Annular Heating of Optical Fiber with a CO_2 Laser Using Reflective Axicon Elements

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Abstract

A method of providing consistent uniform and controlled zone heat at a fiber's surface is presented using a CO_2 laser with axicon reflective elements. This optical configuration converts a laser beam into a light structure resembling a disc or cone that can band a fiber's perimeter. The characteristic of this structure is its inherent ability to deliver increasing power density through uniform convergence toward the structure's center thus applying the appropriate melting heat to varying sizes of fiber. By offsetting the light structure, precise localized zone heating and annealing of specific areas at a fiber's surface can be achieved as well. This is essentially a passive devise into which active feedback elements can be incorporated to allow precise control of processes such as splicing, tapering, ball and axicon lensing, end capping and combiner fabrication.

Keywords: Axicon, Zone heating, Quasi Laguerre Gaussian beam, Conical and cylindrical beam structures, Fiber laser combiners, End caps, Tapering, Ball lensing, Splicing.

1. Introduction

Approaches that have been presented in the generation of conical and cylindrical beams are typically refractive [1] and demonstrate the projection of quasi Laguerre Gaussian profiles, such as LG02 modes [4], shown in Figs. 1 and 2. Cylindrical annular beams and conical beams have been demonstrated for trepanning, ablating and sputtering materials by Danyong Zeng [1]. An expanded cylindrical beam method using a parabolic mirror has been explored by Wysocki, et al [5] at the Hughes Research facility for fiber processing.

Currently, we employ two opposing beams to heat and condition glass fibers up to 2.3 mm [2-3] as shown in Fig. 3. A three-beam configuration is also under development and being employed in the processing of fibers larger than 2.3 mm. In this instance, contiguous zone heating is precisely controlled to ensure even heat distribution round a fiber's surface. Another method, discussed in this presentation, uses an annular light structure and is also being explored to enable delivery of consistent zone heating. In order to accommodate fibers of small-to-very-large diameters, for example, 60 µm to 25 mm, a uniform heat source for all zone heating is essential. Using a single beam conditioned to project an annular or conical heat structure provides consistent uniform heating for changing fiber sizes.

