Pulsed Fiber-MOPA source operating at 1550 nm with pulse distortion pre-compensation

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Abstract: In this paper we present a diode-seeded pulsed Fiber-MOPA source operating in the telecommunication band with pulse distortion pre-compensation using arbitrary shaped input pulses. 100 ns long flat-top pulses were obtained.
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1. Introduction

Fiber-based sources in MOPA (Master Oscillator Power Amplifier) configuration became recently a very attractive alternative to solid-state lasers in many technological applications, like material processing, laser welding, etc. Recently most attention was devoted to Ytterbium-doped fiber based constructions operating at 1 μm wavelength range [1,2]. However, there are many important applications where Yb-doped sources cannot be used because of required eye safety, like free space communication, sensing or military ranging systems. In such areas high power 1,5 μm wavelength sources are necessary. Erbium/Ytterbium co-doped fibers make excellent active gain media to build medium/high power sources or amplifiers at the 1,5 – 1,6 μm region. This wavelength makes them compatible with existing telecommunications systems. This opens the possibility to use Er/Yb-doped devices in many applications like: CATV booster amplifiers [3,4], transmitters in WDM-PON networks [5], free-space optics (FSO) [6] or inter-satellite links (ISL) [7].

Diode-seeded Fiber-MOPA sources, despite all their advantages, are strongly vulnerable to unwanted output pulse distortion effects, while high-power nanosecond pulses with kHz-range repetition rate are extracted. In such system, when the energy in the amplifier reaches the saturation level, pulse-shaping will occur. The leading edge of the pulse will get a high gain depleting the population inversion, so the rest of the pulse will be decreased exponentially [8]. It is possible to compensate the disadvantageous influence of energy saturation by properly shaping the input pulse. These methods allow to achieve arbitrary shaped output pulses, meeting the requirements of some applications like nonlinear frequency conversion or materials processing. For example, long flat-top pulses are particularly desirable because of their highest possible energy.

In our work we present a dual stage MOPA source working in the telecommunication band (1550 nm) capable to generate user defined output pulse shapes using an arbitrary function generator (AFG). The temporal input pulse shapes are calculated using a simple model taking into account the pulse distortion in both amplifier stages. The presented setup is fully based on fiber-optic devices, without any free-space bulk elements, which makes the design fully stable, robust and environmentally insensitive.

2. Fiber amplifier design

Our All-In-Fiber MOPA setup is shown in Figure 1. It consists of two amplifying stages. The first stage (pre-amplifier) is an EDFA based on highly erbium-doped fiber pumped bidirectionally by two 700 mW 980 nm single-mode pumps. It provides about 23 dB gain in the whole C-band. The second stage (power amplifier) is based on Erbium/Ytterbium doped double-clad fiber with 7 μm core and 130 μm cladding diameter. It is backward-pumped by a 975 nm 10W laser diode coupled with the double-clad fiber by a pump combiner. The unabsorbed pump light from the second stage is rejected by a specially designed cladding-mode stripper. Both stages are separated with an isolator which prevents the first stage from back-scattered light. A standard telecom 1550 nm directly modulated DFB laser diode was used as a seed source. The results are monitored by a digital 350 MHz oscilloscope coupled with a photodiode.

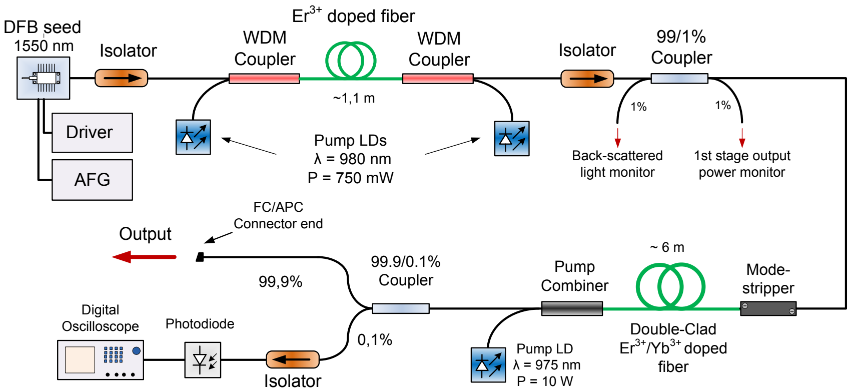

Fig. 1. Two-stage Fiber-MOPA design used in experiments.

