Hybrid diffractive optics offer an elegant solution

Thanks to a set of unique properties, diffractive optical elements have the potential to transform light into almost any desired distribution. **Joshika Akhil** gives the low-down on the technology that can benefit laser marking, material processing, heat treatment, sensing, non-contact testing and optical metrology, to name just a few applications.

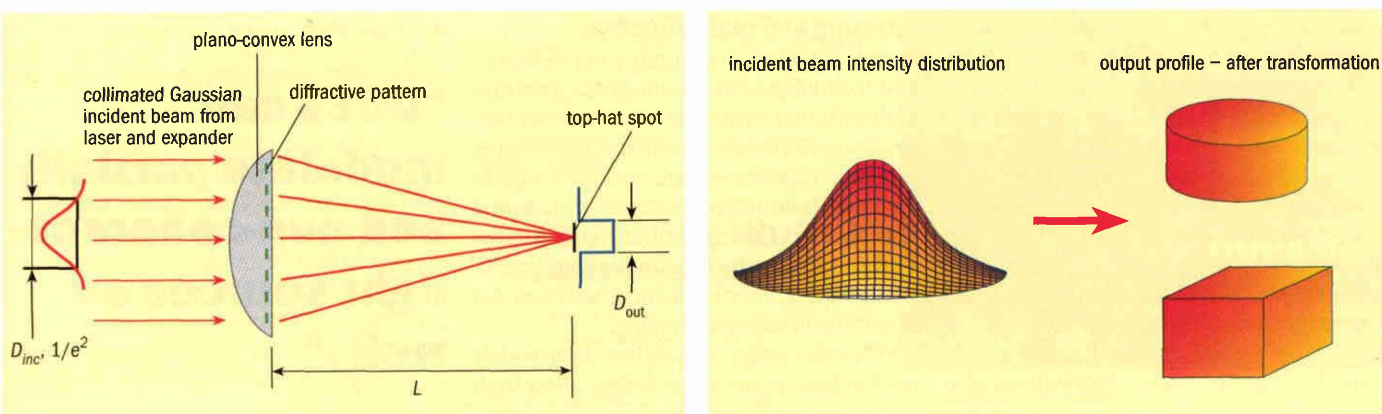

Fig. 1: top-hat beam shapers can deliver outstanding results, transforming a near-Gaussian incident laser beam into a uniform-intensity spot.

Diffractive optical elements (DOEs) can modify laser beams in almost all of the same ways as conventional refractive optics, but with the added attraction of beam manipulation. Elements such as beam homogenizers, diffusers, beam samplers, diffractive focal lenses, beam splitters and various grating structures can transform light into almost any desired distribution. Furthermore, the modulation of light is not limited to laser beams – DOEs can be used to modulate partially and non-coherent light sources as well.

User benefits

DOEs have the unique ability to transform the original beam into a variety of shapes, distributions and numbered spots without unduly affecting the output intensity of the entire system. One of their greatest advantages is that a single optical element can often replace multiple optical systems to customize the beam profile to the desired shape and intensity distribution.

Recent developments in design and process control now allow DOEs to be manufactured in a compact, reliable and cost-effective way. Using lithographic techniques, a microrelief diffraction grating can be etched into the optical element to create a single optical device.

Diffractive optics redistribute the energy between the centre and the periphery of a laser beam, making them ideal for beam shaping (figure 1). Beam homogenizers smooth out the intensity profile of an incident beam and suit applications such as laser ablation and heat treatment, where hot spots within the beam are undesirable.

Traditionally, beam homogenizers have been restricted to operation within the focal plane of a lens (spot operation) or have a minimum working distance. If operated outside of these conditions, undesired peaks can appear in the distribution. However, there is a new device on the market that is less sensitive to positioning, called an HM-type homogenizer.

Beam shapers create specific energy-distribution patterns with sharp edges. The basic technique involves remapping the intensity-distribution profile of the incident beam into a uniform spot distribution of a specific size and shape, and at a specific distance. In principle, any transverse spot shape can be obtained, although the most useful geometries are typically round, rectangular and square. Adding a lens to the diffractive element shifts the location and changes the scale of the distribution, tailoring it to specific applications.

One great advantage of the so-called diffractive top-hat beam shaper over other uniform illumination systems is that it eliminates the trade-off between efficiency and spot uniformity by diffractively redistributing the beam energy. Other techniques can simply block out a significant part of the energy.

Users should remember that to achieve outstanding results, the incident beam must have a collimated Gaussian profile and be centred on the element. Beam expanders and spatial filters can be used to optimize the input beam.

Important role

Top-hat intensity distributions suit applications where a controlled transfer of energy at the spot is essential, particularly in processes that have an exposure level and damage threshold for a given power density. Examples include raster-scan-picture generators and high-power laser treatments in material processing and medical applications.

As a result, DOEs are proving to be an essential component in industry sectors such as laser ablation; welding and drilling; medical and aesthetic lasers; and laser displays. The uniform-intensity spot, steep transition region and sharp profile offer unmatched manageability and accuracy.

