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SPIE.

Event: SPIE LASE, 2018, San Francisco, California, United States

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ABSTRACT

We demonstrates all-fiber master oscillator – power amplifier delivered 70W output power at 1033.33nm with 8 kHz FWHM linewidth without any problems with SBS. The anisotropic ytterbium doped tapered double clad amplifier with 50 µm MFD and polarization extinction ratio about 30 dB is developed as a burst stage. The output radiation demonstrated perfect beam quality (M^2=1.03/1.08).

Keywords: Fiber laser, active fiber, fiber amplifier

1. INTRODUCTION

Technology of high power single-frequency optical sources with extremely narrow line and low level of amplitude and phase noises is in highly demand and developing very quickly to date. Such sources are required for various applications, including coherent LADAR systems [1], gravitational wave detections [2,3], and coherent beam combining [4].

Fiber-based MOPA system with DFB fiber laser as a seed source is an excellent candidate for the new generation of high power single frequency lasers. The fiber-based MOPA system usually represents relatively low power (tens of milliwats) highly coherent seed source and a chain of concatenated fiber amplifiers. The primary limitation of output power scaling for a single-frequency fiber-based MOPA system is stimulated Brillouin scattering (SBS).

At the moment, there are several strategies for SBS suppression at the narrowband fiber MOPA, which have been described in the literature. One of them is the longitudinal temperature gradient of fiber parameters [5,6]. The practical realization of this strategy allowed to obtain 511 W fiber MOPA system as described in [6]. The system comprised DFB fiber laser as a seed source and LMA Yb-doped double clad fiber as a power amplifier. The 9 m LMA fiber with the 43 µm core (NA=0.09) was used as an amplifying media [6]. To suppress SBS, pump-induced longitudinal temperature distribution was employed in counter propagation pump scheme. Longitudinal temperature gradient along the fiber arises at the pumping end proportionally to the absorption rate, and, thereby, broaden Brillouin spectrum. Although authors have demonstrated an impressive result, the measured M2 was only 1.6, which indicated the presence of higher-order modes in the output radiation.

Another team of researchers [7] also employed LMA fiber-based amplifier with counter-pumping scheme, and thus, they applied a temperature gradient along the axis, similar to [6]. Additionally, the active LMA fiber had specially dopants composition in cross section so, that anti-waveguides structure for sound waves has been formed. This resulted in suppression of acoustic waves, which are the primary reason of SBS appearing. As a result, the authors also demonstrated an impressive 500 W output power.

There is one more alternative approach to the creation of powerful fiber amplifiers for narrowband signals. It is using of an active tapered double clad fiber (T-DCF) in burst amplification stage [8-12]. T-DCFs have a number of obvious advantages: large active core diameter (up to 200 µm [8]), which allows to increase a nonlinear effects threshold

Fiber Lasers XV: Technology and Systems, edited by Ingmar Hartl, Adrian L. Carter, Proc. of SPIE Vol. 10512, 105121T · © 2018 SPIE · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2288942

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significantly, a large area of the cladding, resulting in possibility to use low brightness inexpensive powerful pump sources, perfect beam quality (M^2 <1.1) and reasonable physical dimensions (usually the coiling diameter does not exceed 35cm). Stimulated Brillouin scattering (SBS) is a main obstacle for further output power scaling of high coherent seed source. The longitudinal modulation of the fiber core diameter (tapering) it is a well-known measure for effective SBS suppression. Active T-DCF was used for the first time for amplification of DFB fiber laser emission in [9], where the amplifier with 27 dB gain, 100 kHz FWHM and 11 W output power was shown. High power T-DCF amplifiers with output of 160 W and 120 W were demonstrated respectively in [10] and [11]. The core diameters of T-DCF were 30 µm [9], 50 µm [10] and 45 µm [11] accordingly. For further power scaling an active core diameter of T-DCF has to be increased.

In the present work, we, for the first time to our best knowledge, experimentally demonstrated the single frequency polarization maintaining all-fiber MOPA containing birefringent T-DCF with 100 µm core for amplification of kHz-band CW seed laser. This MOPA delivered 70 W output power (36.7 dB gain) at 1033.3 nm with record 8 kHz FWHM bandwidth and demonstrated perfect beam quality (M^2=1.03/1.08).