The pulse distortion effect in high power diode-seeded Fiber-MOPA systems can be easily observed by giving a relatively long, rectangular pulse to the amplifier chain input. When the pulse energy reaches the saturation level, the output temporal shape will be deformed as shown in Fig. 2.

a) b)

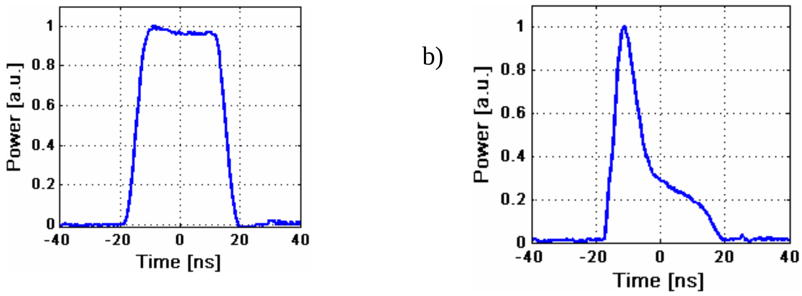

Fig. 2. Rectangular input pulse (a) and a distorted output pulse (b).

The output pulse shape is bound with the input through a gain function [9]:

$$I_{output} = I_{input} \cdot G(t) \tag{1}$$

where $G(t)$ is given by a simple exponential function:

$$G(t) = 1 + \left(G_0 - 1\right) \cdot \exp\left(-\frac{E_{out}(t)}{E_{sat}}\right). \tag{2}$$

The parameters are: small signal gain G_0 and saturation energy E_{sat}. They can be obtained experimentally by launching a rectangular pulse into the amplifier and approximating the output shape. Therefore, to calculate the required input pulse, which gives the desired output shape, we need only to solve the equation (1) to get I_{input}.

Unfortunately, those equations do not take into account that the pulse is traveling through two amplifying stages with their own $G(t)$ functions. In our case both the first and second stage are deforming the pulse exponentially, but with different time constants, as shown in Fig. 3.

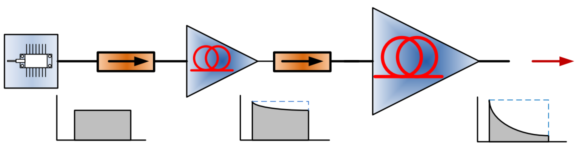

Fig. 3. Pulse deformation in two-stage MOPA system.

Therefore, the complete function that allows to calculate the input shape to obtain desired output can be expressed as:

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$$I_{input} = \frac{I_{output}}{G_{EDFA}(t) \cdot G_{EYDFA}(t)}, \quad (3)$$

where G_{EDFA} and G_{EYDFA} are the gain functions of the first and second amplifier stage, respectively.

3. Experimental results

Examples of obtained flat-top output pulse with 100 ns duration and a corresponding input pulse are shown in Fig. 4 (red curve). The pre-compensated input pulse is calculated using the equation (3). A very good correlation between the model and measurement can be observed. Additionally, the instabilities at the beginning of the pulse can be also easily compensated by smoothing the leading edge of the input pulse (blue curve on the graph).

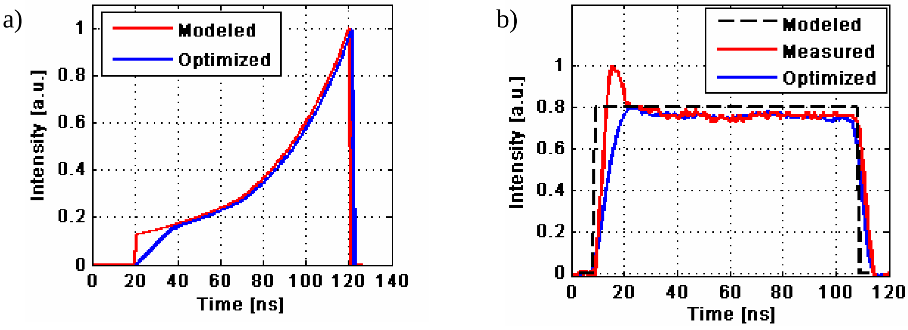

Fig. 4. Pre-compensated input pulse (a) and a corresponding flat-top output pulse (b).

4. Conclusions

In conclusion, we have presented a diode-seeded All-fiber MOPA setup operating in the telecommunication band with pulse distortion pre-compensation. To calculate the required input pulse a simple and effective theoretical model was presented and verified experimentally. 100 ns long flat-top rectangular output pulses were obtained. Presented device can be used as a source for free space telecommunication or eye-safe optical ranging systems.

5. References

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