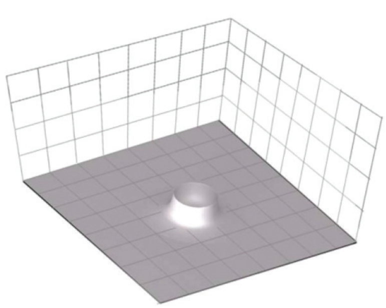

Fig. 1—Quasi Laguerre Gaussian Beam Profile

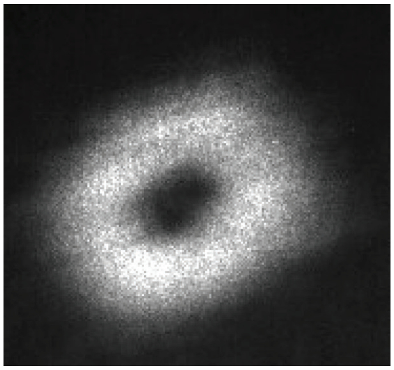

Fig. 2—LG 02 mode

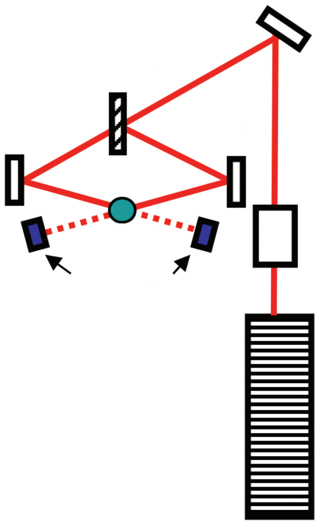

Fig. 3—Laser fusion splicing

Fig. 4—Laser Fusion Splicer

2. Current Technologies

Laser fusion splicing has been employed in laboratory settings for at least 20 years. Over the past two years, AFL has applied an opposing beam configuration to achieve successful splicing, tapering, ball and axicon lensing and combiner fabrication. AFL's LZM-100 LAZERMaster™ Laser Splicing System is the first commercially available laser fusion splicer that can accomplish these processes with fibers up to 2.3 mm in diameter, Fig. 4, [2]. Above 2.3 mm diameters, fusion splicing requires greater power density, a larger source and precision controlled heat zone distribution. The primary challenge is to evenly distribute contiguous heat zones around very large diameter fibers. Kiln type methods can be employed, as with Vytran's Omega filament technology [6], but precise localized melting becomes a challenge with large diameter fibers.

3. Even Continuous Heat

In addition to AFL's three beam configuration currently under development, an annular type heating application is being developed and tested for uniform heat delivery for melting fibers of varied sizes from 60 μm and upward. On the following page, Fig. 5 illustrates one method used to accomplish this. A single-beam source hits the apex of an axicon reflector or cone reflector which generates a conical beam. This conical beam is then converted using a secondary conical or cylindrical reflector to produce a quasi Laguerre Gaussian beam. The beam bands the fiber evenly creating a symmetric heat zone. The power density increases as the reflected annular beam converges to the center thus maintaining the power densities necessary for melting varying sizes of fiber with little or no adjustment of the source power.

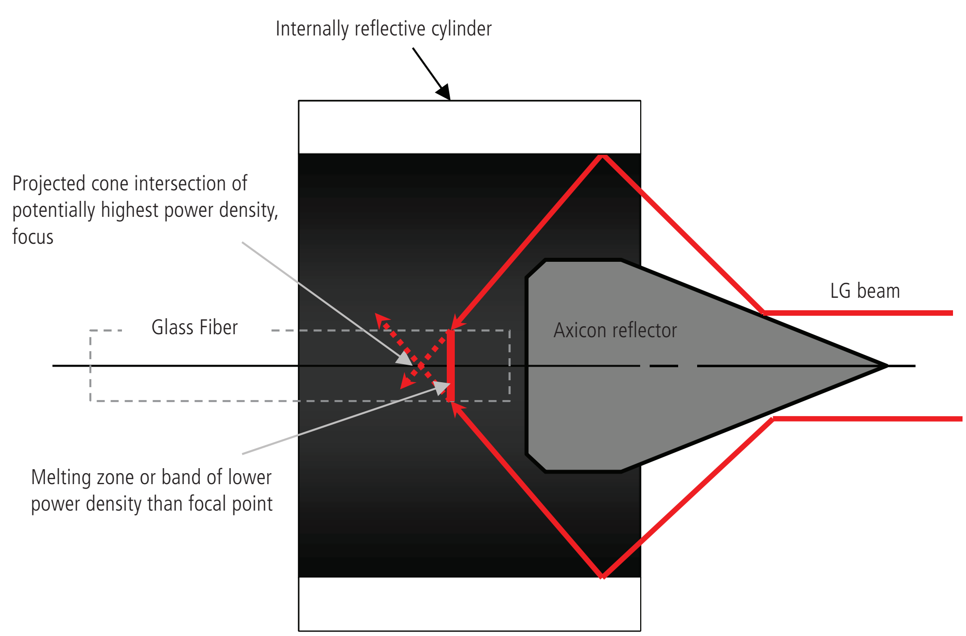

Fig. 5—Cone Generation

A reflected 635 nm cone projection can be seen in the following demonstration in Fig. 6 and an acrylic burn by CO_2 laser demonstrated in Fig. 7. Both images demonstrate a clear circular pattern that is conducive to evenly heating and melting fiber at proper power densities. This can be set initially by calibrating the source to the optimal melting power level.