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2. EXPERIMENT

To successfully realize the amplification of the narrow linewidth laser we employed two strategies: longitudinal gradients of the temperature and core/cladding area in the powerful amplifier. The system was based on MOPA scheme. The experimental setup of all-fiber MOPA system was shown in Fig.1. The in-house made fiber DFB laser described earlier in [12] was used as a seed source in our experiment. The DFB laser emits 15 mW with central wavelength equal to 1033.3 nm. The seed source radiation launches without any additional pre amplification stages via isolator into the tapered double clad amplifier. The T-DCF amplifier pumped from both sides was very similar that we used earlier in [8]. 1% coupler was used to control backward SBS radiation.

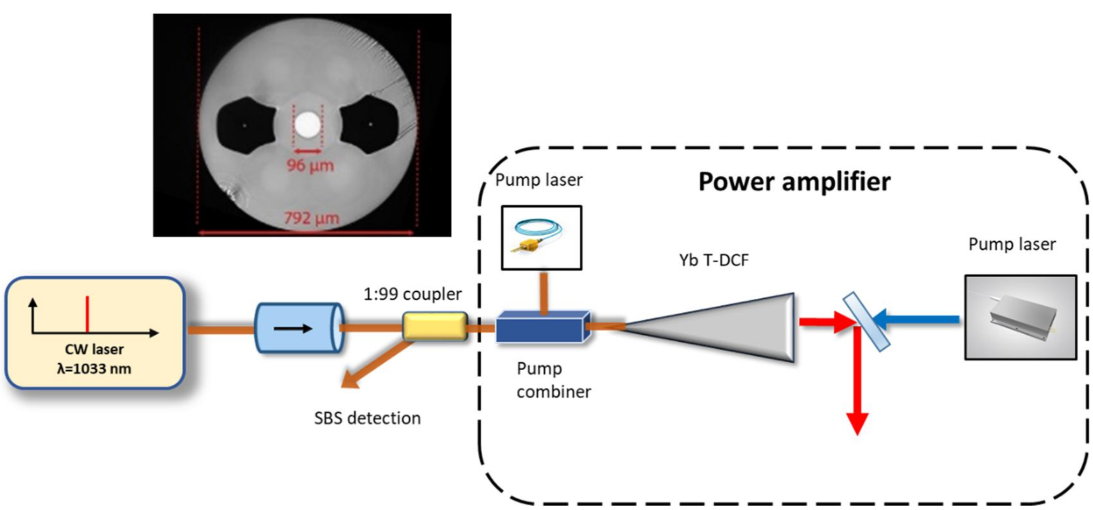

Fig.1. The experimental setup of fiber-based single-frequency MOPA system. Inset: end-facet image of Yb-doped T-DCF.

The accurate measurement of the single-frequency laser linewidth was carried by heterodyne method used previously in [12]. We utilized two almost identical DFB lases with close central wavelength value. The central wavelength of two lasers were matched roughly via spectrum analyzer with resolution of 0.01 nm. The further fine adjustment was performed by using RF analyzer to obtained beat note spectrum. The beat note spectrum of two lasers recorded by RF analyser was shown in Fig.2. The FWHM of the measured beat note spectrum was 1.4 kHz limiting by the resolution of the RF analyzer. The results of the performed experiments allow to conclude that the amplified emission linewidth is half –width of the measured beat note spectral line and it does not exceed of 700 Hz at least. We have performed the set of the measurements, all of them gave identical results.

