New optics for industrial laser applications: VariSpot® and VariFoc™

Julio Serna[a], George Nemeş[b]
[a]Departamento de Óptica, Universidad Complutense, 28040 Madrid, Spain; azul@fis.ucm.es
[b]Astigmat, Santa Clara, CA 95050, USA; gnemes@astigmat-us.com

ABSTRACT

Two new families of zoom optical systems, developed for industrial and medical laser applications, are introduced. First we discuss the main physical processes involved in industrial laser applications and the requirements for the optics. The spatial beam parameters are reviewed, explaining the relatively new concepts of intrinsic stigmatism and intrinsic astigmatism. Then two new zoom systems are discussed, including experimental examples: VariSpot®, which delivers round spots with adjustable diameters at fixed working distances, and VariFoc™, able to adjust spot shapes and sizes at different working distances. We conclude that these systems represent a valuable addition for industrial and medical lasers.

Keywords: Zoom optics, laser beam, intrinsic stigmatism, intrinsic astigmatism, VariSpot®, VariFoc™

1. INTRODUCTION

The design of any industrial or medical laser systems should start with the study of the main physical processes involved and the parameters that are important for the application. We can divide the typical physical processes induced by most industrial lasers in three wide regions: heating, melting and vaporization. For them, the basic parameters that control the working regime are pulse power P, spot area A, pulse duration τ, irradiance $E = P/A$, and fluence $H = E\,\tau$. Spot area has a special importance, since not only it defines the area affected by the laser beam, but it also can be used to control both irradiance and fluence. Typical spot sizes range from 30 mm – 2 mm used in heating processes, such as annealing or hardening, down to 0.1 mm – 0.005 mm used in the vaporization regime. A brief summary of the physical processes and the laser beam requirements can be found in Table 1 and Figure 1, adapted from Reference 1. Therefore, if we want to have a laser system with an extended range of applications it is important to have an adequate control over the spot size. There are other two desirable properties: it would be advantageous to have a fixed working distance and it would be advantageous to provide round or elliptical beams. For these purposes, two new optical systems, VariSpot® and VariFoc™, are especially suited. Compared to classical optical systems they offer a wider range of variation of the spot size and control over the beam shape.

2. SPATIAL CHARACTERIZATION OF LASER BEAMS

Traditional optics uses imaging systems, while lasers use optical systems for transforming the beams, often not imaging systems. Therefore, it is important to have an adequate understanding of optical beams, optical systems and how optical systems modify the beams. For this purpose it is helpful to use the ISO 11146 standards,[2] where definitions of the spatial parameters of laser beams and their measurement procedures are given. ISO 11146 are based on the second-order moments method, and define parameters such as beam widths, divergences, waists positions and beam propagation ratios.[3] Laser beams have different symmetry properties in free-space propagation. Some of them are round everywhere along their axis (as, for example, a He-Ne laser beam), and are called stigmatic beams, some others have in their most symmetrical form an orthogonal symmetry (as, for example beams from diode lasers or from excimer lasers), and are called simple astigmatic. Less symmetrical beams do also exist, and are called general astigmatic, even though, sometimes, they look in free-space very similar to the stigmatic or the simple astigmatic ones.[2,3] Optics based on lenses/mirrors and free-spaces is used to change the spatial beam properties and often we are interested to get for applications the most symmetrical beams. However, some intrinsic beam properties cannot be changed by such optics. Beams that can be transformed with lenses/mirrors into stigmatic ones, are called intrinsic stigmatic (IS), and those that cannot be transformed into stigmatic beams are called intrinsic astigmatic (IA). Many gas lasers, solid state laser and low

INDLAS 2007: Industrial Laser Applications, edited by Mircea Udrea
Proc. of SPIE Vol. 7007, 700704, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.801927

power diode lasers deliver IS beams. Most excimer lasers, high power diode lasers, and diode bars and stacks generate IA beams. When designing an optical system it is important to know if we are going to have different beam widths, divergences or waists along different orthogonal transversal axes (the so called actual or classical astigmatism). But it is also important to know the type of beam, IS or IA, since the actual astigmatism can be totally compensated for IS beams, but only partially for IA beams.

Table 1. Physical processes, the corresponding applications, and typical requirements to obtain them.