Fig. 6—635 nm cone projection

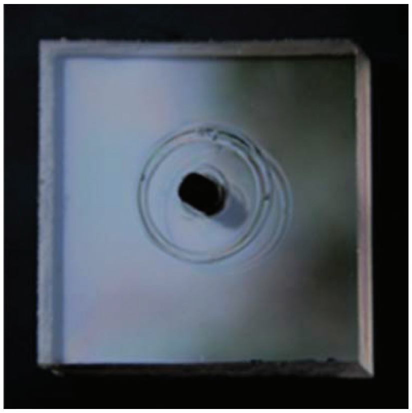

Fig. 7—10.6 µm acrylic burn

Figures 8 and 9 illustrate the methods of zone heating fiber using the projected annular structure. In our experiment the structure is centered about a fiber or fiber bundle and has also been offset to generate more intense localized heat distribution at specific zones.

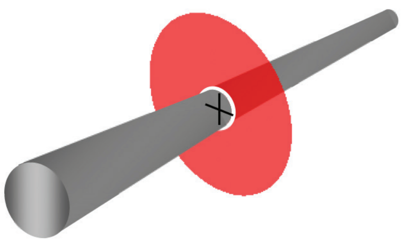

Fig. 8—Centered Even Annular Heating

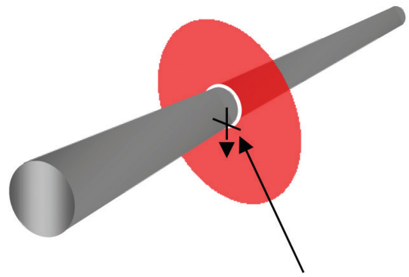

Fig. 9—Offset Annular Zone Heating

4. The Axicon Elements Tested

Figure 10 shows the reflective axicon configuration used to fuse 3 mm diameter fused silica glass rod to a 500 µm fiber.

The arrangement comprises three polished copper elements and a polished tungsten electrode. The beam passes through an aperture at the back of the 45 degree parabolic mirror. The initial beam passes through this aperture striking the tungsten electrode first and generates a conical beam structure onto an axicon back reflector. The reflector projects a steep conical (almost cylindrical) cone structure back to the parabolic mirror which then reflects a shallower cone into the polished copper cylinder.

During this experiment the output from the polished cylinder focused the conical laser energy onto the face of the glass rod. The 500 µm fiber was then stuffed into the glass rod for 5 seconds which bonded the smaller fiber to the preheated larger rod. Notice that the 500 µm fiber in Fig. 10 passes over the parabolic mirror and into the polished cylinder. The power density at the periphery of the cone is low enough allowing the fiber to pass through the cylinder without melting until it is arrives at the highest power density at the face of the glass rod, Fig. 11.

This arrangement is applied to fabricating end caps, splicing very large glass rods to smaller fibers and fiber bundles.

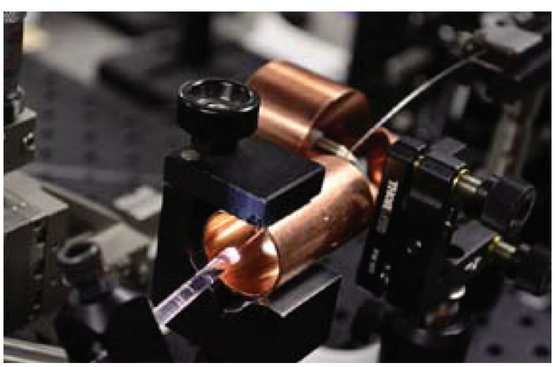

Fig. 10—Four element configuration using axicon elements

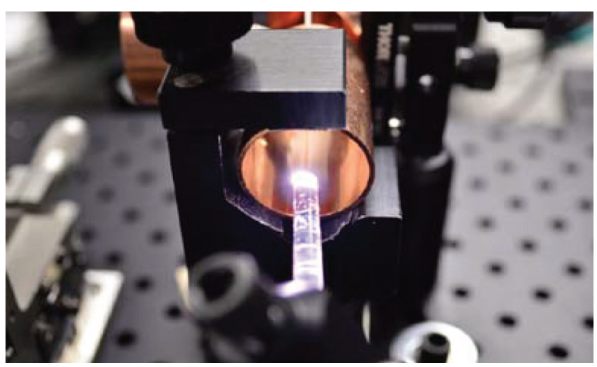

Fig. 11—500 µm fiber fused to 3mm glass rod

5. APPLICATIONS

5.1 Combiners

A 3-to-1 fiber combiner is illustrated below, Fig. 12. This 3-to-1 fiber combination can be fused together with other 3-to-1 fiber clusters to create for example, a 9-to-1 combiner. The 9-to-1 can then be used to produce a 27-to-1 combiner, 27-to-1 can yield a 63-to-1 combiner and so on.

