310 W single-frequency all-fiber laser in master oscillator power amplification configuration

To cite this article: X L Wang et al 2012 Laser Phys. Lett. 9 591

View the article online for updates and enhancements.

Related content
- A 330 W single-frequency retrievable multi-tone monolithic fiber amplifier
  Wang Xiao-Lin, Zhou Pu, Leng Jin-Yong et al.
- Suppressing the stimulated Brillouin scattering
  J Y Leng, X L Wang, H Xiao et al.
- A 280 W high average power, single-frequency all-fiber nanosecond pulsed laser
  Xiaolin Wang, Pu Zhou, Rongtao Su et al.

Recent citations
- An efficient low-noise single-frequency 1033 nm Yb**+-doped MOPA phosphate fiber laser system
  Huaqiu Deng et al
- All-fiber-integrated single frequency tapered fiber amplifier with near diffraction limited output
  Zichao Zhou et al
- 52 W kHz-linewidth low-noise linearly-polarized all-fiber single-frequency MOPA laser
  Changsheng Yang et al
**Abstract:** We present a high power, single-frequency fiber amplifier based on master oscillator power amplification (MOPA) chains in all-fiber configuration. A 1.5 meter long highly doped Yb fiber with absorption coefficient as high as 16 dB/m at the 975 nm wavelength is used for the main power amplifier, no special assistant stimulated Brillouin scattering (SBS) suppression approach is employed. The maximal output power of the single-frequency fiber amplifier is 310 watt and of good beam quality with a measured $M^2$ factor about 1.3. The amplifier is tested more than 10 hours, no obvious power decrease is observed. To the best of our knowledge, this is the highest power of single-frequency fiber amplifier in all-fiber format.

**310 W single-frequency all-fiber laser in master oscillator power amplification configuration**

**X.L. Wang, P Zhou, H. Xiao, Y.X. Ma, X.J. Xu, and Z.J. Liu**

College of Optoelectronic Science and Engineering, National University of Defense Technology, Changsha, 410073, China

Received: 7 April 2012, Revised: 18 April 2012, Accepted: 21 April 2012

Published online: 11 June 2012

**Key words:** all-fiber laser; single-frequency; master oscillator power amplification

---

**1. Introduction**

High power, single-frequency lasers are desirable for many applications, including coherent combination, remote sensing, gravitational wave detection, nonlinear frequency conversion and laser radar [1–4]. In earlier investigation, high power single frequency fiber amplifier operating at 600 watt level had been demonstrated using bulk free-space components [5–7]. For many applications involving high-power lasers, the use of all-fiber based components can significantly simplify system configuration and thus become much more compact and robust. Recently, single-frequency fiber amplifier in all-fiber format had been under intense research [8–10]. Up to now, the highest output power of an all-fiber single-frequency fiber amplifier is reported by Zeringue et al., which provides a 203 W single-frequency fiber laser beam [9]. The main difficulty in scaling the output power is the limitation induced by stimulated Brillouin scattering (SBS). Number of approaches, such as the use of thermal gradients [11,12], acoustically tailored fibers [11], strain gradients [13], and gain-competition [9,14] have been either demonstrated or suggested to suppress SBS in fiber amplifiers. Those techniques had been proofed to increase the SBS threshold by a factor of 2–3 or even more. Using short active fiber is also an effect way to suppress SBS and been demonstrated in experiment [15,16]. In [16], Geng et al. have demonstrated a fiber amplifier with kilowatt peak power by employing 20 cm long Tm doped fiber. In the present paper, we will demonstrate a high-power single-frequency fiber amplifier in all-fiber format using a large mode area (LMA) highly doped active fiber. Due to the high absorption coefficient

* Corresponding author: e-mail: wxllin@nudt.edu.cn
2. Experiment setup

The full master oscillator power amplification (MOPA) chain used in our experiment is depicted in Fig. 1. A 1064-nm, 40-mW short-cavity structured Yb$^{3+}$-doped fiber (YDF) laser [17] with a linewidth less than 20 kHz is followed by three YDF amplification stages: two pre-amplification stages and a power scaling stage, which were all built with all-fiber components. The first stage is a conventional single-mode YDF amplifier. The core and cladding diameter of the active fiber in the first stage is 6/125 $\mu$m with core NA of 0.14. The first stage can boost the output power to 200 mW when pumped by a 500 mW single-mode fiber pigtailed laser diode (LD) with 974 nm central wavelength.

