All Fiber Cladding Mode Stripper with Uniform Heat Distribution and High Cladding Light Loss Manufactured by CO_2 Laser Ablation

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ABSTRACT

Cladding mode strippers are primarily used at the end of a fiber laser cavity to remove high-power excess cladding light without inducing core loss and beam quality degradation. Conventional manufacturing methods of cladding mode strippers include acid etching, abrasive blasting or laser ablation. Manufacturing of cladding mode strippers using laser ablation consist of removing parts of the cladding by fused silica ablation with a controlled penetration and shape.

We present and characterize an optimized cladding mode stripper design that increases the cladding light loss with a minimal device length and manufacturing time. this design reduces the heat generation by improving the heat distribution along the device. We demonstrate a cladding mode stripper written on a 400 µm fiber with cladding light loss of 20 dB with less than 0.02 dB loss in the core and minimal heating of the fiber and coating. The manufacturing process of the designed component is fully automated and takes less than three minutes with a very high throughput yield.

Keywords: CO_2 laser splicing, Glass ablation, Glass processing, Glass shaping

1. INTRODUCTION

Cladding mode strippers (CMS) are essential components in fiber lasers and are used to attenuate the high order modes propagating in the pump guide of a double cladding fiber. Cladding mode strippers serve two major purposes: in the co-propagating direction, they help maintain good beam quality by attenuating the cladding light mainly originating from the un-absorbed pump and leaks from the fiber core due to bending and splice losses. In the counter propagating direction, CMS help protect the laser from back-reflected light, easily coupled in the large numerical aperture pump guide, in order to ensure a stable and reliable operation of the fiber laser.

Considering that output power of fiber lasers have reached a multi-kilowatt levels, the amount of power that cladding mode strippers are exposed to can be significantly high. For the example of a 10 kW laser with 70% efficiency and 99% of pump absorption, one can expect to have around 143 W of unabsorbed pump light. In practice, this pump power can be higher due to temperature induced wavelength shifts of pump diodes which affect the actual fiber pump absorption. [1] As a result, high power handling is a major consideration when designing a cladding mode strippers design in addition to pump attenuation and signal loss.

Several CMS fabrications techniques have been presented in the literature. The use of high index recoating material was explored as a straight forward method to leak cladding light out of the pump waveguide. [2] This solution can be used with relatively low power lasers and amplifiers but has a few practical limitations. High index polymers refractive indexes are temperature dependent and therefore, the efficiency of these CMS devices often varies with the output power of the laser. In addition, the heat generated by the CMS manufactured with this method is localized at the input side of the device, which limits the device's power handling and its long term reliability.

Acid etching was also studied as an alternative method to fabricate CMS by tapering a double clad fiber using hydrofluoric (HF) acid vapors. [3] While showing promising results, this method requires a long exposure of the fiber to highly corrosive acid vapors and therefore requires elaborate safety control measures which makes it unattractive to production environments.

Laser-ablated cladding mode stripper were recently developed[4] showing very high pump extraction in a well-controlled and chemical-free experiment. In the latter study, a periodic structure was laser engraved on the cladding of a double cladding fiber achieving a -20 dB attenuation of the cladding light as well as a very low signal loss. While yielding excellent results, the light extracted using this method was mostly localized at the input side of the device because of the fixed depth of the engraved features. As a result, a hot spot of nearly 80°C was generated when exposed to pump light.

In this work, we present an improved version of laser engraved cladding mode strippers, optimized for device length, processing time and heat generation. We present and characterize a cladding mode stripper design that improves the cladding light loss while reducing the heat generation by improving the heat distribution along the device. We demonstrate a cladding mode stripper written on a 400 μm fiber with cladding light loss of 20 dB with less than 0.02 dB loss in the core and minimal heating of the fiber and coating. The manufacturing process of the designed component is fully automated and takes less than three minutes with a very high throughput yield.

