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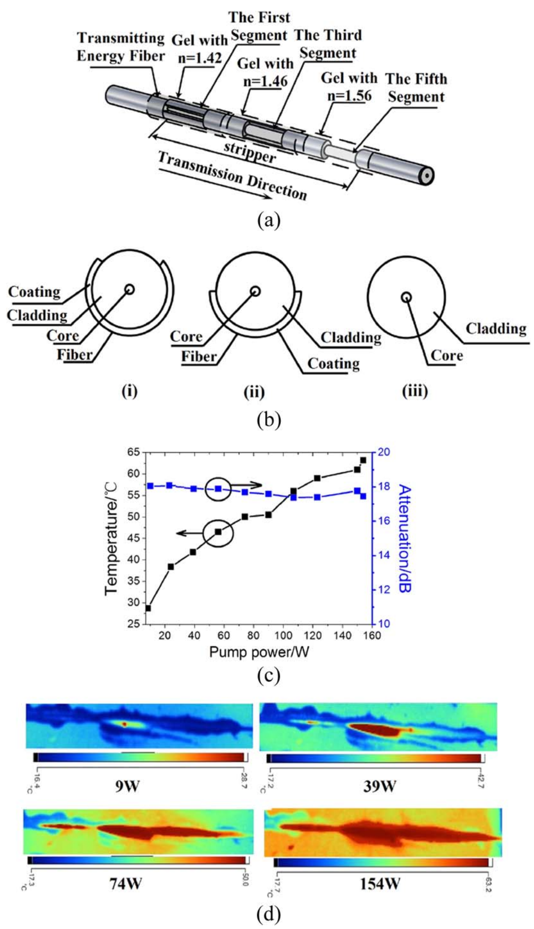

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Cascaded Cladding Light Extracting Strippers for High Power Fiber Lasers and Amplifiers

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Abstract: We demonstrate efficient cladding light extracting through cascaded strippers for high-power fiber lasers and amplifiers. A selected part of the fiber is divided into five segments, and the fluoroacrylate jackets of three interval segments are gradually removed and replaced with different higher index polymers. It is shown that such cascaded strippers can overcome the challenging problems of localized heating and thermal degradation of the recoating materials, which are limiting factors for the conventional high power cladding light strippers. The power-handling capability of the device is tested up to cladding light of power up to 150 W. A high attenuation of 18 dB has been achieved, whereas the maximum local temperature is less than 64 °C. We anticipate that this simple configuration offers a practical solution for cladding light extracting in high power fiber lasers and amplifiers.

Index Terms: Cladding light stripper, double-cladding fiber, fiber lasers and amplifiers.

1. Introduction

Fiber lasers have attracted enormous attention in recent years due to their rich advantages, such as high beam quality, high efficiency, low cost, high power, and so on [1]–[7]. In high power double-cladding all-fiber lasers and amplifiers, there are many splice loss sources of fiber and leakages of light from the core to the cladding [8], [9]. The main source of the cladding light is unabsorbed pump light at the end of the gain fiber, which can reach hundreds of watts in the kilowatt-class systems [10], [11]. If the cladding light is not filtered properly, it will not only degrade the laser beam quality, but also increase the risk of damage of different components, e.g., collimators. In order to improve the quality of the systems and the output beam, it is important to filter all of the cladding light efficiently.

In the design of a cladding light stripper, there are three points that should be considered. Initially, to avoid localized heating, the stripper should have the capacity to remove the cladding light within a reasonable length. In addition, the signal light must not be affected while traveling through the core. Furthermore, several parameters are of importance to have impacts, including refractive index and thickness of the recoating layers, the fiber diameter, and geometrical, thermal, and optical features of the whole package [12]. To achieve this goal, several methods have been presented to remove

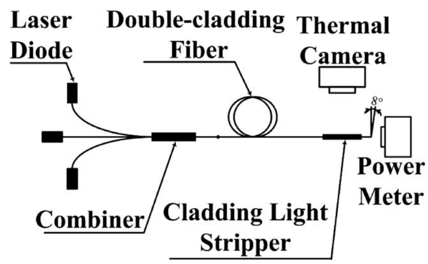

Fig. 1. Schematic setup of the experiments. Three laser diodes are coupled into a 3 × 1 combiner and the output fiber is spliced to the cladding light stripper and observed by a thermal camera.

the cladding light. Conventional method is to use different recoat gels, of which the refraction indexed are larger than that of the inner cladding [13]. However, this kind of stripper always leads to heat localization, which further worsens as the cladding light increases. In another method, the inner cladding is eroded from 400 μm to 125 μm to strip the cladding light [14]. In [12], they managed to extract the unwanted cladding light uniformly by tapering the fiber and corroding its surface using HF acid and HF acid vapor, respectively, and then used a low-index polymer to make the most uniform light stripping possible. However, the fabrication of this stripper is time-consuming and very complicated.

