

ANALYSIS OF THE LASER MARKING TECHNOLOGIES

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ABSTRACT

The characteristics of the materials laser marking concerning its productivity, flexibility and quality obtained, led to an industrial implementation of this technique. Based on the vaporizing, melting or colour changing of the irradiated material, laser marking is well adapted for all types of materials. The paper presents different marking methods, revealing the advantages of laser marking versus other marking technologies. The mechanism and the quality characteristics of the materials laser marking technologies are also presented.

KEYWORDS : laser marking, laser systems, marking technologies

1. INTRODUCTION

Product laser marking is one of the most common industrial applications of lasers. The laser marking systems using different lasers and optical delivery systems may be used to mark an almost endless list of materials including metals, plastics, ceramics, glass, wood and leather as well as painted surfaces and photographic emulsions.

Laser marking most commonly takes the form of an alphanumeric code imprinted on the surface of the product to indicate the date of manufacture, best-before, serial number etc.

Laser marking is superior in quality and flexibility to traditional marking techniques; it leads itself to automation and integrated production techniques. The common advantages of all laser marking techniques are:

- permanent, high quality marks;
- high efficiency and low operation cost;
- good accessibility, even to irregular surface;
- non-contact marking and no special working environmental needed;
- easy to automate and integrate (direct writing of patterns can established using computer-controlled movement of the beam or sample);
- precise beam positioning and a beam highly localised energy transfer to the workpiece;
- high reproducibility and high speed ;
- contamination - free.

2. LASER MARKING MECHANISM

The marking processes include one or a combination of the following processes (table 1):


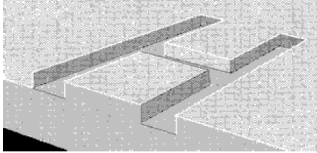

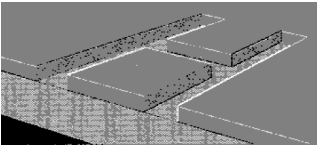
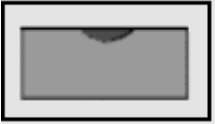
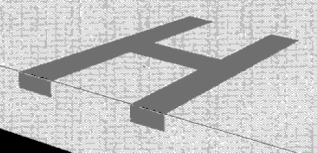

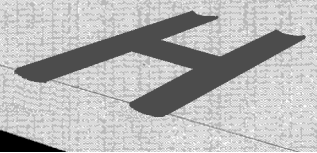
- black carbonisation;
- bleaching or changing the colour of a colorant in the material;
- physical modification of the surface finish;
- scribing a shallow groove into the material by vaporisation;
- highly-controlled modification of the surface by melting.

Briefly, it comes out that the laser marks are created by vaporizing, melting or annealing the material. Each has a specific effect for different marking applications. Vaporization produces a mark with depth in the material, like engraving. Melting creates a contrasting mark through a thermal-chemical reaction. This technique is often used with plastics. Annealing the surface of a material, such as steel or titanium, can produce a dark mark without noticeable surface penetration [1, 2, 3].

3. MARKING METHODS IN LASER MARKING TECHNOLOGIES

There are two basic methods for laser marking: they are mask marking and beam deflected marking. Both methods also use optical techniques to enhance the power densities to levels sufficient to etch the surface of the material to be marked.

Table 1 Laser marking technologies

Process	Schema		Mechanism
Vaporization			Material removal mainly by vaporization
Thin layers material removal			Thin layers material removal by controlled vaporisation, changing the colour of the under layers
Carbonisation or coloration			Colour changing by photo-thermal or photo-chemical reactions
Surface modify by material fusion			Destruction of materials by pyrolyze reaction that leads to irregular structures into the material

In mask marking (fig 1.a), a stencil of the desired mark is projected onto the workpiece. The picture of the mask on the object is made using a lens. Employed in the mask marking are often the pulsed lasers [1], [2], [3].

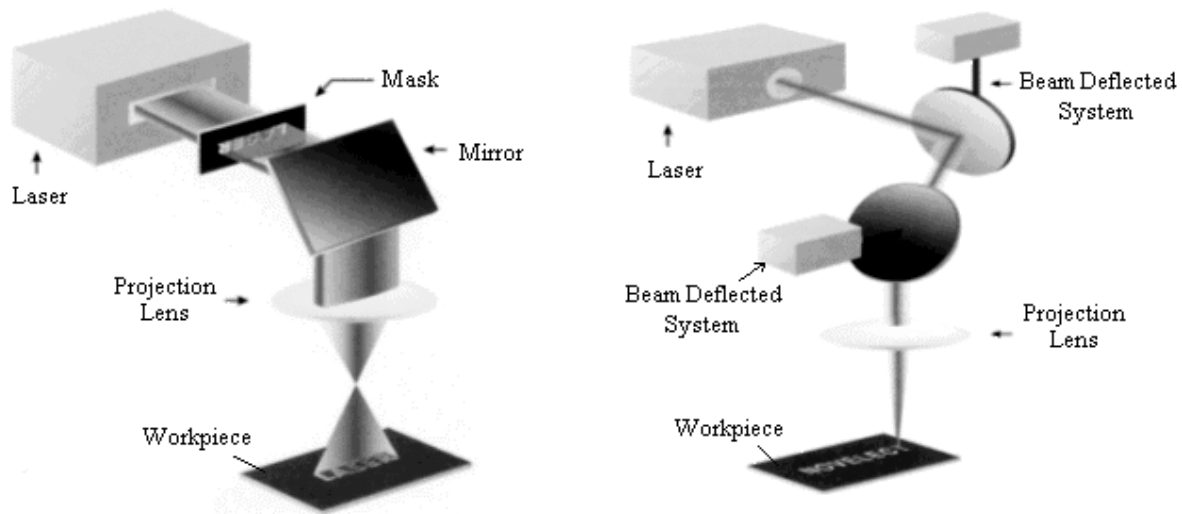
In the beam deflected method (fig. 1.b), the laser is directed via two galvanometer mirrors and a lens system to the object to be marked. Using special software, a computer controls the galvanometer mirrors. The marking is made by directing the beam in directions x and y. The beam deflection method is very flexible and can transmit a high density of information. The lasers used in this method are often continuous wave lasers.