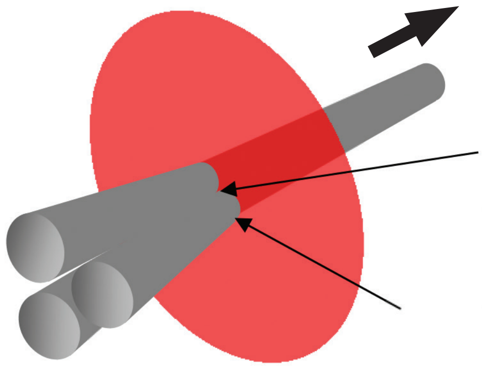

Fig. 12—Drawing a 3-to-1 fiber combiner through an annular heat structure.

5.2 End Caps

A conical shaped heat structure is projected onto a large diameter fiber localizing the heating area to match the size of the smaller fiber to be fused into place, Fig. 13.

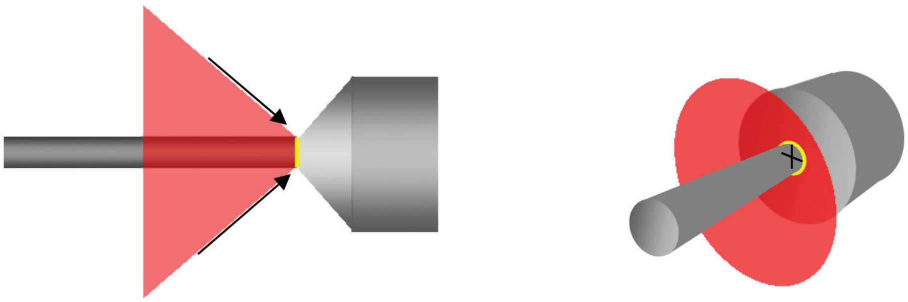

Fig. 13—Heating the surface of a large diameter substrate to accommodate a smaller diameter fiber to an end cap.

5.3 Tapers

As the fiber is drawn through the annular heat structure at controlled rates the precise power density required to melt the changing fiber diameter is maintained, Fig. 14. Power per unit area matches fiber size; the smaller the fiber diameter the higher the power density exhibited toward the center of the structure.

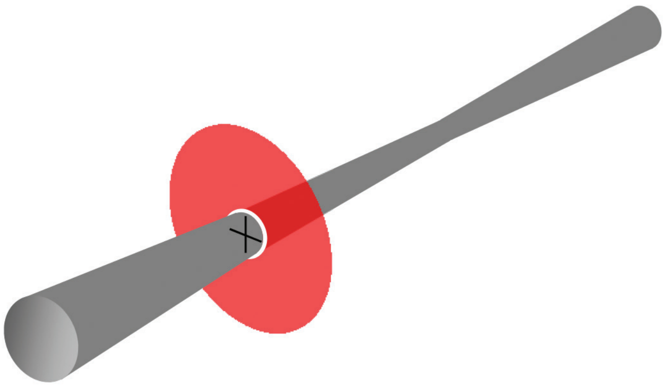

Fig. 14—Drawing a taper through an annular heat structure.

6. Summary

This is a recent endeavor and requires more testing with data collection. It has proven successful for splicing large fibers to smaller fibers and combining small 125 µm fiber bundles which can be applied in the fabrication of combiners. Other applications are being tested at this time.

7. Acknowledgements

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8. References

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