In this paper, a simple method for cascaded extracting for cladding light from the fiber is presented. A selected section of the fiber is divided into five segments and the original fluoroacrylate jackets of three interval segments were removed, which utilizes the high indexes of polymers to make the uniform light stripping possible. The power-handling capability of the device is tested for cladding light power up to 150 W, and attenuation of 18 dB has been achieved with the maximum local temperature less than 64 °C in any region. We also emphasize that the fabrication of this stripper is very simple.

2. Experiments and Results of the Cladding Light Strippers

The first thing to do to strip cladding light in the double cladding fiber is to recoat the fiber with a high index coating. An important step is to remove the original fluoroacrylate jacket and to choose the index of the recoat. There are two kinds of designs for cascaded cladding light extracting strippers, just as follows. In order to evaluate the performance of the two kinds of strippers, the experimental setup is described as follows: three 55 W laser diodes are coupled into a 3 × 1 combiner (input fibers: 105/125 μm, NA0.15; and output fiber: 200/220 μm, NA0.22), and the output fiber is spliced to the cladding light stripper (double-cladding fiber: 30/250 μm, NA0.06). A 90 × 30 × 10 mm copper slab is used to cool down the stripper. The copper slab is water cooled and water temperature is kept constant at 16 °C. The setup of the experiments is shown in Fig. 1.

2.1. Conventional Method of Cladding Light Strippers

As a first step, we chose the cladding light strippers recoated with one or two kinds of polymers of different refractive indexes. First, 5 cm area of a fiber, stripped continuously, is prepared to be a stripper, as shown in Fig. 2(a). In the first experiment, a fiber is chosen to be recoated with polymer, the refractive indexes of which is 1.46 or 1.56, alternatively, as shown in Fig. 2(b-i) and (c-i). In experiment two, the polymers with 1.46 and 1.56 refractive indexes were equally recoated in the preparation area simultaneously, as shown in Fig. 3(a).

In experiment one [see Fig. 2(b)], the results of 1.46-refractive-index polymer are as follows: 83 W power of diode laser light was launched into the fiber and attenuated by 16.73 dB, and the highest temperature of the hot region reaches 95.2 °C. For the configuration of the polymer with 1.56 refractive index [see Fig. 2(c)], 83 W power of diode laser light was launched into the fiber and attenuated by 17.43 dB, and the highest temperature of the hot region reaches 86.3 °C. A hot spot could be formed by the accumulative heat and observed by thermal camera (Fluke Ti32, which range is −20 °C ∼ +600 °C and the resolution is ≤ 0.045 °C.), as shown in Fig. 2(b-iii) and (c-iii).

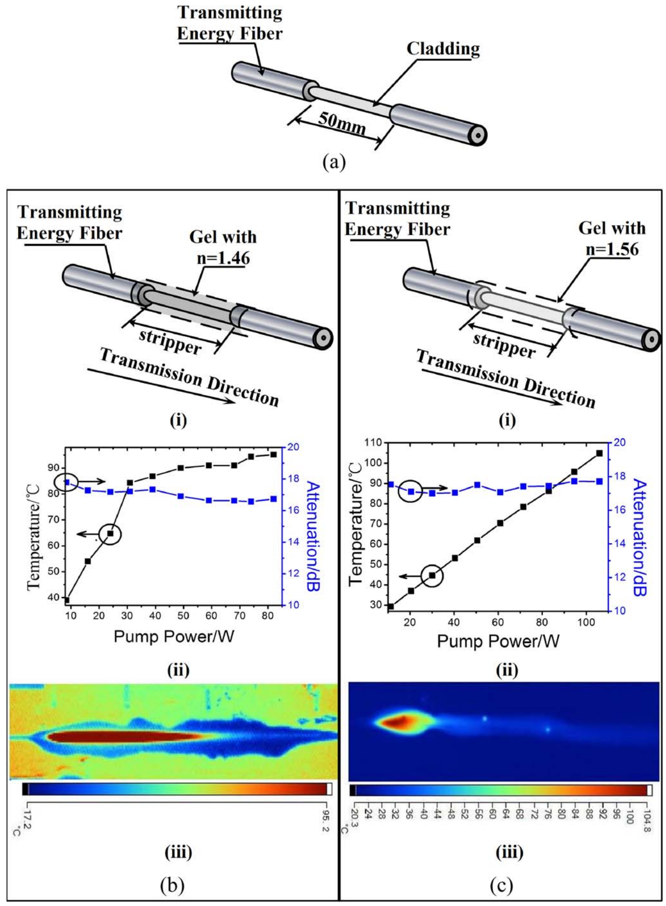

Fig. 2. (a) Schematic illustration of the stripped fiber. (b-i) Schematic illustration of the stripper consisting of a polymer with refractive index of 1.46. (b-ii) Graph of relationship between the temperature and the attenuation consisting of a polymer with refractive index of 1.46. (b-iii) Thermal image of the stripper consisting of a polymer with refractive index of 1.46, tested with 83 W of pump power. (c-i) Schematic illustration of the stripper consisting of a polymer with refractive index of 1.56. (c-ii) Graph of relationship between the temperature and the attenuation consisting of a polymer with refractive index of 1.56. (c-iii) Thermal image of the stripper consisting of a polymer with refractive index of 1.56, tested with 83 W of pump power.