Process (physical phenomena)	Requirements	Typical spot sizes
(i) Heating Heat-treating Annealing; Hardening Stereolithography (rapid prototyping, solid imaging)	Constant temperature Avoid melting Long pulse, quasi-CW: 10^{-4} s – 10^{0} s Low-medium irradiance, 10^{2} W/cm^{2} – 10^{6} W/cm^{2}	2 mm – 30 mm 0.05 mm – 0.8 mm
(ii) Melting Cutting; Welding Cladding; Sintering	Avoid vaporization Long pulse, quasi-CW: 10^{-6} s – 10^{-1} s Medium-high irradiance, 10^{4} W/cm^{2} – 10^{10} W/cm^{2}	0.1 mm – 10 mm
(iii) Vaporization Marking / Cutting / Drilling Microprocessing: IC repairing; Mask repairing; Hard disk texturizing Wire stripping; Resistor trimming; Surface cleaning; Paint removal; Thin film deposition	Short pulse: 10^{-12} s – 10^{-4} s (even fs pulses) High irradiance, 10^{6} W/cm^{2} – 10^{12} W/cm^{2}	0.005 mm – 0.1 mm

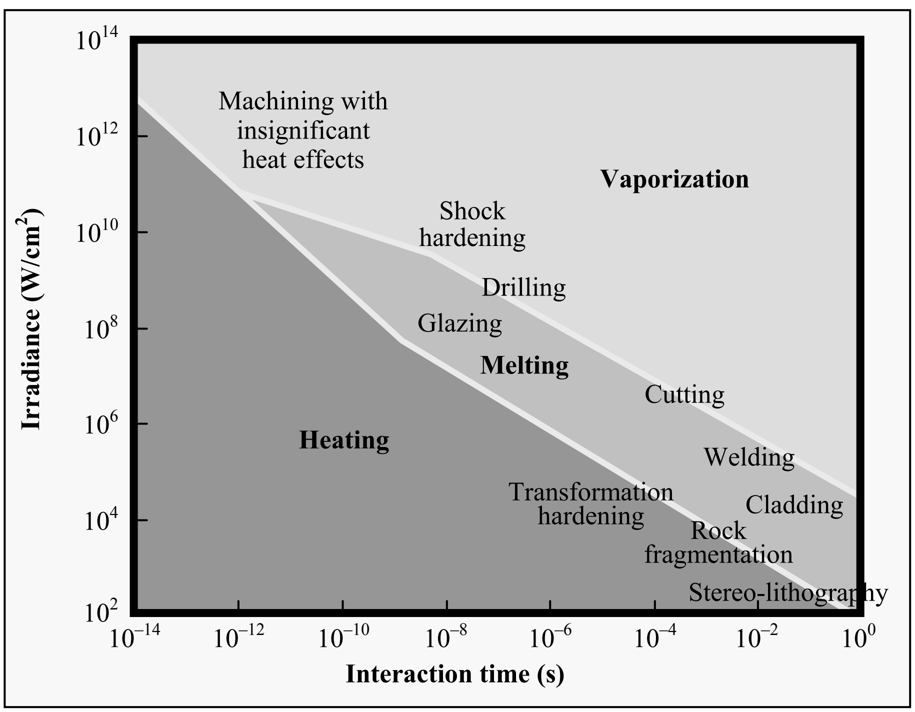

Figure 1. Irradiance vs. interaction time for three physical processes leading to various laser applications (from Reference 1).

3. NEW OPTICAL SYSTEMS: VARISPOT® AND VARIFOC™

There are several requirements for an optical system to be able to cover all three ranges of processing (heating, melting and vaporization):

- it should be able to provide a wide range of spot sizes at the target plane for IS beams, 0.005 mm – 30 mm (see Table 1)
- it should have a large dynamic range of spot sizes, $K \geq 100$, to assure a dynamic range of irradiances on target greater than 10^4 ($K = D_{Max}/D_{min}$, ratio of maximum to minimum spot size (diameter))
- it should have a fixed, or adjustable, working distance
- it should be able to work with IS and IA beams.

Considering these requirements it is found that classical solutions, such as single lenses or zoom systems working with collimated beams, have limited performances. In the simplest case, if we use a single lens with a collimated stigmatic laser beam we can have a constant spot size at a fixed working distance. Variable spot sizes can be obtained in this case only if we accept a variable working distance. With a collimated beam and a 2× – 40× adjustable demagnifying telescope we can obtain a better result, but to have a fixed working distance the resulting K is still relatively small, $K \leq 20$. To overcome such limitations two new optical systems, VariSpot® and VariFoc™, are proposed. These systems have a wide range of potential applications, keeping at the same time a level of complexity similar to the classical solutions.

