Mode Field Adaptation for High Power Fiber Lasers

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Abstract: Low-loss all-fiber® mode field adapters for a variety of single and multimode fibers have been developed using a flexible fabrication technique. Combination of thermal-core-expansion and tapering characteristics ensures beam quality for fiber lasers and amplifiers.

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1. Introduction

Fiber lasers and amplifiers have received great attention because of their ability to provide high wall-plug efficiency and excellent beam quality even at high power levels [1-2]. Because of the feasibility of all-fiber integration eliminating free-space components and alignment, fiber laser require fewer components and mechanical parts making them quite robust and compact [3-4]. Fig. 1 illustrates a typical fiber laser and fiber amplifier design with, multimode pump combiners (MPC), double clad (DCF) gain fiber and mode field adapters (MFA).

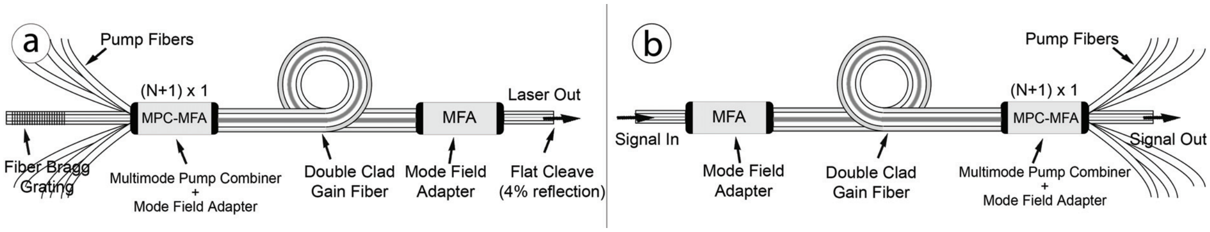

Fig. 1. Example of a fiber laser (a) and amplifier (b) designs. In the laser (a), a fiber bragg grating act as the high reflector and the flat fiber cleave can acts as a low reflector, the output MFA certify a single mode operation of the laser. The amplifier (b) configuration is shown in a counter pump design. The MFA allow a single mode launch for the signal to be amplify.

To take full advantage of the properties of the gain fiber, the detrimental effects of fiber nonlinearities must be minimized which can be achieved using large mode area fiber. The LMA ensures a large effective mode area which greatly reduces the nonlinear coefficient [5]. Concurrently, the number of modes guided by the fiber also needs to be minimized to avoid mode coupling noise and ensure excellent beam quality. One approach is to use a fiber with a lower numerical aperture (NA) to ensure single mode operation. Unfortunately this strategy leads to high bend-sensitivity. Other methods to preserve beam quality using coiling gain fiber for modal filtering, long period gratings [6], microstructured fibers [7] or gain guiding [8] have been demonstrated but little attention has been given the flexibility of the methods to accommodate different fiber types required for specific applications. Another approach is to use few-mode fibers but ensure single mode through proper mode field adaptation. A low-loss method ensuring single mode operation adaptable to many types of input and gain fibers is of great interest for fiber lasers and amplifiers.

We developed a low-loss all-fiber MFA for high power fiber lasers and amplifiers with single mode operation and excellent beam quality. Through simultaneous control of fiber core diameter and dopant concentration using fiber tapering and thermal diffusion, adiabatic mode field adapters are developed for a variety of fibers.

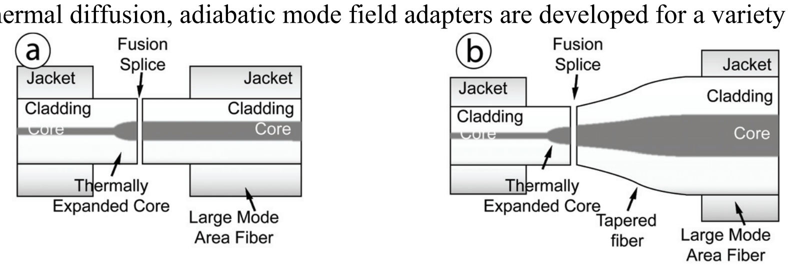

Fig. 2. (a) Thermal expansion of the core through dopant diffusion increases mode effective area in single mode fibers but can decrease it for multimode fibers. (b) Combination of fiber tapering and thermal core expansion. The optimization of both methods of mode field adaptation is possible for a large variety of fibers.

2. Theory and Experimental Results

Mode expansion in single mode fibers using thermally expanded core (TEC) technique has been widely used in single mode fiber [9]. However in LMA fibers, thermal core diffusion leads to a regime of *mode size reduction* followed by *mode expansion*, as seen Fig 3. Moreover, MFDs can also be tailored through fiber tapering. By taking advantage of mode contraction and expansion from TEC combined with fiber tapering, precise adaptation of MFDs with adiabatic evolution of the fundamental mode can be achieved. Each technique used separately limits significantly the types of fibers that can be adapted, but the combination ensures low losses and excellent beam quality for a large variety of dissimilar fibers. Analytical results illustrated in Fig. 3-4 show that a Corning1060 and a 20μm NA0.065 fiber could not be matched using TEC but can be achieve by combining with fiber tapering.