In experiment two [see Fig. 3(a)], 83 W pump power was launched into the fiber and attenuated by 18.78 dB, the temperature of the hot region reaches 74.9 °C. Figs. 2(b-ii) and (c-ii) and 3(b) show the relationship between the temperature and the attenuation, both of which increased linearly as the pump power rose up. As we can see from the thermal images in the two experiments, the high-temperature areas were gathering around the forepart of the strippers.

We use the temperature of 80 °C as standard [15]. The fiber burns easily and thus ruins the laser when the temperature exceeds this point. Comparing experiment one and two, we found that when 83 W power of diode laser light was launched into the fiber, only the stripper in experiment two did not exceed 80 °C. However, when improved the pump power, that is, 106 W power was launched into, the temperature came to 92.5 °C. As can be seen from the thermal images in Fig. 3(c), the temperature severely increased in some points which have exceeded 80 °C. As a consequence, it is not promising for applications in high power fiber laser.

2.2. Cascaded Extract Cladding Light Strippers

To address the problem of high temperature beyond the standard in some local points, we design a new stripper to extract cladding light, that is, cascaded cladding light extracting shown in Fig. 4.

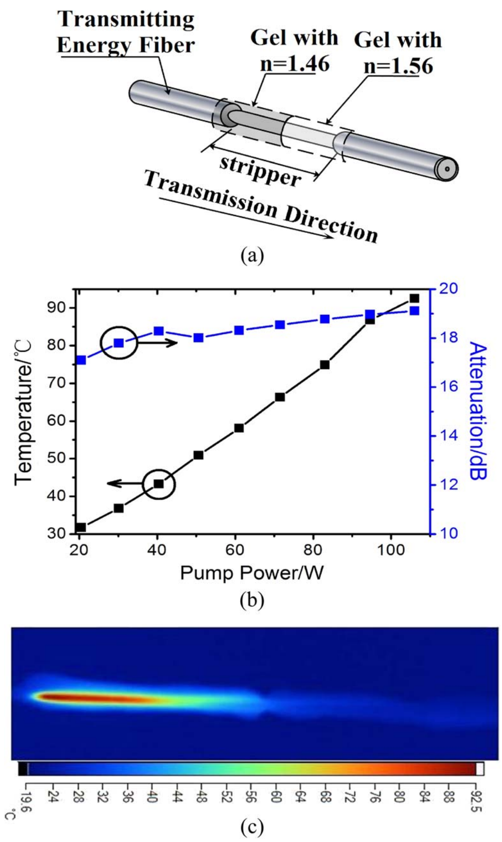

Fig. 3. (a) Schematic illustration of the stripper consisting of different polymers with refractive index of 1.46 and 1.56. (b) Graph of relationship between the temperature and the attenuation consisting of polymers with refractive index of 1.46 and 1.56. (c) Thermal image of the stripper consisting of a polymer with refractive index of 1.46 on left and 1.56 on right, tested with 83 W of pump power.

In this experiment, we selected 50 mm-length fiber as the section of the stripper. The selected fiber is divided into five segments with every one of 10 mm length and they are along the transmission direction of fiber laser, which can be called the first segment to the fifth segment. The quartered coating of the first segment, the half coating of the third segment and the full coating of the fifth segment are implemented. Fig. 4(b) illustrates the transverse section of the stripping segment. Fig. 4(b-i)–(b-iii) shows the transverse section of the first segment, the third segment, and the fifth segment, respectively. By using this method, the gradual dissipation of local temperature can be obtained with increasing stripped areas. The control of the stripping area can only be kept at a appropriate level of precision rather than accurate due to the limited diameter, which is less than 400 μm. The three segments of the removed jacket fiber are recoated along the stripper by three different polymer glues with the refractive indexes of 1.42, 1.46, and 1.56, respectively. Fig. 4(a) shows the schematic illustration of the stripper recoated with three different polymers.