Comparing the two marking methods, it is concluded that

- *marking speed*: mask marking has higher marking speed up to a few tens pieces per second. Because the laser pulse duration is in the range of micro-second to

nanosecond, the workpiece to be marked does not need to stop.

- *marking area*: beam deflected marking has a bigger marking area. The marking area by mask marking is very small because of limited beam spot size and energy per pulse.
- *flexibility*: in mask making, the patterns required are produced by masks. To produce a mask is time-consuming. Therefore, mask marking is more suitable for high-volume production without any change on the patterns. In beam deflected marking, the patterns are produced by software. Thus, it is highly flexible to change patterns.
- *cost of investment*: in general, the cost of beam deflected marking is higher because the scanning system is more expensive.



a) The mask marking

b) The beam deflected method

Fig. 1 Principle of laser marking

4. LASER FOR THE MARKING PROCESS

The most popular systems are lamp-pumped Nd:YAG lasers, which produce near infrared light at a wavelength of 1,064 μm , and CO₂ lasers, which produce light at the 10,64 μm wavelength.

Because of their wavelength, Nd: YAG lasers are more capable than CO₂ lasers—but they are also substantially higher in cost. The 1,064- μm wavelength is more easily absorbed by a vast range of materials. CO₂ lasers are an economical marking solution, as long as the wavelength and material match.

The excimer lasers are used in the laser marking too [4]. Among all laser types, they assure the highest resolution of the mark. But, these lasers are rarely used because of the low productivity of the process and of the very expensive cost of the laser equipment.

Recently, the diode-pumped Nd:YAG lasers are used for the marking process. These lasers offer high beam quality, excellent pulse-to-pulse stability, and long maintenance intervals (typically every 12,000 to 15,000 hours of use).

When selecting a laser marking system for a particular application there are many factors to consider [1], [5], [6]:

- power density
- thermal
 - thermal conductivity

- heat capacity
- melting point
- heat of vaporisation
- reflectivity
 - material
 - wavelength
 - temperature

Power density is determined by the amount of (peak) power generated by the laser divided by the area of focused beam. Wavelength, beam divergence and quality of optics become important factors in determining how small a beam can be produced.

The amount of time the laser power is focused onto the material also has impact on the ease of marking and depth of penetration. Sometimes, the pulse duration is a key factor in determining which laser can be used.

Reflectivity or absorptivity is effected by the type of material, surface condition (i.e. smooth or rough, polish or oxidised), wavelength and surface temperature. In general, metals absorb a greater percentage of Nd:YAG laser energy than that of carbon dioxide laser energy. On the other hand, white paper and most transparent materials absorb a great amount of carbon dioxide laser energy. Some materials such as silicon absorb the same percentage of energy from either laser.

For the evaluation of available laser marking systems in the market for different

applications, the following factors shall be focused:

- laser specifications;
- optical delivery system;
- control system and software;
- ease of operation;
- manufacturer's performance record;
- price.

The laser specifications of different types of lasers are different. For CW lasers, the major specifications should include wavelength, average laser power, power stability, beam quality factors and Q-switch element performance (maximum pulse repetition rate, minimum pulse duration, laser peak power). For pulsed lasers, the specifications should include wavelength, average laser power, maximum peak power, maximum energy per pulse, pulse repetition rate, pulse duration, pulse-to-pulse stability, and beam quality factors.

There are many types of optical delivery systems. For mask marking processes, the systems may include beam expander, homogeniser, CCD camera and monitor or/and microscope, and project lens. The project lens, together with the beam size entering it, determines how big a mark can be obtained per pulse.

For beam deflected marking system, the system may include beam expander, CCD camera and monitor or/and microscope, scanner, fiber optics, and lens. The lens are very important in determining focused spot size, marking field, minimum marked-line width and power density on the workpiece. The scanner together with the marking software determines the scanning speed.

