

# Design and Demonstration of an All-Fiber Tandem Pumped Master Oscillator Power Amplifier

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## Abstract:

We present simulations for an all-fiber tandem pumping configuration and demonstrate kW-level output through a careful management of the in-band pump power level. Experimental results are also presented for a booster amplifier at 1030 nm.

OCIS codes: (140.0140) Lasers and laser optics; (060.0060) Fiber optics and optical communications

## 1. Introduction

Tandem pumping has been proposed and demonstrated as a robust pathway to achieve multi-kW power levels from a single emitter fiber laser [1-3]. Tandem pumping is typically achieved by developing high brightness single mode fiber lasers in the 1018 nm band and using them to perform in-band pumping of Yb:silica fiber amplifiers to achieve multi-kW output at 1064 nm. One of the key challenges in such in-band pumping is the coupling of the 1018 nm radiation into the tandem pumped amplifier section. This has been previously achieved by coupling multiple single-mode fiber lasers at 1018 nm into a tapered fiber bundle (TFB), which is further launched into the reduced cladding of a double-clad Yb:silica fiber [2].

In our work, we propose an alternative technique wherein the in-band pump as well as the seed laser radiation is generated separately and combined at a low power level (<1 W) which is amplified together in a series of amplifier sections (Figure 1). Since both the in-band pump and the seed radiation are confined to the core of the fiber, this configuration avoids several of the drawbacks of double-clad pumping including reduced pump brightness, higher order mode excitation and thermal mode instability. However, the primary challenge in this approach is the utilization of the inversion in the Yb:silica fibers to ensure proper transfer of power from the 976 nm pump to the in-band pump, and then to the 1064 nm wavelength. We have carried out detailed simulations to study such power transfer, resulting in a specific design of the fiber amplifier configuration. We have also experimentally demonstrated preliminary results that show promise for this tandem pumping configuration.

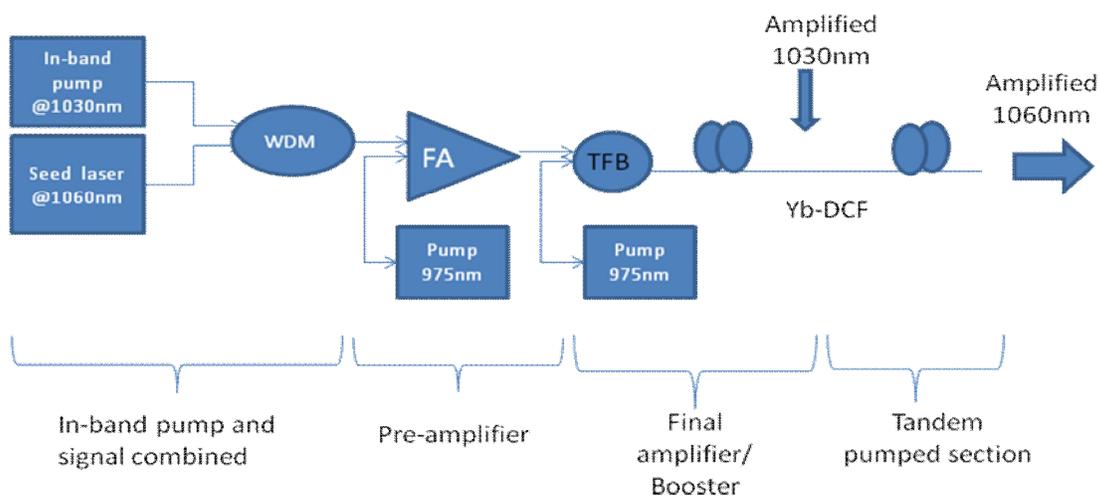


Figure 1: Schematic diagram of our tandem pumped fiber amplifier

## 2. Simulations

We perform simulation for the final amplifier stage of setup show in Figure 1, whose initial length is expected to act as amplifier for 1030nm and the later part of fiber is tandem pumped to amplify 1060nm. Our simulations incorporate a Yb-doped large mode area double clad fiber from Nufern Inc. (LMA-YDF-25/250-VIII). The input power fed in to the amplifier is considered to be 10W at 1030nm and 0.1W at 1060nm. The pump wavelength is chosen as 975nm with about 1 kW power level. The simulations were performed using RP FiberPower software. From simulations, we found that about 7 m length is required to transfer power from 975 nm to 1060nm. The simulation results obtained are shown in Figure 2.