However, beam shaping is not limited to simply a top-hat output intensity profile. Custom optical elements can be manufactured to give various spot shapes and intensity distri-

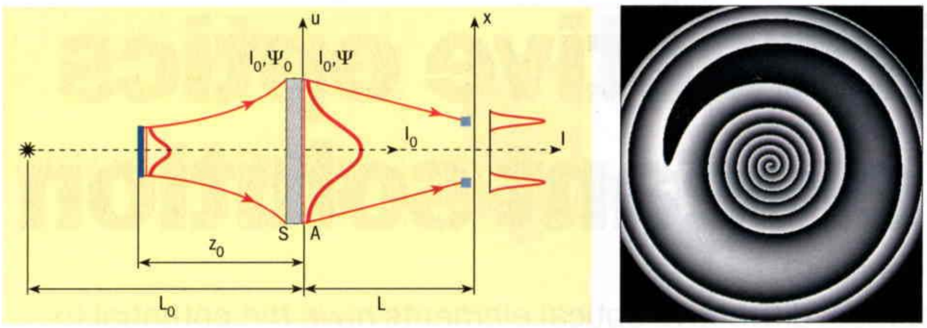

Fig. 2: Schematic view of a line contour set-up (left) and the corresponding output pattern (right).

butions while maintaining high efficiencies.

Conventional lenses generate focused spots, whereas a diffractive focusing element can provide the required caustic line in the focal plane (figure 2). Using a plano-convex lens as the focusing element with a diffractive microrelief pattern on its plano surface, the DOE directs laser light towards the line contour (straight line, ring, polygons etc) instead of at a single focal spot. Thus, a line-contour focal image is achieved from the collimated laser beam without any scanning system.

The line-contour focusing element provides novel opportunities in laser marking, drilling and in the welding of plastics and metals using high-power lasers. Applications also exist in machinery and microelectronics; the optical heads of scanning laser writers; optical information processing; and laser surgery.

Splitting and multiplication

Recent advances in diffractive optics theory and technology have made beam splitting/multiplication a valuable resource for optical designers. Applications range from spot-array generation and fibre-optic coupling through to laser heat treatment of material surfaces and laser ablation. Other promising opportunities for the technique include multiple and multi-focal imaging, laser-beam mode selection and simultaneous contour shaping.

Diffractive beam splitters have been widely used in laser perforation as they allow high throughput and accurate positioning, without leaving any working residual materials (figure 3, p35). By integrating diffractive beam splitters into these systems, several perforations can be achieved simultaneously with extremely accurate distances between the spots, removing the need for a moving *x–y* table and improving performance.

Multiple-spot (including double-spot) DOEs provide a line or an array of identical focal spots located in the focal plane and can be arranged in a one or two-dimensional pattern. DOE beam splitters offer advantages including uniformity in power between the spots (±1% can be achieved for standard 1 × 2 and 2 × 2 splitters and significantly more for other designs). The positional predictability of each beam/spot is also enhanced.

"DOEs can modulate partially and non-coherent light sources as well."

Beam sampling

Another DOE closely related to the beam splitter is the beam sampler, which enables inline measurements of high-power laser beams to be made. The device produces two exact copies (samples) of the input beam with only a small fraction of the total power, while the main part of the master beam continues in the optical train. This allows the sample beams to be measured and analysed while the main beam remains unaffected and operational. Beam samplers can be produced to suit custom angles, wavelengths and various power fractions of the main beam.

Diffractive beam samplers are being used in place of conventional optics more and more, because they offer a clean, non-invasive analytical solution. For example, they are replacing burn-off modal measurements for CO_2 lasers. Since there are no burning elements in the system, no by-products are produced. Also, the diffractive beam samplers are not polarization dependent and so measurements can be taken while the laser is operating online.

Diffractive beam samplers can be used to monitor high-power CO_2, Nd:YAG and other lasers in materials processing, medical applications and in laser radar systems.

A single diffractive corrected focusing lens can equal the high performance of a complex multiple-optical-element objective lens. The

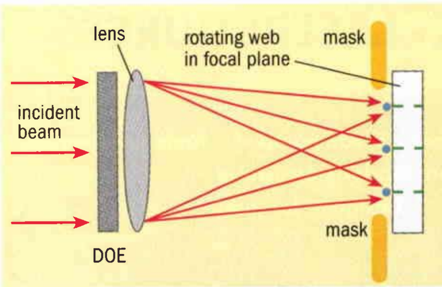

Fig. 3: the beam splitter DOE accepts a collimated beam and produces a number of beams with the same characteristics as the incident beam except for angle of propagation and power. By placing a focusing lens close to the element, all beams can be focused into spots. A mask is recommended for blocking higher order diffraction fringes.

diffractive microrelief pattern on the plane side of the lens gives a diffraction-limited spot size that demonstrates a sharp focusing effect and a dramatic increase in power densities, even for long focal length DOEs.

Diffractive corrected focusing lenses offer unique properties not matched by conventional optics. "Special effects" include off-axis sharp focusing; control of the focal spot shape; controlled introduction of spherical aberration; longer depth of focus; chromatic correction; and double (multiple) spot focus.

Combining two beams

Many medical CO_2 (10.6 µm) laser systems use a red He:Ne (632.8 nm) laser or laser diode (635 nm) module (LDM) to generate an aiming or pilot beam. It is essential that the visible He:Ne/LDM beam coincides with the invisible CO_2 beam so that the CO_2 focal spot can be easily identified. Conventional methods often use lens doublets and crystalline optics such as potassium bromide elements, which are hygroscopic and relatively inconvenient to work with.

An elegant solution to this problem is a single hybrid diffractive element called a dual-wavelength beam combiner. This is a zinc selenide lens with a microrelief diffraction pattern etched into the plane side. The diffractive pattern can be designed to control just one wavelength. When placed in the path of the 10.6 µm and 633 nm laser beams the DOE superimposes both wavelengths at the same focal spot, without the need of doublets.

The durability of the diffractive beam combiner far exceeds the two-lens system alternative. Also, the integral light transmittance of the diffractive dual wavelength element outperforms any on-axis reflective systems, with figures exceeding 98%. □

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