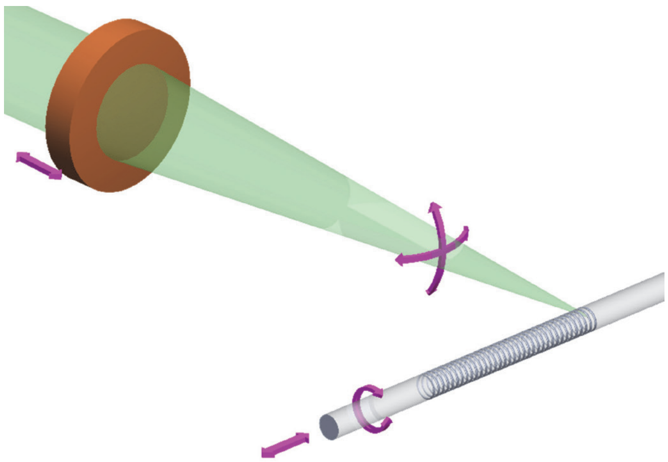

Figure 1 — Glass ablation with LZM- 110A+

2. FUSED SILICA ABLATION USING 10.6μm CO_2 LASER

The cladding mode strippers were fabricated using the LAZERMaster LZM-110A+ glass processing system. The LZM-110 family uses a feedback control stabilized 40 W CO_2 laser operating at 10.6 microns. [5][6] The laser beam is focused into a ~40 micron diameter spot and aligned to be at 0.26 radians angle to the fiber axis. The beam waist location is controlled via high precision actuators that guarantees sub-micron position control in all (x,y,z) directions. The fiber is held with a pair of holders designed to accommodate fiber diameters ranging from 80 to 2000 microns in diameter. The fiber can be continuously rotated around its axis and moved in the longitudinal and radial directions with submicron precision, as shown in Figure 1. The fabrication process consists of ablating a continuous groove with a controlled depth by continuously rotating the fiber around its axis and simultaneously moving it in the longitudinal direction (z). Different ablation parameters were used to optimize the device's cladding light stripping while maintaining the lowest signal loss, beam quality and heat generation. Figure 2 shows an example of fixed depth cladding mode stripper with a length of 20 mm and ablation depth of 35 μm. Control over the ablation depth of the surface features was achieved by moving the focusing lens along the beam propagation axis.

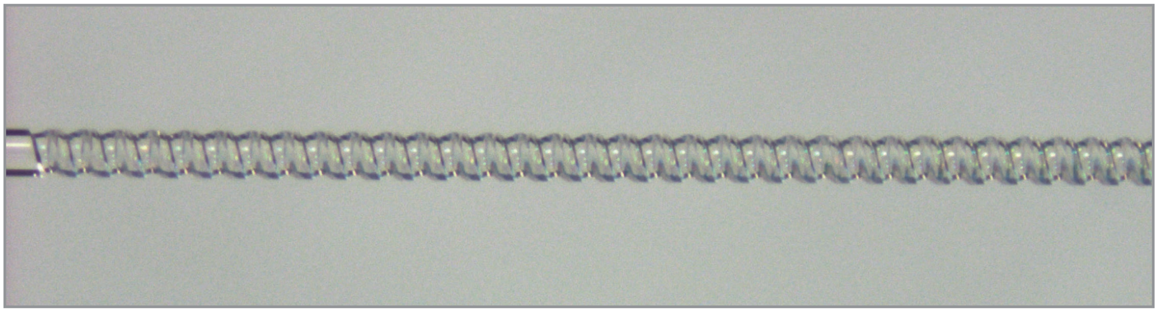

Figure 2 — Fixed depth cladding mode stripper laser ablated on a 20/400/440 LMA fiber with a depth of 35 microns

3. METHOD FOR DEVICE CHARACTERIZATION

Figure 3 depicts the CMS experimental characterization setup where a fiber laser pump configuration is constructed. A set of 965 nm multimode pump diodes are combined using a 6+1-> 1 Tapered fused bundle (TFB) combiner. The output fiber of the pump diode is a 105/125 multimode fiber with a numerical aperture of 0.22. The signal fiber of the TFB is a 20/400/440 double clad optical fiber DCOF with a core NA of 0.08 and cladding NA of 0.45, manufactured by AFL using the LZM-100 glass processing system. The signal branch of the combiner is connected to a single-mode source operating at 1064 nm and fiber coupled into a standard 6/125 single clad fiber with an NA of 0.1. Because of the large core and NA mismatch of the two fibers, a Mode Field Adapter (MFA) also manufactured by AFL is used to properly couple light from the single-mode 6 micron core into the fundamental mode of the 20 micron core of the large mode area fiber. The characterization experiment consists of a cut-back measurement of the insertion loss of the CMS for both the signal and pump light.