The second stage amplifier is a double clad YDF amplifier co-pumped by two 9 W wavelength stabilized pigtailed laser diodes (LD) with central wavelength of 975 nm. The gain fiber in this stage has a 15 $\mu$m diameter core with a NA below 0.08. The diameter of inner cladding is 130 $\mu$m, and the inner cladding NA is 0.46. The active fiber has an absorption coefficient of 5.5 dB/m at 975 nm pump wavelength and a length of 3.5-meter is used in this stage. A 0.5 meter long of matched passive fiber is spliced to the active fiber to delivery output power. Then the passive fiber is fused to an isolator to prevent backscattering light. The output power of this stage is measured to be 12.5 W under a full pump power. It is to be noted that, in a single-frequency fiber amplifier system, the power of signal laser and the backward light should be carefully monitored to avoid the damage caused by amplified spontaneous emitting (ASE) and SBS. After the isolator, a 99:0.1 tap coupler cooperated with two photo detectors (PD1 and PD2) are used to monitor the output power in the current stage amplifier and the backward power of the next stage amplifier. When the power detected by PD1 is more than 1 mW (which means the total power of the backward light in the tap coupler is $\sim$ 1 W) or the power detected by PD2 is less than 10 mW (which means the total power of the signal laser is less than 10 W), the power supply of the pumps in main amplifier will be cut off by a special designed control circuit automatically to avoid unwanted damages in the former stage amplifiers. In the power amplifier, the signal laser and the pump light are launched into the power scaling stage via a...
(6+1)×1 pump and signal combiner. Six 65-watt, 105 μm multimode fiber pigtailed, 975 nm central wavelength laser diodes are launched into combiner. The output port of the combiner is fused to the high absorption Yb-doped LMA double clad fiber. The core/inner cladding diameter of the active fiber is 30/125 μm, respectively. The NA of the core and the inner cladding are 0.06 and 0.46. Thanks to the high absorption coefficient (~16 dB/m around 975 nm wavelength) of the active fiber, only 1.5-meter-long active fiber is required in the amplification stage. And therefore the SBS can be mitigated a lot compared with a longer length of fiber. And therefore the SBS can be mitigated a lot compared with a longer length of fiber. A ~0.2 m long double-clad passive fiber of the same core/inner cladding diameter and NA with the LMA YDF is spliced to the LMA YDF for power delivery. The spliced region is covered in high-index gel. In order to make the amplifier working in the fundamental mode, we coiled the fiber with a diameter less than 10 cm.

Thus, the high-order mode as well as residual pump in inner cladding can be stripped by the high-index gel. The output end of the amplifier fiber is angle cleaved at 8° to suppress spurious lasing as a result of Fresnel reflections. The output power of the amplifier is measured by a power meter.

3. Experiments results

In experiment, we first confirmed the linewidth of the single-frequency laser by used a Fabry-Pérot interferometer (FPI 100, FSR = 4 GHz, fineness ~ 10 MHz, Toptica Inc.), as shown in Fig. 2. Results show that the measured linewidth is less than 10 MHz (~8.8 MHz). As the fineness of the FPI is about 10 MHz, therefore, the seed laser is confirmed to be a single-frequency one. For the lacking of acoustic optical modulator (AOM), we didn’t measure the linewidth more accurately.

When seed and the first two amplifiers are working at the full power, the output power in the main power amplifier is measured at the incremental pump power and shown in Fig. 3. A stable maximum 310 W output is achieved with 390 W fully launched pump power. The calculated optical efficiency is about 76.4%. Using the measured power in PD1, the calculated backward power in the main amplifier at the incremental pump power is also shown in Fig. 3. It can be seen that maximum backward power is of about 0.55 W, and no nonlinearly increasing up of the backward power is observed. At the maximum output power level, our amplifier operates for more than 10 hours with no obvious power fluctuations or backward power rising and has performed a good stability.

Shown in Fig. 4 is the spectrum of the amplifier operating at its full-power measured using an optical spec-
trum analyzer. It is observed that the amplified spontaneous emission (ASE) has built up in shorter wavelength region but very weak compared with the signal laser and thus has little effect on the amplifier’s performance. We also found in Fig. 4 that there still exists pump light centered at 975 nm in the amplifier’s output. It can be neglected in this experiment because it is about 38 dB lower than the signal laser.

In order to study the beam quality of the amplifier, we measured the beam quality by using $M^2$ factor measurement equipment (M-200s-FW). The measured data and the beam profile are show in Fig. 5. Results show that the $M^2_x$, $M^2_y$ are about 1.3 and 1.25. Therefore, it can be conclude that the beam quality is about 1.3.

In theory, the threshold of the SBS can be estimated by $P_{th} = 21 A_{eff}/g_R L_{eff}$ [18]. In experiment, $A_{eff}$ is calculated to be $7.0 \times 10^{-10}$ m$^2$. $L_{eff}$ is the effective interaction length. In experiment, there is 1.5 m active fiber delivery a non-uniform power and a 0.2 m passive fiber delivery a power up to the full power W. The effective interaction length at the full power can be estimated to be less than 0.9 m. For a Silicon-based fiber, $g_R = 5 \times 10^{-11}$ m/W. Therefore, the SBS limited power is calculated to be 329 W, which is a little higher than that value in our experiment.

To the best of our knowledge, this power level is the highest reported in the literature for an all-fiberized, Yb-doped single-frequency amplifier. Moreover, by working in conjunction with other SBS suppressing techniques such as acoustic tailoring or gain-competition, we estimate that further power scaling to the 500W without significant SBS if six 150 W, 105 μm multimode laser diodes are used. This would be tested in our next step.

4. Summary

In conclusion, we have presented the detailed characteristics of a stable MOPA structured high power single-frequency amplifier in all-fiber configuration. Thanks to the highly doped Yb fiber with absorption coefficient as high as 16 dB/m, the SBS is mitigated and the single-frequency seed laser can be stably boosted to a 310 W maximum output without generating significant SBS effect. The amplifier has exhibited good stability and beam quality when operates at high power level. The amplifier’s output power can be both further advanced with more powerful pump source. It should be noted that no special SBS suppression technique is employed in this system, by working in conjunction with other SBS suppressing techniques such as acoustic tailoring or gain-competition which have been proofed to be effect methods to suppress SBS effect, it is straightforwardly to scale the all-fiber single-frequency fiber amplifier to 500 level.

Acknowledgements This work is supported by (1) program for new century excellent talents in university, ministry of education, China and (2) Scientific research project in National University Defense of Technology of China.

References