Laser fibers designed for single polarization output

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Abstract: Single mode, single-polarization output is demonstrated in a large mode area (LMA) fiber laser. Both mode filtering and polarization filtering are demonstrated by simply coiling multimode Polarization Maintaining Fibers (PMFs). The design is scaleable for all-fiber high power lasers.

1. Introduction

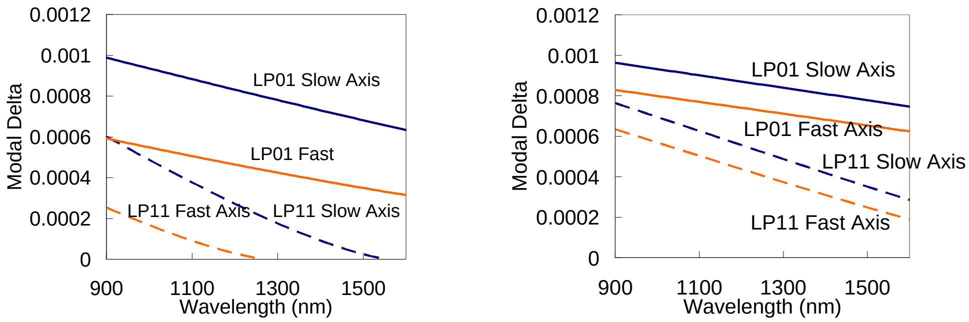
Linear polarization from a fiber laser is traditionally done with the use of an external polarizing element in conjunction with polarization maintaining (PM) fiber [1] or with the use of fiber bragg gratings written into PM fiber acting as the polarization selective element [2,3]. This latter approach is attractive in removing the need for external components to select polarization, but is most often used in low power applications and may not be applicable as fiber lasers approach kilowatt output power levels [4]. In this paper we demonstrate that the polarization dependant bend loss in panda-type PM double-clad fibers can be used to obtain a robust, simple linear polarization fiber laser with good slope efficiency. Furthermore we describe how this technique can be applied to large mode area (LMA) fibers which have become a popular method for power scaling fiber lasers [5] and amplifiers. Our data clearly show that the optimum coil diameter for effective higher order mode filtering in LMA fibers can also be used to control the polarization state of the fiber laser. Experimental demonstration of the technique in a 20μm core diameter PM-LMA fiber coil shows a laser slope efficiency ~65% with PER>20dB, operating in a single mode.

2. Polarizing behavior

Tankala et al have described in detail the theoretical, geometrical and manufacturing considerations for PM fiber birefringence, particularly with reference to double clad fibers [6]. Large mode area fibers are often coiled to specific diameters in order to strip out the higher order modes. When PM-LMA fibers are coiled, the dual phenomena of mode stripping and polarization stripping occur simultaneously. Due to the lower effective index of refraction, light polarized along the fast axis of the fiber will have higher macro-bend loss when the fiber is wound into a coil. If birefringence is sufficiently high, bend loss will effectively suppress light in the fast axis and prevent lasing along the fast polarization. Two LMA designs were compared: (i) Fiber A: 20μm core/400 μm inner cladding diameters, and (ii) Fiber B: 30 μm core/250 μm inner cladding diameters because they represent different regimes of birefringence. Using internal models which consider optical and manufacturing constraints, the fibers were designed for predicted birefringence for Fiber A of 4.56×10^{-4} and Fiber B of 1.39×10^{-4}. Yb-doped PM-LMA fibers for the two designs were fabricated by solution doping and MCVD, and characterized for optical properties and birefringence, as described in [6]. The properties of the two fibers are summarized in Table 1. The modal index difference for fibers A and B are plotted as a function of wavelength in Figure 1. Within the wavelength range of the Yb-laser, the fast polarization state for LP_{01} has a higher modal index than the slow polarization state for the next highest order mode (LP_{11}). Hence, by coiling the fiber, the higher order modes are stripped out at a larger coil diameter than the fast polarization state of the fundamental mode. Thus, if polarizing behavior is obtained, it also implies that mode filtering has been achieved.

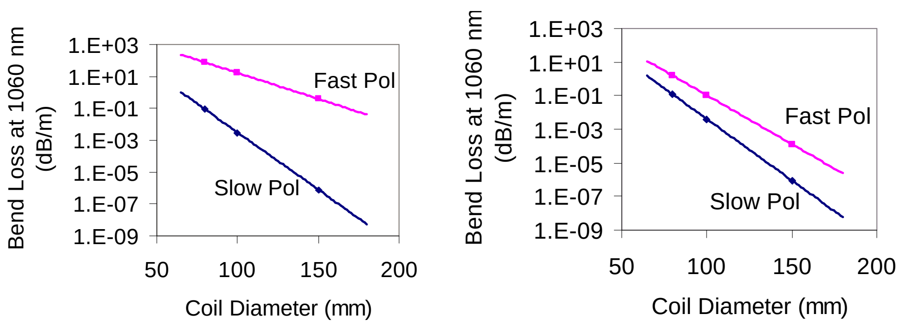
Table 1. Geometric and optical properties of PM-LMA fibers used in analysis

	Fiber A	Fiber B
Stress Member Type	Panda	Panda
Core Size (μm)	20	30
Core NA	0.060	0.056
Clad Size (μm)	400	250
Clad NA	0.46	0.45
Absorption at 915/975 nm (dB/m)	0.56/1.85	1.09/3.60
Crosstalk (dB) 10 meters, uncoiled	-45	-26
Beat Length normalized to 633 nm (mm)	1.52	4.66
Birefringence ($\times10^{-4}$)	4.17	1.36



(a) (b)

Figure 1. Modal index difference for (a) Fiber A: 20 mm core, 400 mm cladding fiber; and (b) Fiber B: 30 µm core, 250 µm cladding fiber



(a) (b)

Figure 2. Bend loss of the fundamental mode for the two polarizations for (a) Fiber A; and (b) Fiber B

Estimated bend loss for fast and slow polarizations is shown in Figure 2. The fast polarization is more susceptible to bending. At appropriate coil diameters, the fiber can be made to support only the slow polarization. Differential bend loss between the two polarizations is greater for Fiber A. The analysis shows that from both considerations of mode filtering and polarization filtering, Fiber A was preferred for the laser experiment. By increasing the birefringence so that the LP_{01} modal index for the fast polarization is nearly equal to the LP_{11} modal index in the slow polarization, Fiber B can also be operated in polarizing mode.

