INDUSTRIAL Laser Solutions FOR MANUFACTURING

application report

Marking and engraving—when less is more

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ADVANCES IN LASER DESIGN TECHNOLOGY FOR MARKING APPLICATIONS ENHANCE EFFICIENCY, BEAM QUALITY AND PROCESSING TIME

Marking lasers are now fundamental tools in most manufacturing industries. CO_2 lasers are typically employed when a simple thermal continuous wave interaction between laser and material to be marked is required. The more versatile Q-switched Nd:YAG lasers with a modulated output of a train of giant pulses produce a strong interaction with many materials ranging from any kind of metal to many plastics and ceramics. Today, diode-pumped, Q-switched solid-state lasers are the preferred choice for most industrial applications because they exhibit long maintenance-free operating periods in the range of 10,000 hours.

The most important laser beam parameters that influence laser beam/material interaction are summarized as follows. A given material can be processed efficiently only if the laser wavelength falls in a range where light absorption is sufficiently high; the shorter the wavelength, the more energetic the photons, making short wavelength lasers particularly aggressive on most materials. The beam diameter in the focal spot is proportional to laser wavelength, so shorter wavelengths also result in smaller spots, higher processing precision and higher energy density on the workpiece.

In Q-switched lasers, energy can be concentrated in pulses as short as a few nanoseconds, at a repetition frequency up to hundreds of kilohertz producing peak power several thousand times higher than average power. For instance, a 10W Q-switched marking laser can easily show a peak power of 50 kW, resulting in very efficient interaction with any kind of material surface, even the most reflective metals.

Beam quality relates to the ability of the laser beam to be collimated or tightly focused. When the laser beam approaches the theoretical limit of light diffraction, it can be focused to the smallest possible spot. Measurement of beam quality is specified by a numerical factor called M^2 whose value is equal to 1 in the case of diffraction limit (TEM_{00} laser mode) and higher in all other cases (multimode lasers). Beam quality is directly linked to the concept of laser brightness (optical power per unit area per unit solid angle). In simple terms, a "bright" laser source exhibiting an intense, tightly focusable single-mode beam should have a low M^2 value.

Average power alone is not sufficient to define the effectiveness of a laser source in a given marking application or to compare the effectiveness of one laser versus another.

Assuming the source wavelength is fixed; peak and average power density in the focal spot (power per unit area) can better tell if a surface interaction between light and matter can take place as desired. Only laser sources with close figures of power density in the focused spot can be compared on an average output power basis. Conversely, sources in the same average power range should be compared on a power density basis, which is strongly affected by beam quality. Given a laser beam with a certain M^2 value, a

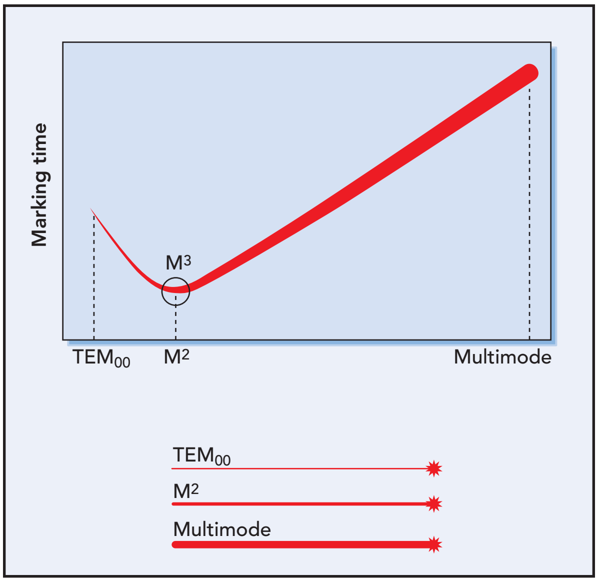

FIGURE 1. M3 Design technique allows optimized laser resonator design for marking applications. It grants the shortest execution time versus M^2 beam quality parameter of the laser source.

laser beam with the same output power and twice the M^2 value shows four times lower power density in the focal spot. Typical M^2 values of commercial marking lasers can range between 1 and 30; unfortunately not all laser manufacturers specify M^2 values of their products, thus making an evaluation of the actual power density in the focal spot difficult.

