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Mode field adapters improving the efficiency of fiber laser systems for nonlinear imaging

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Abstract

Low-loss optical fiber fusion splicing plays a key role in constructing fiber laser systems that can be used for nonlinear imaging. In this work, we present a CO2 laser-based splicing technique that enables the fabrication of mode field adapters. Our approach is tailored for polarization-maintaining optical fibers and can reduce the splice loss by 30%. The proposed fully-fused components can significantly increase the efficiency of ultrafast high-energy fiber-based systems.

Keywords:

Mode field adapter, mode field diameter, nonlinear imaging, optical fiber fusion splicing, polarization-maintaining fiber.

1. Introduction

Optical fiber splicing can be defined as a permanent connection between two fibers without using any additional connecting elements. The goal is to create a link that guarantees the lowest possible losses in optical signal transmission. Splicing optical fibers is a crucial process in manufacturing fiber laser systems. Despite the advanced fiber technology, plenty of factors still result in different splice losses. One is the necessity of splicing fibers of various sizes, particularly those with different mode field diameters (MFD). The MFD mismatch is the leading cause of signal loss when splicing two optical fibers. One way to overcome this problem is to create a mode field adapter (MFA) by heating a fiber with a lower MFD. The temperature increase leads to its core's expansion through the thermal diffusion of dopant ions, referred to as thermally-expanded-core (TEC). A number of sources can be used as a heating source, starting from a torch, through an electric arc discharge, and ending with laser radiation. Several methods for expanding the core of the optical fibers with a symmetrical structure, used mainly in telecom applications, have been developed. However, these techniques require the optical fibers to be spliced in advance, and often, the heating process can take up to several hours. With existing methods, it is difficult to enlarge the core of the fiber, which has an asymmetric geometry, particularly a polarization-maintaining (PM) fiber. An example of the PM fiber is the PANDA-type structure, in which the asymmetry is introduced by the stressing rods in the structure of the cladding. A particular challenge is to ensure that the deformation of the stressing rods is avoided when heating the fiber, as it affects the beam quality and polarization properties of the fiber. This aspect is addressed by this project, which aims to develop a method capable of enlarging the core of a PM fiber to achieve the lowest possible losses when splicing with a large mode area fiber.

2. Methods and results

Within the framework of this project, a method of TEC fabrication using a CO_2 laser was developed. The experimental setup consisted of commercially available devices, such as Fujikura LAZERMaster LZM-100 laser splicer. The system enabled the possibility of controlling the fiber position as well as the rotation of the optical fiber along its longitudinal axis. The built-in CO_2 laser delivered the heat in the form of pulses with a user-defined time duration and a repetition rate. The scheme of the setup for the TEC fabrication is presented in Fig. 1. The CO_2 laser beam was split in two, and thanks to that the optical fiber could be heated from two directions. Moreover, there was a possibility to observe the heating process in real-time with two cameras. In our case, we did not use an additional lens and the size of the heating zone was a length of (4 ± 0.5) mm.

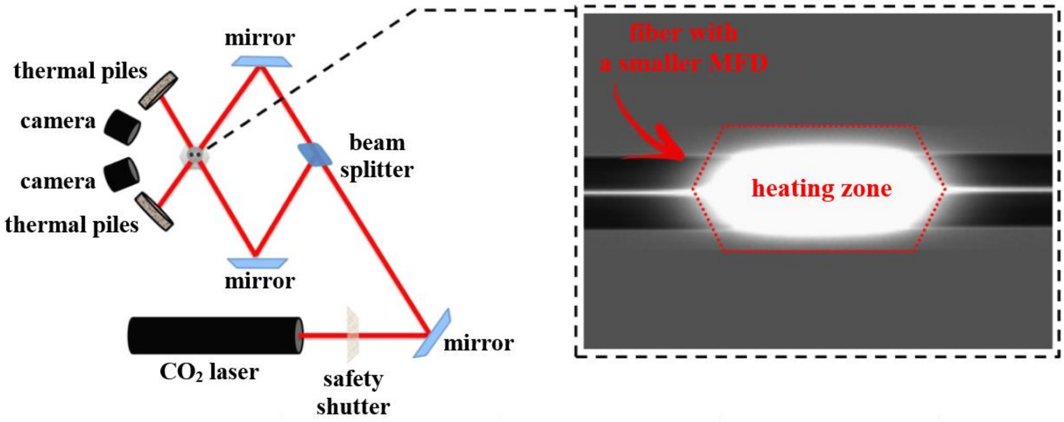

Fig. 1. A schematic diagram of the system used for TEC fabrication based on the Fujikura LAZERMaster LZM-100 laser splicer.

Thanks to, among others, clever rotation of the optical fiber during the process, it was possible to quickly expand the core while maintaining the proper structure of the stressing rods of PM fibers. In the further steps, the fiber with an expanded core was precisely cleaved and spliced together with the fiber having a smaller MFD. We verified the presented TEC fabrication method using commercially available PM optical fibers which can be successfully used for the construction of fiber laser systems for nonlinear imaging: Coherent PM980-XP, Coherent PLMA-GDF-14/125-UF, and CorActive SCF-UN-3/125-25-PM. For example, in the case of the connection between PM980-XP and PLMA-GDF-14/125-UF, the transmission was increased from 63% ± 2% to 92% ± 2%. The fiber heating time can be decreased to less than 1 minute, and fabrication of MFA does not require additional prior splicing of the two fibers. Moreover, we integrated our MFAs into the high-peak-power fiber laser systems, and the adapters remained resistant to peak powers as high as 50 kW.

This research can significantly contribute to developing laser systems for nonlinear imaging based on PM fibers. Thanks to the PM fiber design, such lasers are resistant to external factors, which makes them applicable in the industry and medicine. For nonlinear imaging tunable laser sources are used. Broad wavelength tunability is typically achieved through frequency conversion nonlinear effects, which require high-energy pumping. In an all-fiber configuration, these pump beams necessitate the use of large mode area (LMA) fibers. However, photonic crystal fibers (PCFs), where frequency conversion occurs, have a small core. We hope that presented MFAs can be successfully implemented in such laser imaging systems and deliver the possibility of low-loss splicing of fibers that differ in core sizes. In addition, our technique can be attractive for high-power applications in ultrafast fiber laser systems as well as splicing large mode area fibers with low loss leads to improving their efficiency.

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