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High strength fusion splicing of hollow core photonic crystal fiber and single-mode fiber by large offset reheating

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ABSTRACT

High strength fusion splicing hollow core photonic crystal fiber (HC-PCF) and single-mode fiber (SMF) requires sufficient energy, which results in collapse of the air holes inside HC-PCF. Usually the additional splice loss induced by the collapse of air holes is too large. By large offset reheating, the collapse length of HC-PCF is reduced, thus the additional splice loss induced by collapse is effectively suppressed. This method guarantees high-strength fusion splicing between the two types of fiber with a low splice loss. The strength of the splice compares favorably with the strength of HC-PCF itself. This method greatly improves the reliability of splices between HC-PCFs and SMFs.

1. Introduction

Hollow core photonic crystal fibers (HC-PCFs) have attracted much attention due to their unique optical properties [1]. Usually they are used with single-mode fibers (SMFs) in most applications, which requires fusion splicing between the two types of fiber. Researchers have proposed several methods for fusion splicing of HC-PCFs and SMFs using arc splicers [2–5] or filament splicers [6,7]. The splice loss between HC-PCFs and SMFs has long been considered as the main parameter to evaluate the quality of the splice. However, the splice strength of HC-PCFs and SMFs are not taken seriously in these studies as high strength is difficult to realize using traditional method.

Researchers has proposed several methods for high strength splicing PCFs and SMFs using GRIN fiber lenses [8] or parameter optimization [9]. But these method are mainly applied for solid-core PCFs. Since high strength splice of HC-PCFs and SMFs is difficult to achieve, there are several other methods for splice protection such as recoating and heat shrinkable splice protector tubes. It should be noted that recoating is used to protect the surface of fusion splice from mechanical or chemical degradation [10]. This method doesn't strengthen the splice itself. In fact, successful recoating is entirely dependent on high strength splice joint itself. Heat shrinkable tubes provide strong protection for splice. However, they are rigid designed, which means that they can't be wound around a fiber spool. This limits the package of fiber component. For example, HC-PCFs are promising material for fiber-optic gyroscopes in space application as they suppressed some deleterious effects [11]. Heat shrinkable tubes will enlarge the volume and weight of FOGs, which is not acceptable in such circumstance. To ensure a good reliability, the whole fiber length in FOGs has to be proof-tested at a high strain level (typically 0.5% to 2%) for a few seconds [12]. The strain is equal to the ratio between the fiber diameter and the coil diameter. So the splice in FOG should be able to withstand a bend radius of 0.3–1.2 cm without breakage.

Generally, the collapse of air holes is not allowed to achieve a low splice loss between HC-PCFs and SMFs [3,5]. The collapse of air holes in HC-PCFs at high temperature will destroy the bandgap effect of HC-PCFs, resulting in significant increase of splice loss. Most of the studies choose to lower the fusion current and time to strictly avoid air-hole collapse of HC-PCFs. However, the reduced current and time can't provide enough energy to form robust splice. So there is often a trade-off between low-loss and high-strength when splicing HC-PCFs and SMFs. The splice between HC-PCFs and SMFs with a bending radius around 2 cm and splice loss of 1.3–2.0 dB has been reported in [2,3]. The bending radius is about one order of magnitude larger than that of common SMF splice. This is not even strong enough to recoat successfully. NKT Photonics also published application note about general advice on fusion splicing of HC-PCFs and solid fibers [13], while it doesn't focus on splice strength either. So there is no recipe for high strength fusion splicing HC-PCFs and SMFs so far.

Here, we report on a method for high-strength fusion splicing of HC-PCFs and SMFs by large offset reheating method. The splice

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with strength higher than 50kpsi between HC-PCFs and SMFs is reported, which means the splice could be bent to a radius smaller than 0.5 cm. Though a trade-off between achieving low-loss and high-strength of the splice still exists, the additional splice loss induced during the strengthening process has fallen by two thirds compared with conventional method. This method makes the splice of HC-PCFs and SMFs more reliable and easier to handle.

2. Experiment setup and method

2.1. Equipment and fibers

The fibers we used in our experiment are HC-1550-02 from NKT photonics and Corning's SMF-28. The mode field diameter (MFD) and numerical aperture (NA) of the HC-1550-02 are 7.5 μm and 0.2 respectively at 1550 nm. The MFD and NA of SMF-28 are 10.4 μm and 0.14 at 1550 nm. After manual core alignment of the two types of fiber, the butt-coupling loss from SMF-28 to HC-1550-02 is measured to be ∼1.3 dB at 1550 nm. The butt-coupling loss agrees well with the value given in [4].

