Linearly polarized high power fiber lasers with monolithic PM-LMA-fiber and LMA-grating based cavities and their use for nonlinear wavelength conversion.

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Abstract

We report our recent progress in designing and manufacturing new, completely monolithic, linearly polarized, continuous wave (CW) fiber lasers that provide more than 300W of output power in a near diffraction limited, single transverse mode, spectrally stabilized output beam having a narrow line-width. The demonstrated design is simple and practical: the monolithic laser cavity can consist of only of a coil of polarization maintaining (PM), large mode area (LMA) active fiber having a fiber Bragg grating (FBG) at one end and a fiber cleave at the other end. Proper selection of the coil diameter enables gain in only one polarization mode so as to provide the linearly polarized output. Fiber lasers built using this novel technique do not require any external polarizing components or the use of polarizing fiber. Such compact and robust fiber lasers are suitable for a variety of applications, such as multi-kW power scaling through coherent beam combining, nonlinear wavelength conversion processes using a variety of nonlinear materials, etc.

Keywords: large mode area fiber, linearly polarized laser, nonlinear conversion

1. Introduction.

Advances in LMA fiber designs[1, 2] and the development of high power multi-kW pump diodes[3] have led to high power fiber lasers with single transverse mode output. Single fiber CW lasers with an $M^2 < 1.5$, random polarization and output power exceeding 1kW have been demonstrated recently[4, 5].

Linearly polarized high power fiber lasers having a spectrally stabilized, narrow linewidth output beam are highly desired for further high power scaling through coherent beam combining and additional applications, such as, for example, nonlinear frequency conversion. Such fiber lasers can be constructed using PM-LMA fibers. So far, however, linearly polarized fiber lasers with more than 100W output have been demonstrated with either external free space polarizing elements[6] or using complex MOPA schemes[7, 8], thus significantly limiting the robustness and power handling capacity of such designs.

Here we report the first completely monolithic, linearly polarized CW fiber laser providing a diffraction limited, spectrally stabilized, narrow line-width output beam having an output power of more than 300W. The demonstrated design is simple and practical: the monolithic laser cavity can consist of only of a coil of PM-LMA fiber having a FBG at one end and a fiber cleave at the other end. Proper selection of the coil diameter selects one polarization mode so as to provide the linearly polarized output[9].

2. Experimental setup

A novel technique for obtaining a single mode, linearly polarized output from a fiber laser utilizes the polarization dependent bend loss of PM-LMA fibers for filtering polarization modes. A special Panda-type PM-LMA, ytterbium doped fiber (YDF) has been developed. The fiber has 20 micron diameter core doped with ytterbium, a 400 micron octagonally shaped inner cladding, a 0.06 core NA (core V# ~ 3.5) and a 0.46 cladding NA. Figure 1 illustrates a typical cross section of the fiber.

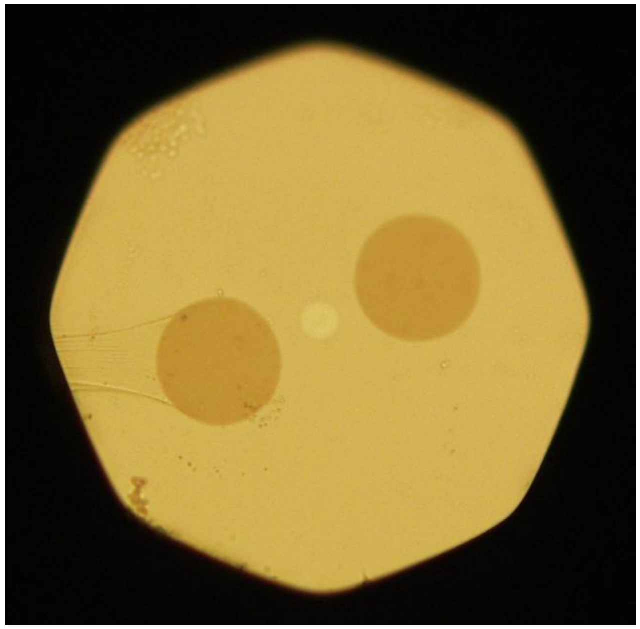

Figure 1 - Microscope image of fiber cross-section

Two borosilicate stress rods surround the core to induce birefringence and provide the PM behavior. The birefringence of this structure is as high as $3 \cdot 10^{-4}$.