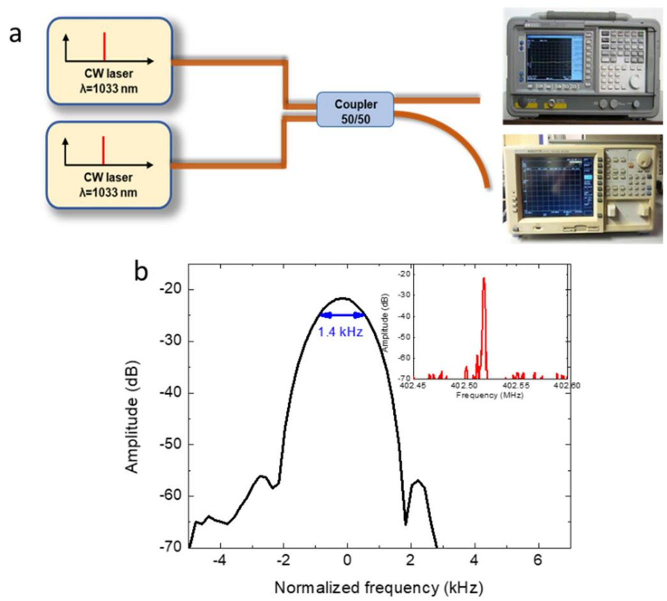

Fig. 2. Line-width measurement by heterodyne technique. a – setup of beat-note measurement technique; b – Normalized RF-spectrum of the beat-note. Inset: The measured spectrum of beat-note.

Ytterbium doped preform for drawing of T-DCF was fabricated by surface plasma chemical vapor deposition (SPCVD) process. The core has gradient refractive index profile with maximum value of refractive index difference of 0.004. The preform for the tapered panda-type birefringent active fiber was made by stacking method. The active core part produced by SPCVD method is surrounded by a set of different shaped and sized rods from pure and boron doped silica, thus it is a way to arrange panda-like structure (Fig.1, inset). Then, this assembly was collapsed to a solid preform and drawn to a T-DCF. The core and clad diameters were 96 and 792 µm accordingly (Fig.1 inset) at the wide side of T-DCF. The fiber was tapered dawn to 110 µm of the cladding diameter with tapering rate of T=7.2. A typical longitudinal profile of the active taper was shown in Fig.4 at Ref. [8]. The presence of borosilicate tensile rods in the cladding leads to a good mixing of the cladding modes, and therefore no shaping of the clad was required for good cladding pump absorption. The measured value of in-core absorption was 1200 dB/m and the measured value of co-propagated cladding pump absorption at 976 nm was 26 dB. The birefringence of the active T-DCF was measured by using a standard method for polarization modes beats measuring. The calculated birefringence value was $0.41*10^{-4}$ for 1030 nm and polarization extinction ratio (PER) was about 30 dB.

In order to characterize the properties of an amplified beam, M^2 and beam divergence were measured experimentally in an amplification regime. The amplified beam had a round bell-shaped form and its parameters were analyzed with Beamscope-P5 beam profiler (Fig.3). The amplifier output has near diffracted limited pure fundamental mode with M^2_x =1.03 and M^2_y =1.08, respectively. The mode-field diameter was equaled to 50 µm.

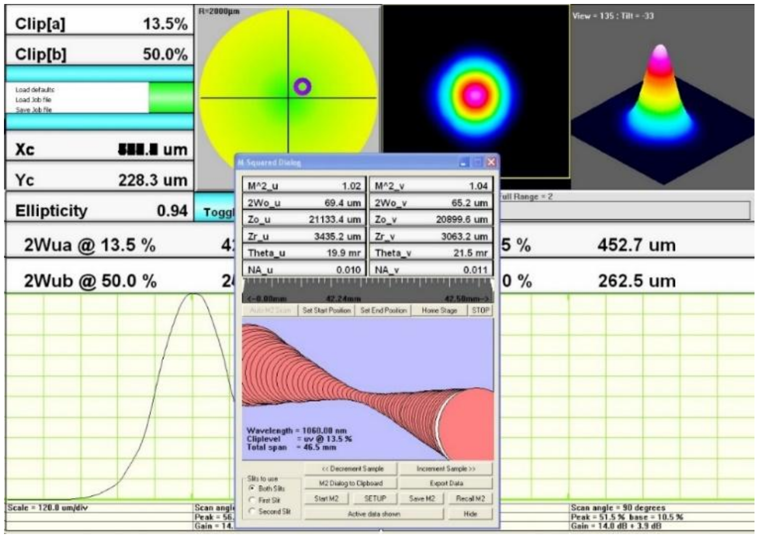

Fig.3. The results of M^2 measurements.

The T-DCF was pumped bi-directionally through the fused pump combiner and dichroic mirror by fiber coupled wavelength stabilized diodes at 976 nm. The dependence of the output power versus the launched pump power and the spectra of the output amplified signal were shown in Fig.4a,b.