In this experiment, 154 W power of diode laser light was launched into the fiber and attenuated by 17.45 dB. Fig. 4(d) shows the thermal images of the stripper recoated with three different polymers with refractive index of 1.42, 1.46, and 1.56 at the different pump powers. In the beginning of the experiment, about 9 W power of diode laser light was launched into the fiber, only in the third section shows the temperature rise. With the increase of the pump power, the first and fifth section shows the rise of temperature, respectively. Fig. 4(d) shows the temperature rise at 39 W and 74 W power of diode laser light which was launched into the fiber. When 154 W power of diode laser light was launched into the fiber, the temperature of the hot region in the third section reaches 63.2 °C, which is much lower than the former configurations. The relationship between the highest temperature and the attenuation is shown in Fig. 4(c). From this picture we can know that the temperature

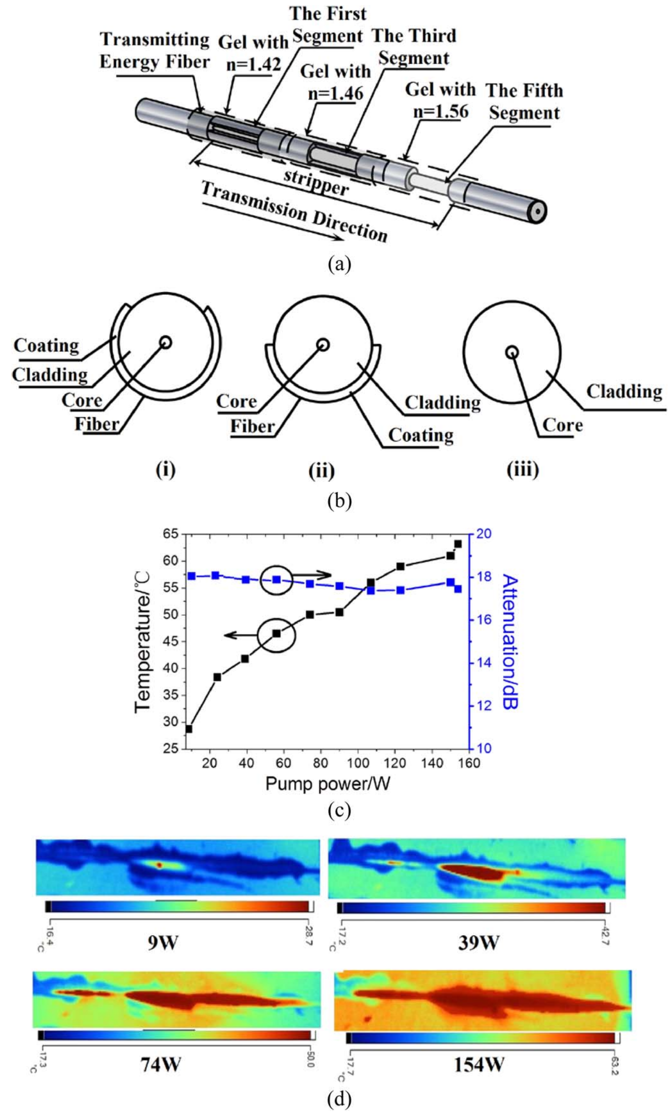

Fig. 4. (a) Schematic illustration of the stripper consisting of a segmented stripped incomplete fiber recoated with three different polymers with refractive index of 1.42, 1.46, and 1.56. (b) Transverse section of the stripping segment (b-i), (b-ii), and (b-iii) show the transverse section of the first segment, the third segment, and the fifth segment, respectively. (c) Graph of relationship between the temperature and the attenuation consisting of polymers with refractive index of 1.42, 1.46, and 1.56. (d) Thermal images of the stripper consisting of a segmented stripped incomplete fiber recoated with three different polymers with refractive index of 1.42, 1.46, and 1.56 at the different pump power.

increases slowly and smoothly. The level of attenuation was close to 18 dB when the pump power increases from 50 W to 160 W.

In the conventional method, the attenuation is very low if we use the refractive index of 1.42 because it could not stripe the low NA cladding light. In order to compare the effect of the different methods, the distances in all three different configurations are roughly the same, 5 cm.

3. Conclusion

In summary, we demonstrate efficient extracting of cladding light through cascaded strippers for high power fiber lasers and amplifiers. A selected part of the fiber of 50 mm length is divided into five segments. Then fluoroacrylate jackets of three interval segments are gradually removed and replaced with different higher index polymers. It is shown that such cascaded strippers can overcome the challenging problems of severe localized heating and thermal degradation of the recoating materials, which are limiting factors for the conventional high power cladding light strippers. The power-handling capability of the device is tested up to cladding light of power as high as 150 W. A high attenuation of 18 dB has been achieved while the maximum local temperature is less than 64 °C, which is much better than conventional approaches. We emphasize that this experiment is only a proof of concept experiment. The configurations shown here of cascaded light strippers can be possibly further improved through employing more segments, different recoating materials and recoating areas. We anticipate that this simple configuration offers a practical solution for cladding light extracting in high power fiber lasers and amplifiers.

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