The first family of optical systems we discuss is called VariSpot®. These systems work with collimated IS beams, transforming the input beam into an astigmatic beam with an adjustable-size round spot at a fixed working distance. There are many versions within the VariSpot® family, each with its advantages for a specific application: long/short option, focus-mode/image-mode, round/elliptical incoming collimated beam. VariSpot® works with no translational movement of optics, but just adjusting (continuously or in steps) an angular position of an optical element with a rotating ring. The design can be adapted to different laser types, wavelengths, and different laser working regimes. In a VariSpot® the "depth of roundness" (DOR) substitutes the classical "depth of focus" parameter. DOR is approximately 2 z_R, where z_R is the Rayleigh range of the outcoming beam corresponding to its smallest spot size.[4,5]

Figure 2 is a picture of a particular VariSpot®, a long version designed for the visible and near-infrared range.

Figure 2. VariSpot®, long option, for visible and near-infrared beams (400 nm – 800 nm).

The typical input/output beam characteristics of the system pictured in Fig. 2 are:

- Incoming beam characteristics:
  - Low average power ($P \leq 1$ W)
  - Stigmatic, round beam, $M^2 \leq 2$
  - Wavelength (λ): Visible/near- infrared range (400 nm – 800 nm)
  - Waist diameter (D_0): 0.5 mm - 6.0 mm
  - Waist positioned at VariSpot® input aperture
- Output beam characteristics:
  - Round spot at working distance
  - Working distance: 140 mm (other working distances possible)
  - Minimum spot diameter (typical: λ = 670 nm, M^2 = 1.6, D_0 = 4 mm): 0.05 mm
  - Maximum spot diameter: 12 mm
  - K (typical): ≥ 200
  - DOR (typical): ≥ 4 mm

In the focus-mode regime VariSpot® systems can be designed to provide a large dynamic range of spot sizes, K = 10 – 400, with a minimum spot size being the diffraction limited spot compatible to the incoming beam divergence and the working distance. In the image-mode regime the dynamic range is smaller, K = 2 – 20, but the irradiance profile of the input beam is maintained in the round spot at the target plane, something very useful when we are dealing with special profiles at a certain plane. An example can be seen in Figure 3, taken from Reference 4, where a K = 10 dynamic range in the image-mode is obtained for a Fermi-Dirac flat-top beam.

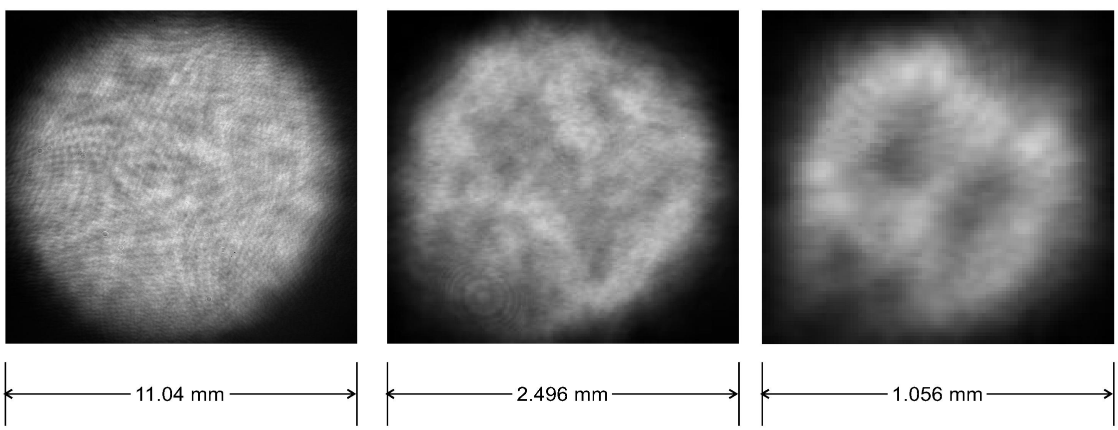

Figure 3. K = 10 dynamic range of output spots obtained with an incoming Fermi-Dirac flat-top beam and a VariSpot® short-length option working in the image-mode regime (from Reference 4).

A second type of new optical system is the VariFoc™. The system is equivalent to two identical zoom systems acting independently on horizontal and vertical direction. It works with incoming IA and IS beams, not necessarily collimated, so it is extremely useful for IA lasers (excimers, diode bars, diode stacks) but it is equally useful for the lasers having an IS beam. It can compensate the actual astigmatism of a beam, since it acts independently in two perpendicular transverse directions. With VariFoc™ different spot shapes and sizes are obtainable, as can be seen in Figure 4 in the case of a N_2 UV laser. Starting with a circular or an elliptical spot it can deliver either a circular spot or another elliptical (elongated) spot, both with adjustable-sizes. The working distance is adjustable from a minimum distance to infinity. VariFoc™ focusing is obtained using a rotating drum. It can also be designed for different wavelengths and laser working regimes. VariFoc™ is thus an optical system complementary to VariSpot® and provides a large flexibility to obtain different spot shapes, spot sizes and working distances, but can also be used as a stand-alone beam delivery system practically for any type of laser.