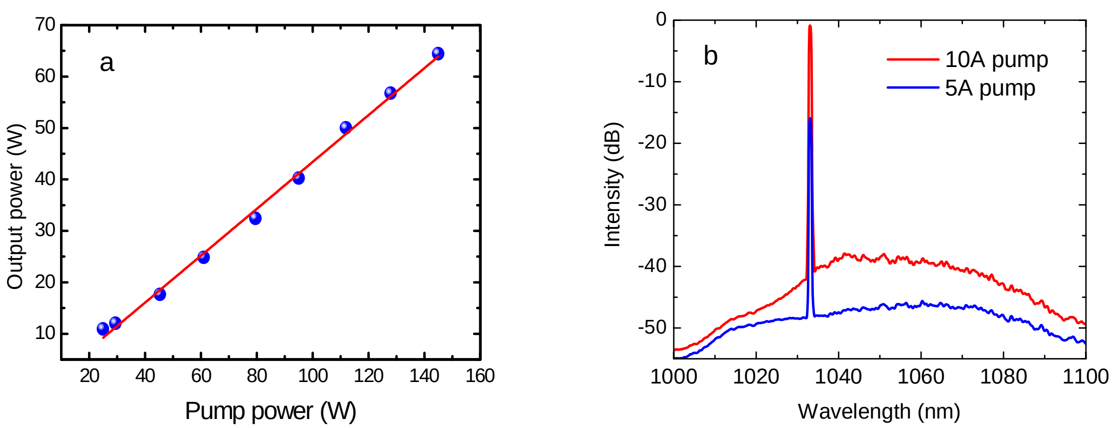

Fig.4. a - Output power as function of launched pump power, b - Spectra of amplified signal for two different pump the T-DCF amplifier pump current.

We have launched 15 W pump power from the narrow side and 150 W from the wide end of the T-DCF. It was allowed to get 70 W of the output power without any roll up. The slope efficiency exceeded 40% level. As it can be seen from Fig. 3a, the T-DCF based amplifier was not saturated, therefore, the output power was primary limited by the amount of pump power. The output spectra of the amplified signal (Fid. 3b) revealed slight increasing of the amplified spontaneous emission at the long wavelength side. The appearance of SBS was investigated experimentally as a function of the output power. To do it, 1% tap coupler was included into optical scheme for recording of the back propagated SBS radiation. The results of the measurement of the dissipated power in the backward direction were presented in Fig.4. The measurement demonstrated neglected level of the back reflected power confirming the absence of SBS radiation.

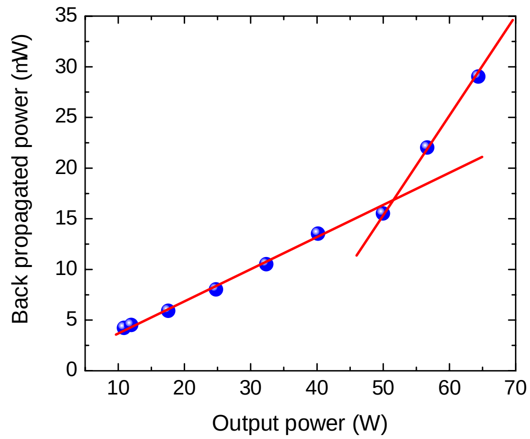

Fig.4. Back propagated power as function of output power.

3. CONCLUSION

In conclusion, we have demonstrated all fiber MOPA delivered 70 W power at 1033.3 nm with sub-kHz FWHM linewidth without any sign of SBS radiation. To do it, we developed an anisotropic ytterbium doped T-DCF amplifier with 50 µm MFD and polarization extinction ratio about 30 dB. The output radiation demonstrated perfect beam quality (M^2=1.03/1.08). Due to the absence of the SBS radiation and saturation effect of the powerful amplifier the further power scaling is possible by increasing of the pumping level.

This work was supported by the Ministry of Education and Science of Russian Federation (grants No. 14.578.21.0109, 16.3788.2017/4.6 and 16.4959.2017/6.7) and Academy of Finland (Project No. 285170).

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