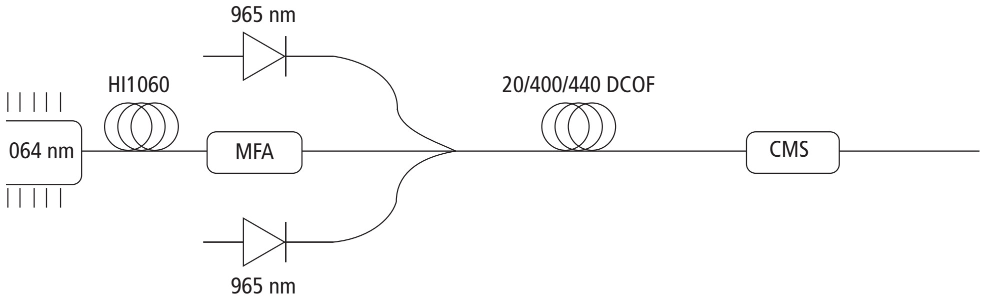

Figure 3 — Cladding Mode stripper characterization setup

We experimentally compared five CMS samples fabricated at the same length but with different depth profiles. The first step in the characterization process is to gradually increase the pump power and record the device temperature. A maximum pump power of 160 W was injected into the different samples. The second step is to turn off the pump diodes and turn on the signal laser to reference the output power using an integrating sphere. The device is then removed to measure its insertion loss.

In order to accurately characterize the device's pump insertion loss, an aperture was placed between the cladding mode stripper and the thermopile detector as shown in Figure 4. The aperture's role is to block the leaked light along the cladding mode stripper from reaching the thermopile and affecting the cutback measurement.

The LZM-110A+ was used to create the five cladding mode strippers. The 20 mm lengths of the 20/400/440 double clad fiber were grooved at various depths and then spliced into the system shown in Figure 3.

The cladding mode strippers in Table 1 were produced in two ways. Firstly, CMS #1-3 were translated along the Z-Axis with continuous rotation as the beam ablated the fiber at a fixed focus position.

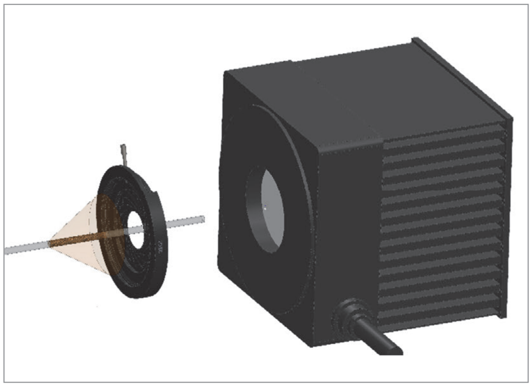

Figure 4 — Cladding Mode Stripper measurement setup

CMS #	MAX GROOVE DEPTH (μm)	SLOPED LENGTH (MM)	FIXED LENGTH (MM)	ATTENUATION (dB)	FAILURE POWER (W)	CORE LOSS (dB)
1	37	0	20	-12.2	—	—
2	70	0	20	-26.4	30	—
3	60	0	20	-26.3	52	—
4	67	20	0	-17.74	—	—
5	67	15	5	-19.6	—	0.01

Table 1 — Experimental Cladding Mode Strippers produced with the LZM110A+

As this fixed depth was increased from 37 μm (CMS#1) to 70 μm (CMS#2), the device attenuation increased from -12.2 dB to -26.3 dB. However, the power density of the leaked cladding light was located within the first 7 mm of the device and caused catastrophic failure at only 30 W of power Figure 5 . Similarly to a cladding mode stripper created using high index recoating material, nearly all of the heat was concentrated on the input side of the device. CMS#3 was created with reduced groove depth which increased the damage threshold from 30 to 52 W while achieving an acceptable pump attenuation of -26.3 dB.