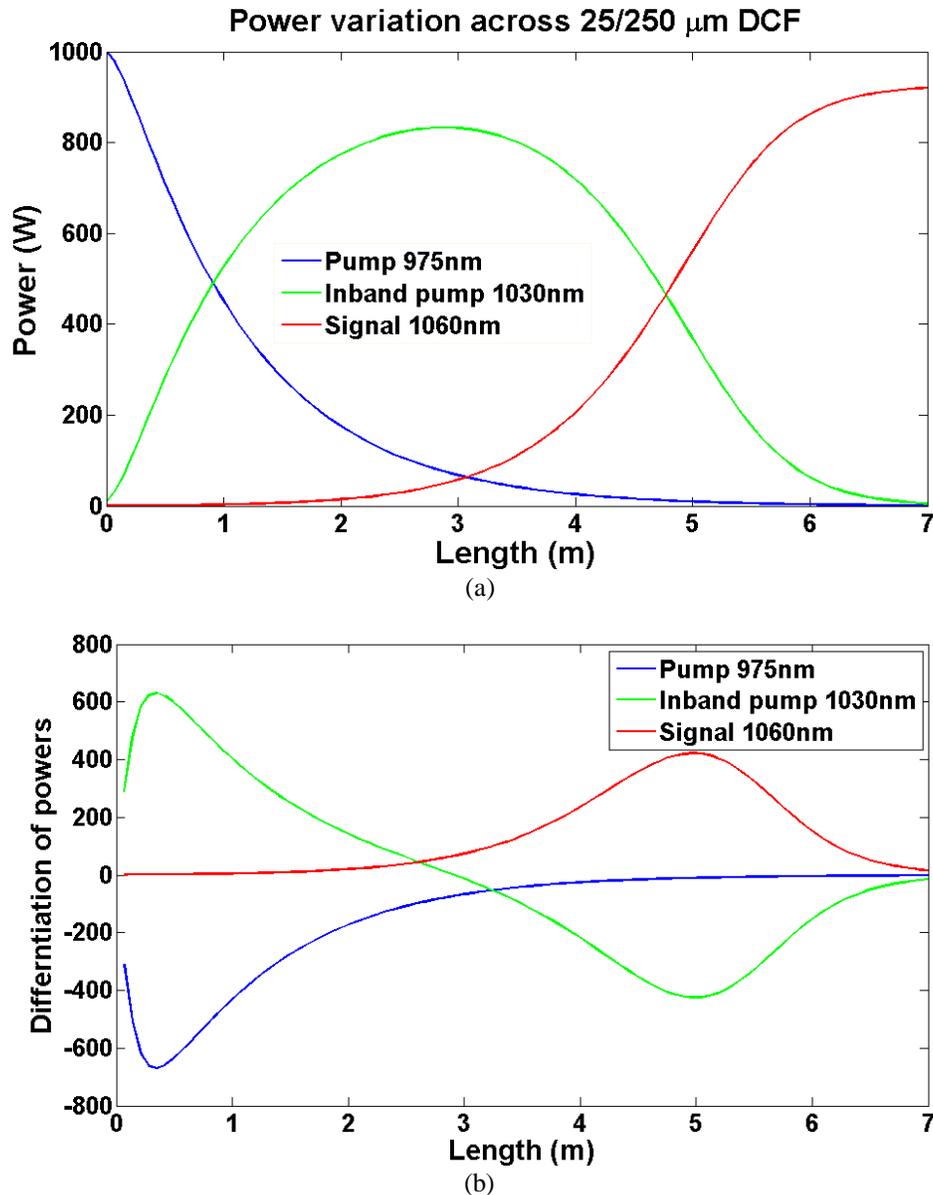


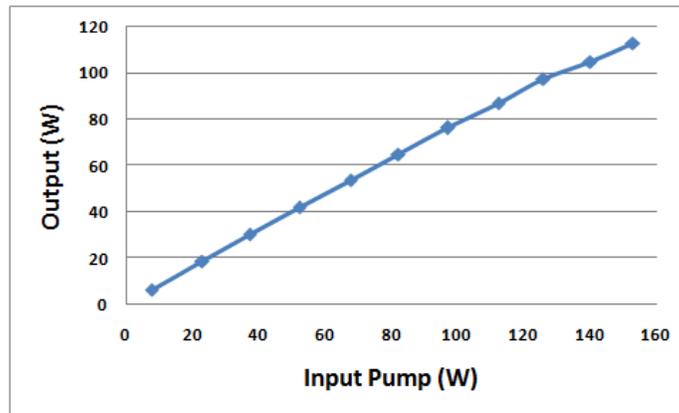
Figure 2: (a) Simulation results for power variation for 976 nm pump, 1030 nm in-band pump, and 1064 nm signal across the Yb-doped fiber, (b) differentiation of the above curves to clearly illustrate the region where much power is getting transferred to the other wavelengths.

From simulations it can be seen that the major power transfer occurs from 975nm to 1030 nm in the initial 3 m length of Yb:silica fiber. During this length, we also observe that 1060 nm amplifies to a significant level (as 1060

was considered 40 dB below 975 nm power level) such that the power transfer initiates now from 1030 nm to 1060 nm. Figure 2b shows the differentiation of power with respect to length which clearly shows that most of the power transfer from the 976 nm to the in-band pump happens within the first 1 m of the amplifier. Similarly, the power transfer to the 1064 nm wavelength is accomplished primarily around 5 m.

### 3. Experiments

Based on the above simulation results we carried out experiments using the experimental setup shown in Figure 1. Fiber ring lasers emitting radiation at 1030 nm and 1060 nm were made using Yb-doped double clad fiber with core/clad diameter of 5/125  $\mu\text{m}$  (ORC Inhouse fabricated fiber). The 1030 nm laser was operated at higher power levels of about 200 mW and 1060 nm was operated just above threshold to give about 20 mW power level and about 10 dB extinction can be achieved between 1030 nm and 1060 nm. Both the signals are then combined using standard low power WDM coupler. Fiber amplifier is used to mainly to amplify 1030 nm to higher power levels before it is fed to our final amplifier stage. This fiber amplifier consists of similar fiber used for