All-fiber counter-propagation pumped amplifier tailored for Coherent Beam Combining technique

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Abstract: we report on the qualification of an all-fiber counter propagating pumped amplifier by using a narrow-linewidth single-frequency nanosecond fiber laser. The proposed amplifier design is tailored to be used for coherent beam combining of fiber amplifiers in tiled-aperture configuration.

1. Introduction

Applications such as remote sensing and coherent detection LiDARs require narrow-linewidth single frequency nanosecond lasers with high energy and high quality single mode beam [1]. However, the output energy power of such laser is mainly limited by Stimulated Brillouin scattering (SBS). One efficient approach to mitigate the SBS effect, besides classical solutions [2] is to rely on a counter-propagation pumping scheme instead of co-propagation pumping. On another hand, increasing and scaling the total average power and energy could be achieved by using the Coherent Beam Combining (CBC) method.

In the co-propagative pumping scheme, pump and signal are injected into the fiber amplifier along the same direction, through a pump/signal combiner located before the active fiber. The amplified signal is then extracted through the output fiber without any obstruction from any other fiber components, and thus, could easily be stacked within a 2D array laser head satisfying CBC tight geometrical arrangements [3,4]. In counter propagative pumping, the pump and signal are launched into the fiber amplifier in opposite direction. The pump/signal combiner is located after the active fiber and its signal port is used to extract the amplified signal. This configuration allows for high signal injection efficiency at the input of the active fiber offering thus a better laser efficiency while diminishing nonlinear phase accumulation and therefore its associated deleterious nonlinear effects. However, the conditioning of such amplifier at its exiting port somehow limits its use for CBC lasers where the amplifiers outputs should be arranged into a 2D array with very stringent pitch and angular positioning accuracies. We report here on the qualification of an all-fiber counter propagating pumped amplifier in the nanosecond regime, tailored to be used for coherent beam combining of fiber amplifiers in tiled-aperture configuration. The behavior of the amplifier within the presence of SBS is discussed and compared to the case of co-propagative pumping.

2. Results and discussion

Figure. 1(a) illustrates the counter-propagative fiber amplifier designed and functionalized by Optical Engines. The amplifier stage is a single-mode, polarizing double-clad large mode area Yb-doped fiber supplied by NKT Photonics. The signal input port is followed by two Mode Field Adapters (MFA 1,2). The unabsorbed pump light is stripped out by using a passive aircladless fiber section. The signal coupling efficiency is ~90 % at the input of the active fiber. At the output, we use a (9+1)x1 pump/signal combiner, allowing an efficient coupling (> 95%) of 9 contra-propagative injected pumps. This combiner is able to handle very high average power both for the pump ports (up to 100 W/port) and the amplified output signal.

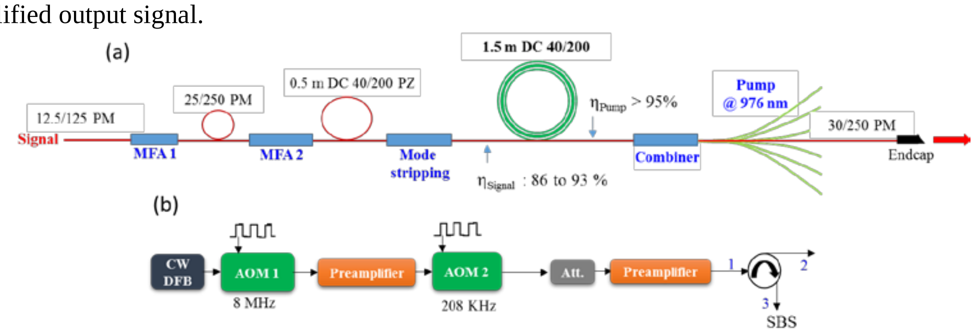

Figure 1. (a) Counter-propagative fiber amplifier and (b) the experimental setup.