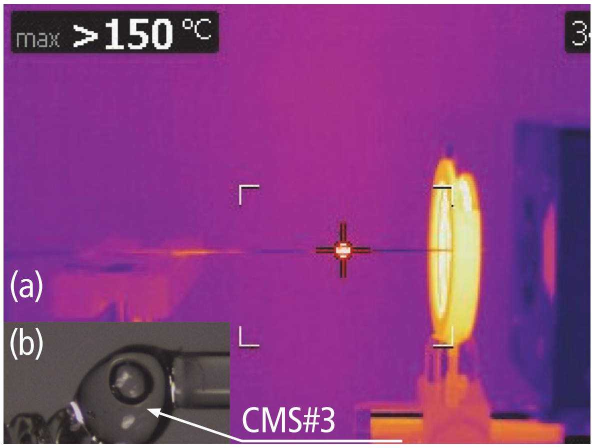

Figure 5 — Thermal measurement of 70 μm-grooved CMS#3, at 30 W pump power

To achieve the target attenuation of -20 dB along the same 20 mm length of fiber, a variable groove depth was introduced. As shallower grooves attenuate less power and generate less heat, the gradual increase in depth allows for much more attenuation from the input direction approaching the deep grooves near the output. In order to produce the sloped grooves, CMS#4-5 were translated along the Z-Axis while ablating the fiber, while the motorized beam expander of the LZM-110A+ translated toward the fiber. The translation of the beam expander resulted in an initially shallow groove with a smoothly increasing depth.

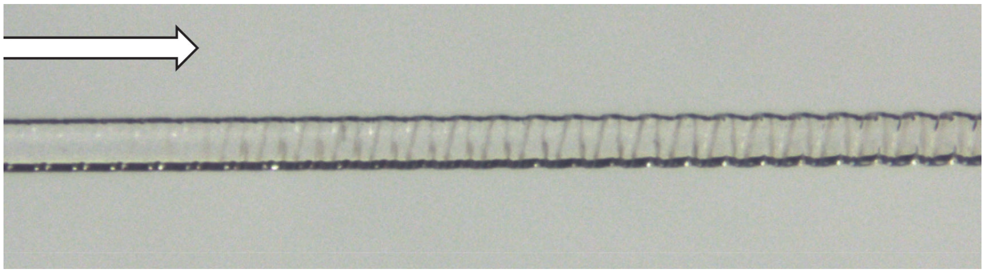

Figure 6 — Linearly increasing depth along CMS#5

Ultimately, this design dissipates heat more uniformly and did not fail at an input pump power of 120 W. In order to achieve better attenuation, the slope of the depth was increased by ~25%. The profile, therefore, was ~15 mm of gradually increasing depth until reaching 67 microns, followed by~5 mm of 67 micron grooves. The resulting cladding mode stripper attenuated 19.6 dB while maintaining less than 0.02 dB signal loss. Both CMS#4 and CMS#5 showed an even distribution of heat over the 20 mm length of the device, as seen in Figure 7. By gradually increasing the ablation depth, the cladding mode stripper allowed a gradual dissipation of the power allowing for a heat-sink free operation at a pump power of 120 W.