The PM-LMA fiber is coiled to a selected diameter in order to provide the desired linearly polarized, single mode output beam. Figure 2 helps illustrate this concept.

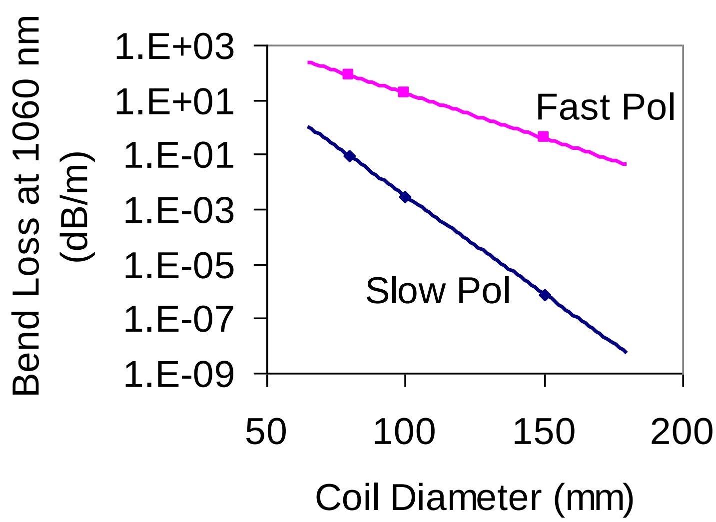

Figure 2 – Estimate of bend loss of the two polarization states for the fundamental mode of an LMA fiber

Note that when the fiber is coiled to diameter of 100mm, the bend loss at a wavelength of 1060nm for the fast polarization is at least two orders of magnitude larger than that of the slow polarization. Thus, only light in the slow polarization undergoes significant gain.

3. Experiment results

Figure 3 illustrates the design of the laser. The laser cavity includes 33 meters of the aforementioned rare-earth doped PLMA fiber and is formed by a spliced-on fiber Bragg grating (FBG) with >99% reflectivity on one end and a flat fiber cleave providing 3.5% Fresnel reflection on the other end. The YDF was coiled to a 9cm diameter around an aluminum mandrel to eliminate both the undesired polarization-mode and higher-order transverse modes. The laser was pumped from both ends by fiber coupled, wavelength multiplexed diode bars (915nm+940nm+976nm). The total amount of pump power coupled into the fiber laser was ~ 496W.

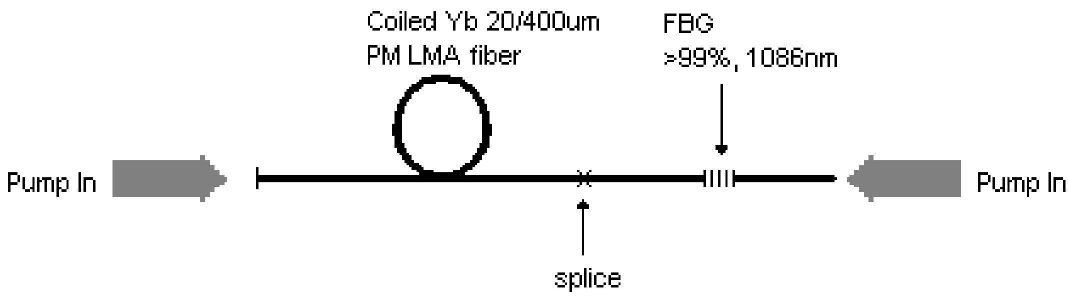

Figure 3 - Experimental setup

Figure 4 shows the 1086nm laser output power vs. coupled pump power. The laser exhibited a threshold of ~3W and a slope efficiency of 62%; the latter is comparable to other techniques of making polarized fiber lasers. The maximum laser output power was 306W. A Polarization Extinction Ration (PER) up to 19dB was measured at the output of this simple laser cavity.