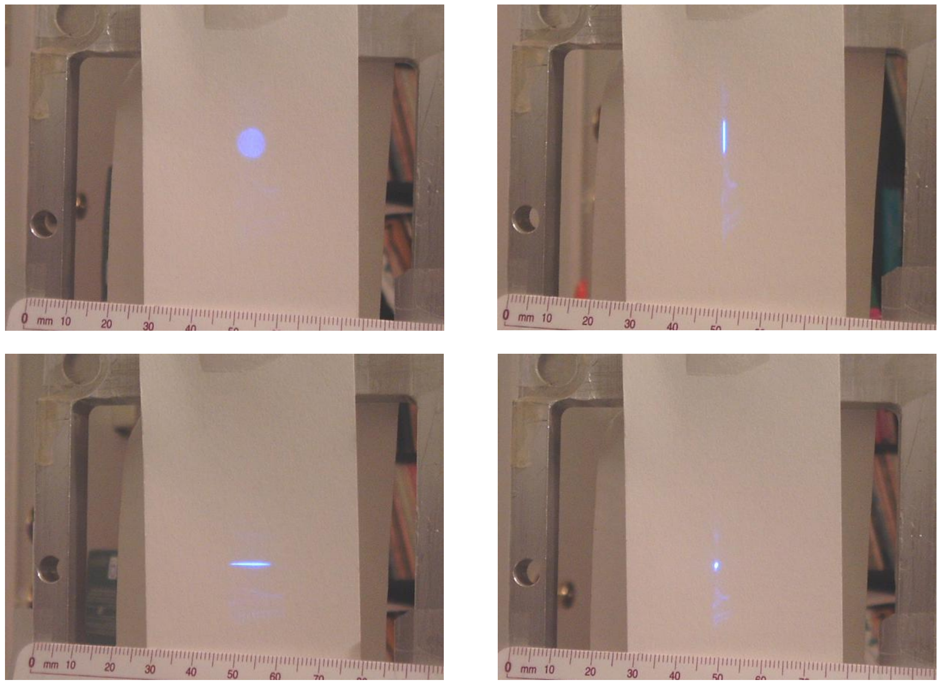

Figure 4. Different spot shapes and sizes obtained with a VariFoc™ and a N_2 UV laser.

4. CONCLUSION

Two new families of zoom-type optical systems, VariSpot® and VariFoc™, intended for industrial or any other type of applications requiring adjustable spot shape and size, and fixed or adjustable working distance, were presented. VariSpot® systems work with incoming IS and relatively well-collimated laser beams and provide a round spot, adjustable in diameter, at a fixed working distance. In the so-called focus-mode regime the highest dynamic range of the spot sizes (ratio between maximum to minimum spot size) of any known zoom systems can be obtained, 20 – 400. In the so-called image-mode regime an adjustable-size replica of the incoming beam profile (for example a flat-top profile) is obtained in the target plane, at the working distance. VariFoc™ systems work with any kind of incoming laser beams, IS and IA, and the output beam spatial characteristics can be independently adjusted in two transverse orthogonal directions. Thus, various spot shapes and spot sizes, at desired and adjustable working distances can be obtained. VariFoc™ systems complement the capabilities of VariSpot® systems.

REFERENCES

1. K. H. Leong, “Evolving laser processing,” *Industrial Laser Solutions* 19, 17–19 (2004).
2. Standards ISO 11146-1, 2, 3:2004-2005, “Lasers and laser-related equipment – Test methods for laser beam widths, divergence angles and beam propagation ratios,” International Organization for Standardization, Geneva (2004, 2005).
3. G. Nemeş, J. Serna, “Laser beam characterization with use of second order moments: an overview,” OSA TOPS 17, 200–207 (1998).
4. G. Nemeş, J. A. Hoffnagle, “Optical system for variable resizing of round flat-top distributions,” Proc. SPIE 6290, 629008 (2006).
5. C. Fenic, L. Neagu, C. Viespe, Gh. Honciuc, and G. Nemeş, “Damage tests for 355 nm laser mirror by using a VariSpot® optical system,” Proc. SPIE 6606, 66060C (2007).