A VYTRAN's FFS-2000 filament fusion splicer is used in our experiment to splice HC-PCFs and SMFs. The model of filament is F35-2520 made by VYTRAN. It's "Ω" shaped and made by tungsten. The diameter, width and thickness of the filament is 35/1000, 25/1000 and 20/10000 inch, respectively. The purging gas flow rate is set to 0.65 l/min. The tension applied to the fiber during cleaving must be carefully adjusted to guarantee a smooth fiber end face which is critical to acquire high quality fusion splicing as showed in Fig. 1. The angle of the cleave facet should be no more than 0.5 degree and no microstructure debris should be left on the facet, which can be observed on the splicer. The fiber are manually aligned in steps of 0.1 μm, using a 1550 nm amplified spontaneous emission (ASE) optical source and an optical power meter to monitor the transmission power as showed in Fig. 2. The gap between the two fibers is set to −1 μm, which means the two fibers are slightly touched before splicing to prevent misalignment when pushing the fibers together. Before splicing, a 0.4 s pre-fusion duration called hotpush-delay is applied to soften the fiber tips before the two types of fiber are pushed together. The hotpush, which is the overlap distance of the two fibers, is set to 10 μm.

The main splicing parameters affecting the splicing quality in our experiment are power, duration, and offset. Power defines the amount of power applied to the filament, duration defines how long the filament is at power, while offset defines the distance between filament center and the splice point. These three parameters are the main factors affecting the strength of splice.

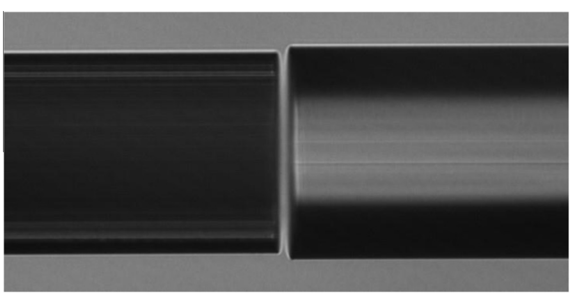

Fig. 1. Smooth fiber end face after cutting.

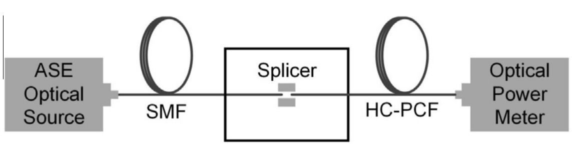

Fig. 2. Experiment setup.

2.2. Large offset reheating method

Collapse of HC-PCFs is inevitable to form strong splice while it also leads to higher confinement loss. The large offset reheating method is a possible solution to reduce the length of collapse, thus minimizing the extra confinement loss. It is related to the temperature distribution inside the filament, which is showed in Fig. 3. Usually the offset is set to 50 μm when splicing HC-PCFs and SMFs [13], which means the filament center is only 50 μm away from HC-PCF end face. In that case, a long section of HC-PCF is heated by high temperature, leading to a long collapse length. However, the temperature drops quickly far away from the filament center. If the offset is large enough, the temperature will drop quickly along the HC-PCF, which means a shorter section of HC-PCF will be influenced by the high temperature and the collapse will be relieved at the same time.

However, it should be noted that we can't splice the fibers with large offset directly. The two fibers can't be pushed together tightly as the body of SMF are softer than the fiber tip when the splice offset is too large, leading to a weak splice. So we divide the splicing process into two steps. In step one, the two fibers are spliced together without collapse. The splice loss should be no more than the coupling loss. In step two, the splice is reheated with large

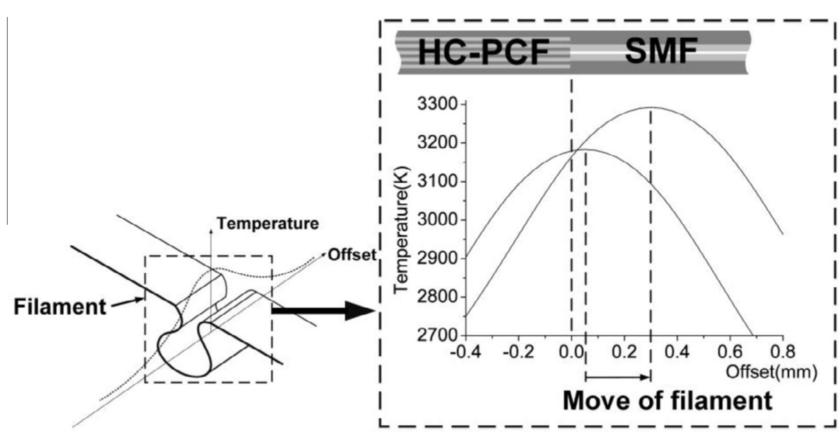

Fig. 3. The temperature distribution inside the filament. The filament moves from 50 μm offset position to 300 μm in reheating process. The temperature at filament center also goes up as the power in reheating process rises.