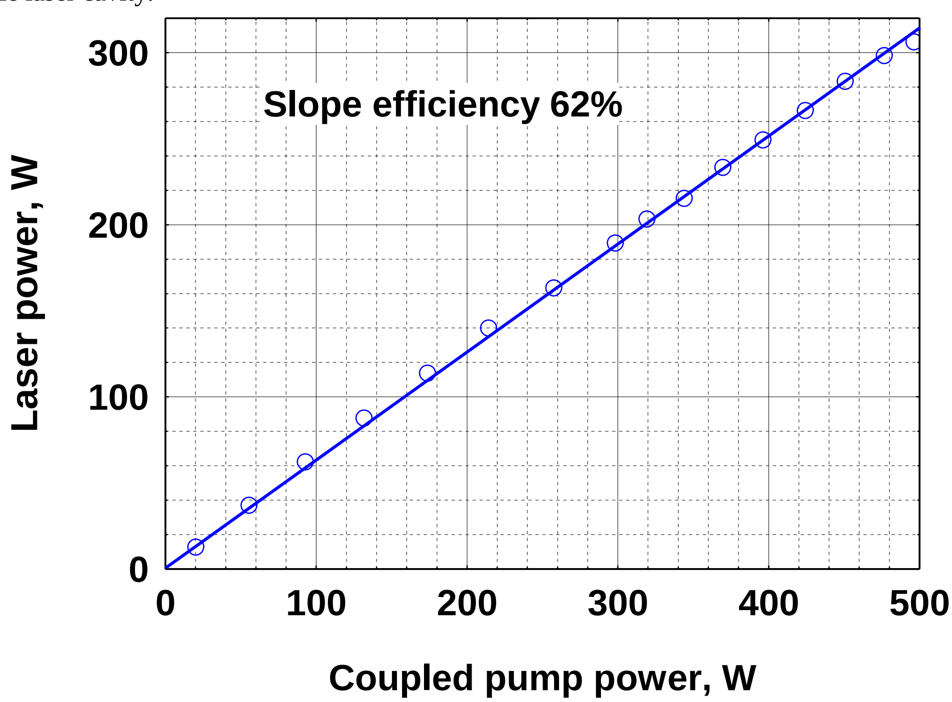

Figure 4 - Laser slope efficiency

The laser produced a near diffraction limited, single mode output. Figure 5 shows the beam quality measurement, which was obtained with an M^2 measurement unit. The beam is close to being diffraction limited, as indicated by the measurement of $M^2 = 1.1$.