making 1030 nm and 1060 nm ring lasers. Shorter length of YB-doped fiber is chosen for amplifier so as to achieve higher power at 1030 nm with good extinction from 1060 nm. However, the extinction of 10 dB reduces to about 3-4 dB at the output of amplifier. As a good extinction between 1030nm and 1060nm is needed before it goes to final amplifier, we inserted a variable attenuator at the output 1060nm laser and WDM. By varying the attenuation, 1060 nm input power is reduced to amplifier, such that the output of amplifier is having 1030 nm power more than by 10 dB compared to 1060 nm. About 2W of total power is achieved at the output of fiber amplifier (FA) and fed to our final amplifier stage which consists of about 3 m of Yb-doped double clad fiber with core/clad diameter of 10/130  $\mu\text{m}$  (ORC fiber). This length of fiber acts as amplifier section for 1030nm. The output power obtained by varying pump power to about 150 W power level is about 114 W. This total power consist of about 6-7 W of pump power (calculated based on fiber absorption of 5dB per meter) and 1030 nm and 1060 nm. The major power is present at 1030 nm which is about 12 dB higher than 1060 nm (based on observing spectrum of output power on optical spectrum analyzer). Further experiments are underway for tandem pumped section.



**Figure 3: Output of FA2, which consists of 3m of Yb-DCF 10/125 $\mu\text{m}$ . Output power consists of un-absorbed pump, signal at 1030 nm and 1060 nm. 1030 nm is about 12 dB higher than 1060 nm at the output.**

*The authors would like to acknowledge Air Force Office of Scientific Research Grant (FA2386-15-1-5044) for Yusuf's travel support and MHRD for his Visvesaraya PhD Scholarship.*

### 4. References

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