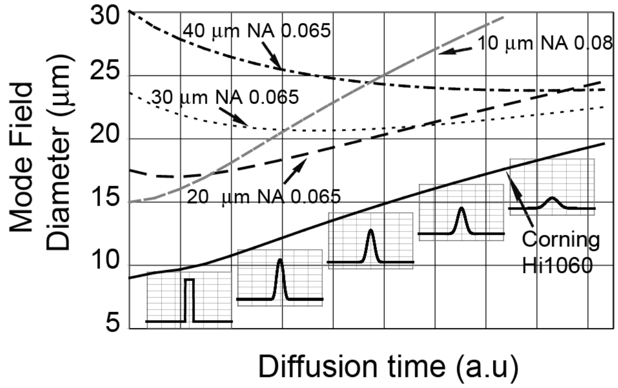

Fig. 3. Thermal diffusion of MM fibers leads to a regime of MFD reduction followed by mode expansion, a phenomena not observed in SM fibers.

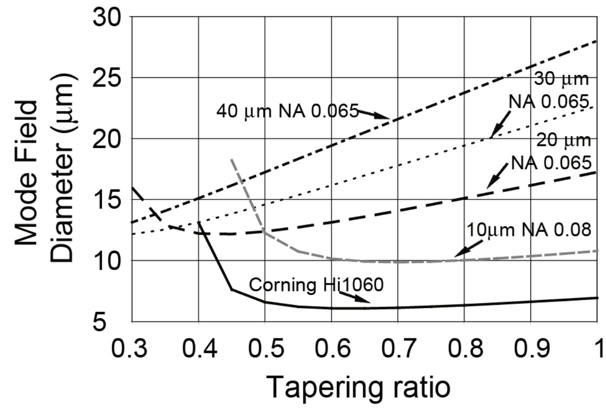

Fig. 4. Tapering optical fibers reduces the core size and changes the MFD accordingly. The two techniques can be used to make a modal match between 2 dissimilar fibers and produce a MFA

Measurement of mode transmission losses of around 0.4dB using two MFA with corning Hi1060 and LMA 20μm NA0.06 are illustrated in Fig.5 Without modal adaptation high loss averaging 8.5dB and modal interference is observed. Qualitative monitoring of near field beam quality is done during fabrication as shown in Fig. 5a.

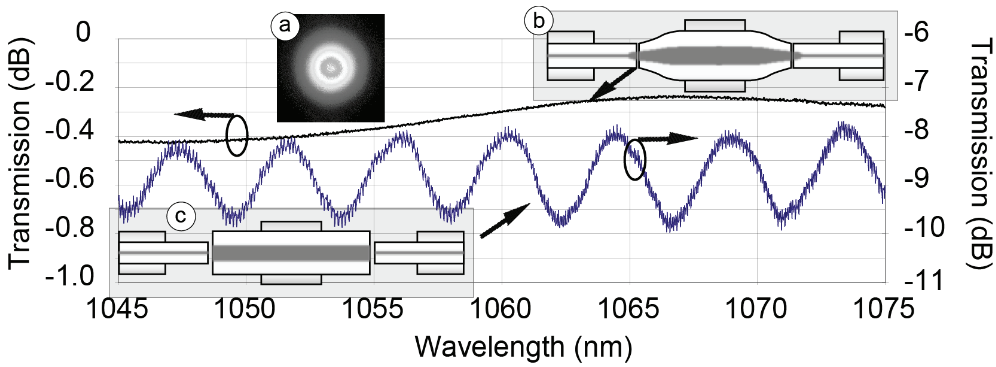

Fig. 5. (a) Experimental beam quality of an MFA between Corning Hi1060 and LMA 20-400 0.06NA. MFA transmission are measured back to back. (c) Without diffusion and tapering, transmission of this fiber assembly shows high loss and mode coupling oscillations. (b) With optimally designed MFA's , low loss is achieved. Each MFA has around 0.2 dB loss.

3. Conclusion

We demonstrated mode field adaption for various single and multimode fibers through the precise combination of thermally expanded core and fiber tapering. Component fabrication parameters are optimized through exact analytical derivation of the parameter-space for single mode transition with very low transmission losses. We have developed and fabricated more than 20 designs packaged for high power lasers and amplifiers applications.

4. References

[1] A. Galvanauskas, "Mode-scalable fiber-based chirped pulse amplification" IEEE J. Sel Top Qu. Elec., vol 7, no.4, pp. 504-517 jul/aug 2001

[2] M. Jäger *et al.*, paper JWB59 *in* CLEO 2005, Baltimore, MA (2005).

[3] F. Gonthier, L. Martineau, N. Azami, M. Faucher, F. Seguin, D. Stryckman, A. Villeneuve, "Highpower all-fiber components: the missing link for high-power fiber lasers," in Fiber Lasers: Tech. Syst. and Applications, Proc. SPIE 5335, 266-276 (2004).

[4] F. Gonthier, "All-Fiber® pump coupling techniques for double-clad fiber amplifiers and Lasers", TFII1-3 Cleo Europe 2005.

[5] Govind P. Agrawal, "Nonlinear Fiber Optics", 3rd Edition, University of Rochester, Rochester, New York, USA, 2001

[6] S. Ramachandran, et al. "Light propagation with ultralarge modal areas in optical fibers, Opt. Lett., vol 31, no. 12, pp. 1797-1799, jun 2006.

[7] W.S. Wong et al. "Breaking the limit of maximum Aeff for robust SM propagation in optical fibers" Opt. Lett., vol 30, no. 21, nov 1, 2005.

[8] J.M. Oh, C.Headley, M.J. Andrejco, A.D. Yablon and D.J. DiGiovanni, "Increased amplifier efficiency by matching the area of the doped fiber region with the fundamental fiber mode" OthC6, OFC 2006

[9] M. Kihara, et al. "Characteristics of thermally expanded core fiber" J. Ligh. Tech., vol 14, no. 10, pp. 2209-2214, oct. 1996.