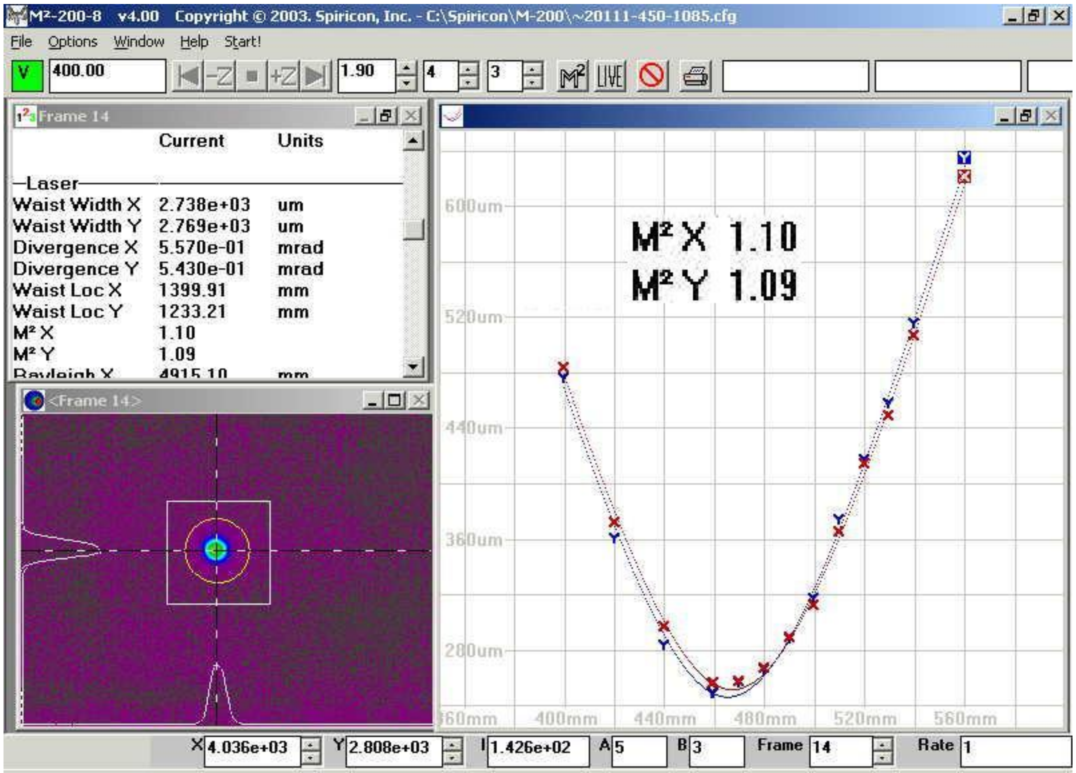

Figure 5 - Laser beam quality measurement

Figure 6 shows the measured laser spectral line-width. The laser had a relatively narrow line-width (0.57nm), stabilized by the FBG. Note that the spectral width was limited by the width of the FBG reflector. We believe narrower spectral line-widths are achievable at this power level.

Output power increased linearly with coupled pump power. No sign of detrimental nonlinear effects, such as Brillouin or Raman scattering typical in small core fibers, was observed. Power density in fiber core was ~ $0.8 W/\mu m^2$ at highest output power. Achieved maximum power density is still low compared to power densities of $1.5\text{-}4 W/\mu m^2$ reported in other work[5, 7].

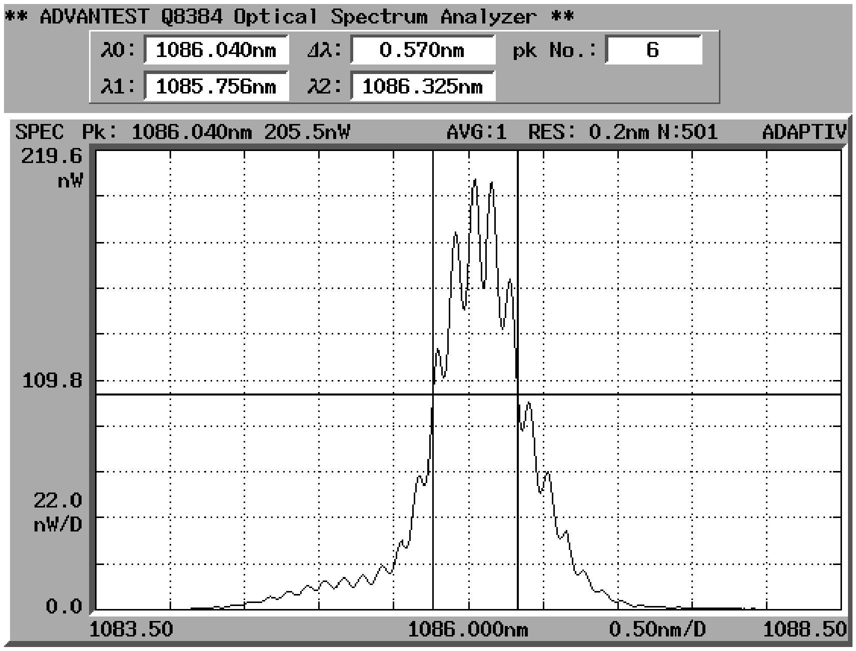

Figure 6 - Output laser spectrum.

4. Conclusions

In conclusion, we have demonstrated a linearly polarized 306W CW fiber laser having a monolithic cavity and a single mode, diffraction limited, spectrum stabilized, narrow line-width output beam. Laser output power was limited by the available pump power. Our estimations indicate that output power using this design is scalable to 1kW CW and higher. This simple and robust all-fiber design is particularly attractive for further fiber laser power scaling to >10kW using multiple beam combining techniques[10], and promises to facilitate a broad variety of practical applications requiring high power, linearly polarized, diffraction limited laser beams.

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