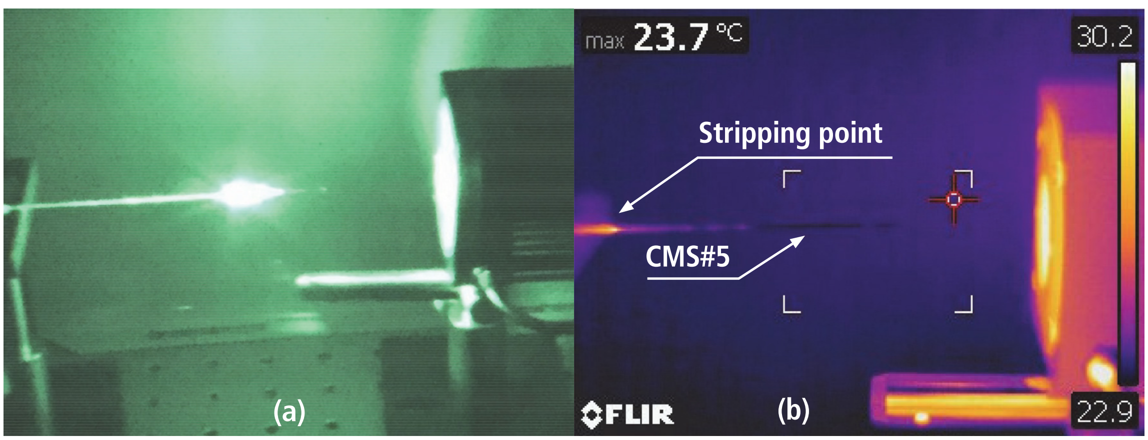

Figure 7 — Thermal measurement of variable depth CMS, 120 W

Figure 7a shows a picture of the measurement setup of CMS#5 at full pump power taken with a camera equipped with a high resolution image converter, that converts near infrared radiation to a bright green light. The bright spot in this picture corresponds to the gradually extracted pump power. The right side of this figure shows the thermal image of the same setup. The cladding mode stripper operated at room temperature when driven at 120W pump power. A slight increase of temperature (~30°) was recorded at the stripping point of the double cladding fiber.

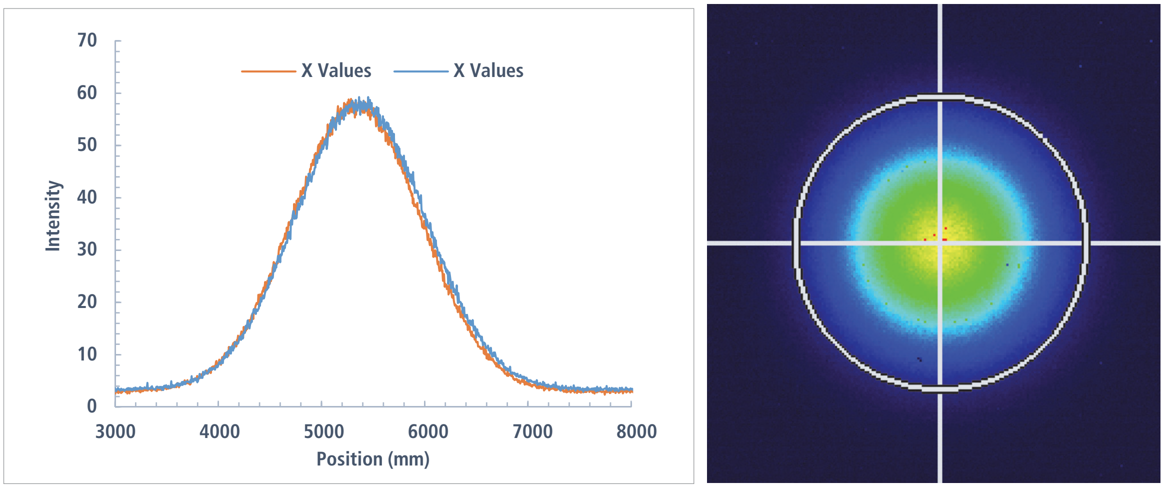

Figure 8 — Beam profile of the output of the cladding mode stripper

The beam profile of the 1064 nm signal launched through the cladding mode stripper is shown in Figure 8. The beam profile is measured to ensure that the ablation process did not induce stresses in the fiber and caused coupling of light into higher order modes.

Figure 9 — LZM-110 family of Glass Processing Systems

CONCLUSIONS

An all-fiber cladding mode stripper was fabricated using glass ablation feature of the LZM-110A+ glass processing system, shown in Figure 9. Different cladding mode strippers were experimentally compared in order to achieve the highest cladding light stripping while maintaining the lowest signal loss and heat generation. Cladding attenuation as low as ~20 dB is achieved while maintaining a core insertion of less than 0.01 dB was measured and Gaussian output beam profile. No significant temperature elevation was recorded on the CMS sample fabricated with a variable ablation depth.

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