Control systems and software are very different for different laser marking systems. The control system may include feeding of workpiece, control of beam on/off, and interfaces among computer, laser generator, stage, and protection/alarm systems. The marking software should be easy to implement in a user's system and to program conveniently.

5. MARKING QUALITY CHARACTERISTICS

The quality of a mark is assessed by its legibility characteristics such as mark contrast, mark width, mark depth, spattering,

and microcracks [2], [7], [8]. The characteristics are usually evaluated using complementary techniques such as optical microscopy, ultrasonics microscopy, electron microscopy, surface roughness measurement, and contrast evaluation devices. The acceptance of level of each of these characteristics generally depends on the manufacturer's requirements.

Mark width refers to the width of the line segment that forms a character. With the mask image marking, the mark width in the characters is essentially determined by the mask geometry and the lens imaging quality. It can be as small as a few micro-meters, which can only be read under a microscope.

In beam deflected marking, the line width is mainly determined by the focused beam spot size, which varies between 20 - 100 μm . Other parameters such as scanning speed, power density and material properties also affect the line width. A toolmaker's microscope or Talysurf surface texture measuring equipment are used for the line width measurement.

Marking depth depends on energy density, types of materials and the beam/material interaction time. In mask marking, the vaporization depth is often determined by the thickness of paint or oxidation layer. It is typical of a few microns to several tens of microns.

In beam deflected marking, greater depth of penetration into the material can be achieved varying between a few microns to several tens of a millimeter. A further enhancement of the effect on the material can be realized by the supply of gases such as oxygen or compressed air, which assist material removal.

Marking contrast is the visual difference between the apparent brightness of the marked surface and unmarked surface of a workpiece.

The sharpness or resolution of the marked edges affects the marking contrast. This parameter is particularly important in marking "bar code", as poor edge sharpness may fail bar code reader. High peak power or power density produces better edge resolution.

Scattering is characterized by the presence of re-solidified droplets of surface material in the marking area. These scattering are undesirable as they distort mark boundary and producing poor line definition.

Visual inspection with an optical microscope is often suffice to evaluate the effect.

Microcracks are created due to thermal stress generated during laser marking. The microcracks affects mechanical properties and may induce corrosion in metals. Scanning acoustic microscope and scanning electron microscope can be used for detection and analysis.

Continuity: when pulsed or Q-switched CW lasers are used, the repetition rate affects the continuity of the marking. Marking speed is another key factor. An optical scope is used to evaluate the effect.

6. LASER MARKING APPLICATIONS

Lasers are used in thousands applications in a wide range of industries, as shown in table 2.

Photographic imaging and invisible coding. Lasers can create high-resolution images that simulate black-and-white photography. It can also embed information into that photograph.


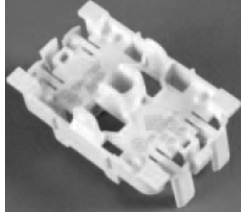


This is an obvious benefit for manufacturing security cards and for making product tracking information invisible.

High-speed marking. Lasers have long been used in the packaging industry to mark production coding and expiration dates, but the technology is just as ideal for putting identifying nomenclature onto parts moving along a high-speed assembly line. Because of their speed, accuracy and flexibility, lasers are a cost-effective alternative to labels in high-volume, high-mix settings.

Data Matrix codes. Data Matrix is a 2D identification code that resembles a checkerboard. It offers tremendous data capacity and built-in error correction. Data Matrix has been embraced by the automotive industry for direct marking of parts, and it's also in the ATA2000 specification for the aerospace industry.

Day and night marking. This concept was developed to make automotive controls easy to locate in the dark. A black topcoat is applied to a translucent white substrate. The laser removes the coating from the substrate, producing clear, white characters that are crisply defined against a colored background. At night the characters are backlit for easy recognition.

Table 2 Some laser marking applications

Medical industry	Electronics compounds	Data Matrix codes	Publicity objects
			

7. LASERS VS. OTHER TECHNOLOGIES

There are many methods of marking parts, including labels, ink systems, mechanical engraving and embossing, and chemical and dry etching [9]. Each has it's use, but lasers are growing more and more popular (table 3).

For metals and other materials, engraving, embossing and other contact processes do not facilitate changeover. Tool wear is also an issue.

Dry etching requires special blast chambers to control debris. Chemical etching uses dangerous acids and requires costly waste

disposal. Both etching processes require screens to be replaced each time a new mark is needed.

Table 3 Comparison of laser vs. other marking technologies

Marking process	Speed	Performance	Image flexibility
Laser marking	Good	Good	Good
Chemical etch	Good	Good	Poor
Photo etch	Good	Good	Poor
Ink-jet	Good	Poor	Good
Mechanical stamping	Good	Good	Poor
Pneumatic pin	Moderate	Good	Moderate
Vibratory pencil	Poor	Good	Good

CONCLUSIONS

Nowadays, among laser processing methods, laser marking is the most utilised. It assures a superior quality of marks versus the conventional marking techniques.

The need to process materials having special characteristics and the necessity of realizing micro-processing impose the designing and the achievement of some technological systems capable to satisfy these requirements.

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