The amplified signal is extracted through a 10 cm long 30/250 passive fiber spliced to a 2 mm long angled endcap with AR coating used to avoid surface damage when high power regime is operated. This short fiber section allows, when CBC is used in a tiled-aperture configuration to easily stack the output beams of independent fiber amplifiers. It is worth noticing that at high peak-powers, nonlinearities can be accumulated is this short section in addition to the amplifier itself. The energies achievable in pulsed regime with this all-fiber combiner should thus be slightly lower compared to classical counter-propagative amplifiers schemes where the pump coupling is performed in free space.
The experimental setup is displayed in figure 1(b). The seed laser is a 50 mW CW distributed-feedback diode laser emitting at 1030 nm (~2 MHz linewidth) modulated by two Acousto-Optical Modulators (AOM) driven by a pulse generator. The first AOM allows the generation of a 13 ns pulses from the CW signal with 34 MHz linewidth at a repetition rate of 8 MHz, whereas the second one is used to decrease the pulse repetition rate. Two pre-amplifiers compensate for power losses all over the laser chain. Thus, we can maintain the same signal power of 100 mW at the input of the amplifier stage for a repetition rate as low as 50 kHz. An optical circulator is inserted before the amplifier stage to monitor the Stimulated Brillouin Scattreing (SBS) arising in these amplification conditions. Figure 2 shows the amplifier efficiency and the backscattered SBS power as a function of the pump power in the case of co-and-counter propagative pumping at a repetition rate of 208 kHz. The amplifier slope efficiency for counter propagative pumping is 68 % to be compared with 60 % for co-propagative pumping.

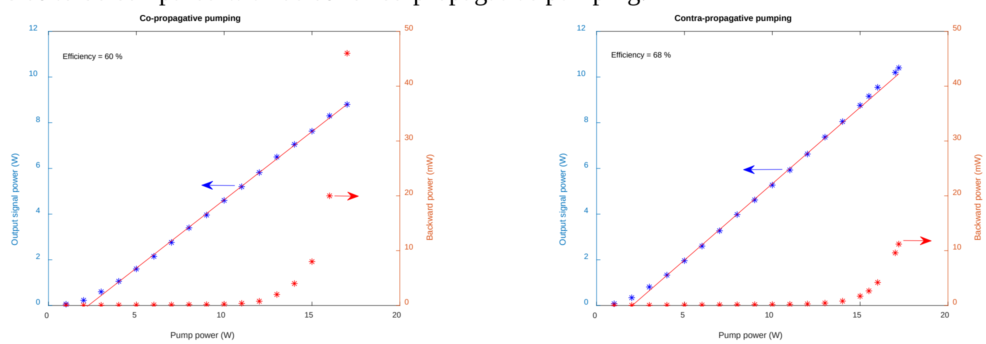

Figure. 2. Output signal and backward powers as a function of pump power for co (left) and contra (right) pumping.

The SBS threshold is reached when the backscattered power attains 1 % of the signal input power. At this point, pumping the amplifier much harder would cause SBS to start depleting the forward signal power and feed the backscattering signal, itself amplified by the fiber gain. This behavior leads to strong gain instabilities, which can cause serious damages to the amplifier. In the case of co-propagative power (Fig. 2-left), the SBS starts to appear when the amplified signal reaches 6.5W for a pump power of 13W, giving a pulse energy of 31 µJ. For harder pumping (17 W), the amplified signal power is 8.8 W and the SBS follows an exponential evolution reaching a critical level of 46 mW, a situation in which the backscattering power signal starts approaching the signal input power (about 100 mW). Moreover, the SBS signal propagates in opposite direction with respect to the pump, a favored amplification scheme. In the case of counter-propagative pumping (Fig. 2-right), the SBS threshold is reached for a pump power of 15 W, giving an amplified signal of 9 W. At this point, the energy is 43 µJ, 39% higher than the energy obtained with co-propagative pumping. Indeed, in addition to a lower nonlinearity level, the backward pumping scheme yields a SBS signal co-propagative with the pump, thus lowering its amplification efficiency through the active fiber and increasing the SBS threshold even more. At 17 W pump power, we measure 10.2 W of amplified signal and 9.6 mW of SBS instead of 46 mW for the co-propagative configuration. At this point, the output energy is stable at 49 µJ.
The next steps of this work would be the realization of CBC of 7 counter-propagative amplifiers in tiled-aperture configuration using an interferometric measurement method along with an active phase control [3]. This work has received funding from the Centre National d'Etudes Spatiales (CNES), the French Ministry of Defense (Direction Générale de l'Armement).

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