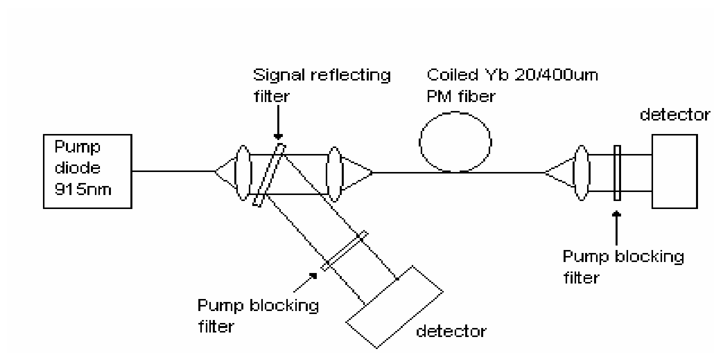


Figure 3. Experimental set-up for characterization of fiber laser

3. Laser results

The experimental set-up used for characterizing the laser slope efficiency is shown in Figure 3. The pump source is limited to 15W at 915 nm. The laser cavity in the present experiment is formed from the Fresnel reflections at the two cleaved fiber ends, thus ensuring that no external polarizing components are affecting the results. Pump coupling efficiency was around 82%. From section 2, we choose to characterize the

20/400 PM double-clad fiber (described above). Cross-talk was measured with selected launch into the slow and fast axis respectively, for various coil diameters (Table 2). Cross talk for both polarizations increases with smaller coil diameter, though the rate of increase is different. We find that the gap between the polarizations widens with smaller coil diameters. Thus, the optimum coil diameter lies at 8-10cm for good PER. Laser output power for different pump powers is shown in Figure 4. Slope efficiency of the polarized fiber laser is 65%, and PER was 20.3 dB. The data presented here is limited only by pump-power of 15 W, and lasing output in excess of 100W has been obtained with this fiber. Importantly we see no degradation in PER at the highest powers used, indicating that the technique should be applicable to higher power operation. Insertion of a polarizing element at the laser output would result in significant loss of lasing power, and could potentially induce instabilities. The polarizing (PZ) fiber design presented here would help circumvent the problem, since lasing is actually suppressed along one polarization, instead of generation followed by loss. Optimized coil diameters around 9 cm are clearly in the mode filtering regime, as seen in the beam quality in Figure 5. The high PER obtained for Fiber A indicates that by tailoring fiber birefringence such that LP_{01} fast axis modal index is made close to the LP_{11} slow axis, PZ is possible in 30 μm core LMA fibers. Subsequently, a modified version of Fiber B with 30 μm core and 400 μm cladding diameters, was made with birefringence of 3.1×10^{-4}.

Table 2. Cross-talk of the fiber under different deployment conditions

Coil diameter, cm	Straight	10.2	7.6
Cross-talk (slow axis launch) dB/m	-33.6	-31.2	-19.7
Cross-talk (fast axis launch) dB/m	-32.5	-25.3	NA

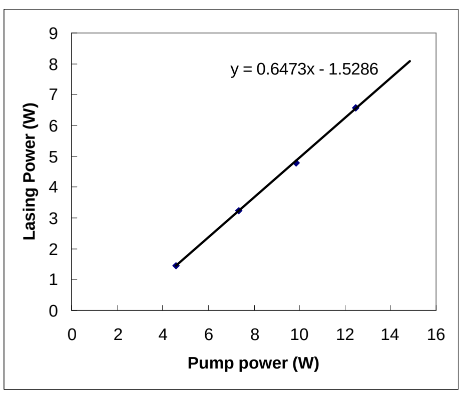


Figure 4. Laser output for Fiber A in a 9 cm diameter coil

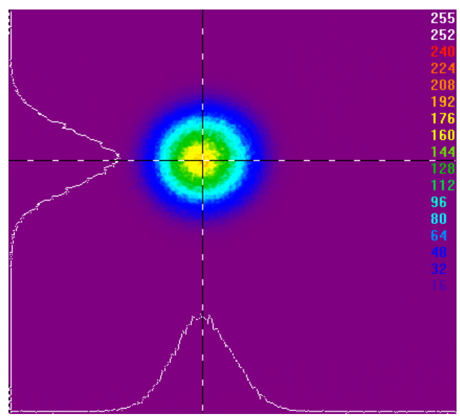


Figure 5. Beam quality of the laser output from fiber A in 9 cm coil

4. Conclusion

We have demonstrated simultaneous mode filtering and polarizing behavior in a LMA double-clad fiber laser without degradation in the laser performance. Clearly control of both mode quality and polarization are desirable features as power scaling of fiber lasers occurs. The method appears highly stable and is applicable to higher power fiber designs, potentially to 30 μm core diameter, and powers in excess of 100W, thus eliminating the need for expensive high power polarizers and making the laser more reliable and efficient.

5. References

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