrast, arc lamps have an operating range of 400-600 hours, based upon average usage conditions, and can be easily replaced by a technician for about $100 or less. Advantage goes to diode/YAG lasers relative to beam power stability since arc lamps age over time. At present, lamp/YAG lasers are significantly less expensive to procure. Lamp/YAG is a much more mature technology and has been in use for decades (1960s). Diode/YAG lasers (1980s) are the newer technology and they have longer mean time between maintenance intervals and lower electrical consumption and heating requirements. Lamp/YAG lasers often times can be more versatile when the marking of various substrates is required. The diode/YAG is a more specialized laser machine.

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Table 1

Comparison of Lamp Pump YAG versus Diode Pump YAG (Basis: 100-Watt laser, 220V, water-cooled)		
Specification	Lamp Pump YAG	Diode Pump YAG
Wavelength	1064 nm	1064nm >
Raw Power	10 - 100 Watt MM	10-100 Watt MM
Power with Best Quality Output	1 - 22 Watt near TEM00	1 - 22 Watt TEM00
Beam quality mode	MM to near TEM00	MM to TEM00
Beam power density	Low to High	Low to Very High
Spot Size	Focus lens, Upcollimator and Mode dependant	Focus lens, Upcollimator and Mode dependant
Laser Pump Source Life	400 - 600 hours	8,000 - 10,000 hours
Pump Source Replacement Cost	$50 - $100	$12,000 - $15,000
Laser System Size	Large	Large to Small
Wall Plug Efficiency ***A***	1.5%	5%
Operating cost annual ***B***	$3,200	$4,100
Initial laser cost	$48,000 – 60,000	$60,000 – $75,000

A Laser (wall plug) efficiency is the electrical power drawn from the wall that must eventually be converted to laser output power. For example, if 1000 watts of wall power consumption results in 15 watts of laser output, then the laser has a wall plug efficiency of 1.5 percent. It follows that 985 watts (98.5 percent of the original 1000 watts) has been converted to heat, not laser output power, and must be removed somehow. Removal is generally accomplished by air or water cooling systems.

B Reference Industrial Laser Solutions, August 2006, Glenn Prentice, Cost based on operating a typical laser eight hours per day, 254 days per year.

Laser control software is as important as any hardware component in the marking system. Advanced software algorithms enable unprecedented speed. Beam-steered laser markers are sometimes wrongly conceptualized as (desktop) printers. In fact, they are plotters. Rather than placing individual pixels to create alphanumeric letters or graphics, the laser draws lines much like writing with pencil and paper. Regardless of the input file format originally used to create the laser marking objects, all marking is eventually reduced to its most simple form, a list of vector lines to be drawn by the scan head and marked by the laser. Complex input file formats often used by design engineers may not necessarily yield the best (or fastest) vector laser marking. Laser marking equipment systems must be safe and conform to ANSI Z136 standards. ■

References:

1. Bruce Mulholland (Ticona, formally Hoechst Technical Polymers) and Scott Sabreen (The Sabreen Group, Inc.), "Enlightened Laser Marking", Lasers&Optronics, July 1997.

2. BASF Corporation (formally Engelhard Corporation) Mark-it™ Laser Marking Pigment Technical Bulletin 2002, with technical content contributions from The Sabreen Group, Inc.

Scott R. Sabreen is founder and president of The Sabreen Group Inc. (TSG). TSG is an engineering company specializing in secondary plastics manufacturing – laser marking, surface pretreatments, bonding, decorating/finishing and product security. For more information, call toll-free at 888-SABREEN or visit www.sabreen.com.