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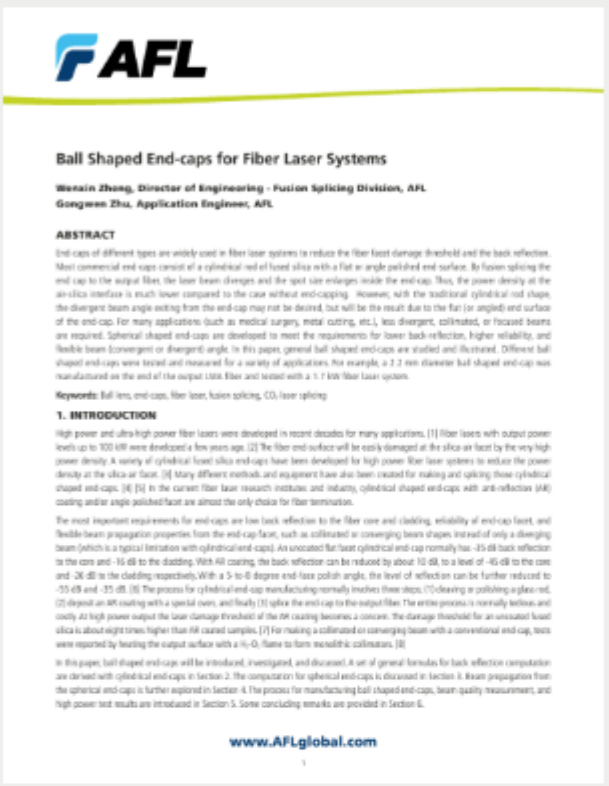

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Ball Shaped End-caps for Fiber Laser Systems

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ABSTRACT

End-caps of different types are widely used in fiber laser systems to reduce the fiber facet damage threshold and the back reflection. Most commercial end-caps consist of a cylindrical rod of fused silica with a flat or angle polished end-surface. By fusion splicing the end cap to the output fiber, the laser beam diverges and the spot size enlarges inside the end-cap. Thus, the power density at the air-silica interface is much lower compared to the case without end-capping. However, with the traditional cylindrical rod shape, the divergent beam angle exiting from the end-cap may not be desired, but will be the result due to the flat (or angled) end surface of the end-cap. For many applications (such as medical surgery, metal cutting, etc.), less divergent, collimated, or focused beams are required. Spherical shaped end-caps are developed to meet the requirements for lower back-reflection, higher reliability, and flexible beam (convergent or divergent) angle. In this paper, general ball shaped end-caps are studied and illustrated. Different ball shaped end-caps were tested and measured for a variety of applications. For example, a 1.2 mm diameter ball shaped end-cap was manufactured on the end of the output 1550 fiber and tested with a 1.1 kW fiber laser system.

Keywords: Ball lens, end-caps, fiber laser, fusion splicing, CO_2 laser splicing

1. INTRODUCTION

High power and ultra-high power fiber lasers were developed in recent decades for many applications. [1] Fiber lasers with output power levels up to 100 kW were developed a few years ago. [2] The fiber end-surface will be easily damaged at the silica-air facet by the very high power density. A variety of cylindrical fused silica end-caps have been developed for high power fiber laser systems to reduce the power density at the silica-air facet. [3] Many different methods and equipment have also been created for making and splicing those cylindrical shaped end-caps. [4] [5] In the current fiber laser research institutes and industry, cylindrical shaped end-caps with anti-reflection (AR) coating and/or angle polished facet are almost the only choice for fiber termination.

The most important requirements for end-caps are low back reflection to the fiber core and cladding, reliability of end-cap facet, and flexible beam propagation properties from the end-cap facet, such as collimated or converging beam shapes instead of only a diverging beam (which is a typical limitation with cylindrical end-caps). An uncoated flat facet cylindrical end-cap normally has ~3.5 dB back reflection to the core and ~ 16 dB to the cladding. With AR coating, the back reflection can be reduced by about 10 dB, to a level of ~45 dB to the core and ~26 dB to the cladding respectively. With a 5- to 8- degree end-face polish angle, the level of reflection can be further reduced to ~55 dB and ~35 dB. [6] The process for cylindrical end-cap manufacturing normally involves three steps: (1) cleaving or polishing a glass rod, (2) dip-coat an AR coating with a special oven, and finally (3) splice the end-cap to the output fiber. The entire process is normally tedious and costly. At high power output the laser damage threshold of the AR coating becomes a concern. The damage threshold for an uncoated fused silica is about eight times higher than AR coated samples. [7] For making a collimated or converging beam with a conventional end-cap, lens were reported by heating the output surface with a H_2-O_2 flame to form monolithic collimators. [8]

In this paper, ball shaped end-caps will be introduced, investigated, and discussed. A set of general formulas for back reflection computation are derived with cylindrical end-caps in Section 2. The computation for spherical end-caps is discussed in Section 3. Beam propagation from the spherical end-caps is further explored in Section 4. The process for manufacturing ball shaped end-caps, beam quality measurement, and high power test results are introduced in Section 5. Some concluding remarks are provided in Section 6.

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