During the past decade many laser manufacturers have implemented diode pumping on their industrial marking laser products. The typical design approach, however, merely replaced arc lamps with laser diodes, a choice that leads to higher reliability and more efficient devices with long maintenance-free operating periods, but still with the typical drawbacks of multimode marking lasers. These multimode diode-pumped lasers may only achieve better beam quality to the detriment of output power and actual pumping efficiency, a figure that contributes directly to the cost of the laser system because the pumping source cost is an important part of the overall laser cost.

Recenty, researchers at Bright Solutions s.r.l. (Cura Carpignano, Italy), the research and development subsidiary of the Laservall group, proposed a novel design concept specifically for solid-state marking and micro-machining lasers. The purpose is to increase the actual pumping efficiency, thus lowering the cost of laser material processing, while reducing laser size, weight and cooling requirements. This method (patent pending) comprises a longitudinal pumping technique allowing total absorption of pumping light, resulting in a very high pumping efficiency and, simultaneously, an accurate control of output beam quality (low M^2). Laservall calls this laser design "M3 Design" (Marking Matched Mode) and offers this technology in a range of solid-state, Q-switched laser sources specifically designed for laser marking applications. Laservall marking lasers such as the Violino and Sagitta series lasers feature pumping efficiency as high as 50 percent with output beam mode specifically designed to match the resolution and beam quality requirements of marking applications and to optimize the material processing rate (marking time).

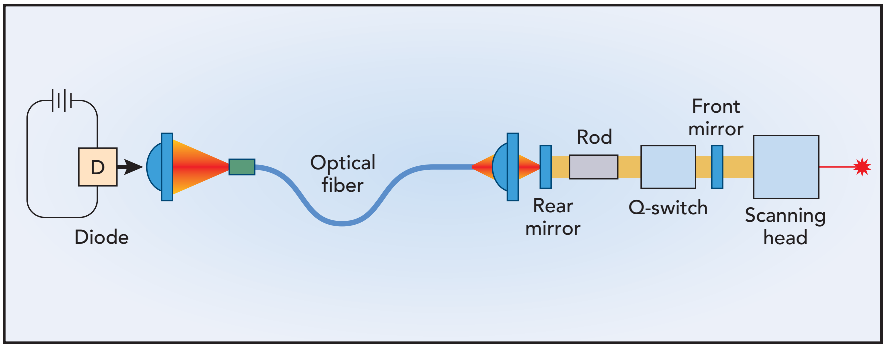

FIGURE 2. Laservall Violino marking laser operating concept.

The M3 Design premise is that, depending on the laser output power, an optimum beam quality can be found that minimizes marking time while keeping a high pumping efficiency. Simply explained: a strongly multimode beam results in poor reaction with the material to be marked, and so marking time becomes very long, while a TEM_{00} laser beam gives a very tight focus resulting in efficient interaction with the material. Even at high power levels, a TEM_{00} laser beam still marks thin lines, thus increasing the time required to process large areas that require marking or engraving of a filled area. This idea is intuitively illustrated in Figure 1. M3 Design is aimed at creating a hybrid quality beam that mixes the benefits of both and maximizes marking quality and process time.

Laservall has installed more than 700 M3 Design lasers worldwide in industrial marking applications. The optimized power conversion of these laser sources makes them lightweight and compact. As an example, a high-brightness, 20W, 1064nm Q-switched laser such as the Violino "3" exhibits an M^2 <2, with a resonator volume of 1.5 liters and wall plug efficiency higher than 10 percent. Such a laser source, using a standard 160mm *f*-theta lens, can reach an average power density higher than 1 MW/cm^2 and peak power density of a few GW/cm^2 using Q-switched pulses shorter than 10 ns. At this beam intensity, the laser interaction with most known materials is surprisingly strong.

These lasers do not need water cooling due to a high pumping efficiency. The laser pump diodes are positioned inside the electrical control rack and pumping light is delivered to the laser resonator via a fiber-optic cable. Exhausted laser diodes can be replaced in the field without interfering with the laser resonator, which contains permanently mounted optics and is sealed in a cleanroom environment. Laser diode temperature is kept under control by a telecom-grade, highly reliable, solid-state thermo-electric cooling system.

These lasers show efficient interaction with non-linear optical media as a result of the high peak power and good beam quality, so second and third harmonic conversion has been proven with the green (532 nm) and UV (355 nm) versions of the Violino series.

These advances in laser design technology have created a new benchmark in laser marking applications in terms of efficiency, beam quality, processing time and ease of maintenance and integration, making lasers a more attractive alternative to traditional marking methods in all fields of application.

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