All-Polarization-Maintaining One- and Two-Stage Holmium-doped Fiber Amplifiers at 2051 nm

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Abstract: We report the performance of one- and two-stage single clad polarization-maintaining (PM) Ho-doped fiber amplifiers (HDFAs) at λ_s = 2051 nm, pumped at $\lambda_p \approx$ 1950 nm. We show that the Ho-doped fiber has a slope efficiency η = 70 %, and demonstrate an output power P_{out} of 3.5 W and a gain G = 43 dB.

OCIS codes: (060.2320) Fiber Optics Amplifiers and Oscillators; (060.2420) Fibers, Polarization Maintaining; (060.2390) Fiber Optics, Infrared

1. **Introduction** Recent results for HDFAs [1-2] have shown that a single clad HDFA can provide significant gain and output power in the 2050-2130 nm spectral region. For single stage standard HDFAs pumped at 1125 nm [1], G > 35 dB and P_{out} = 1 W have been achieved, while HDFAs pumped at ≈ 1950 nm [2] have obtained G = 40 dB, P_{out} = 0.25 W, and noise figure NF = 8-14 dB. Our investigation here considers in particular PM HDFAs in one- and two-stage configurations. We report the performance of all-PM one- and two-stage HDFAs for λ_s = 2051 nm and $\lambda_p \approx$ 1950 nm. The two stage HDFA achieves P_{out} = 3.5 W, G = 43 dB, optical signal to noise ratio OSNR = 58 dB, and a 60 nm bandwidth.

2. **PM Experimental Setup** Figure 1 shows the experimental setup for the one- and two-stage PM HDFAs. A 2 W pump P1 at 1952 nm is combined in a multiplexer (WDM1) with the input signal P_s which is then amplified by F1. Light from a 5 W 1941 nm pump P2 is combined in WDM2 with the output signal from F1 which is amplified by F2. Both PM Ho-doped fibers (F1 and F2) are from IXBlue (IXF-HDF-PM-8-125) with L = 1.8 m and 2 m respectively. The core diameter of the fiber is 8 μm with an NA of 0.16, the cladding diameter is 125 μm, and the absorption at 2051 nm is 14.5 dB/m. Stage 1 functions as a preamplifier while stage 2 is a power amplifier. Isolators I1, I2, and I3 in the signal path ensure unidirectional operation

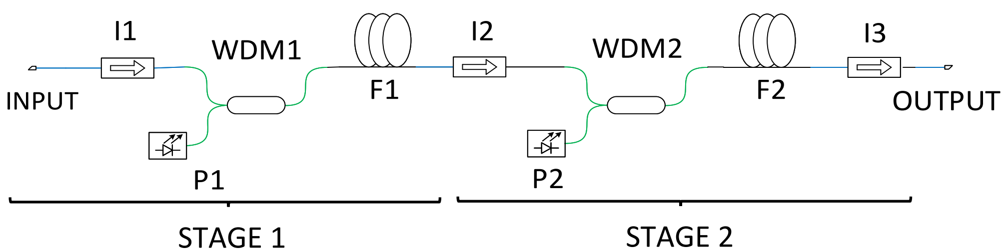

Figure 1. Two stage PM HDFA with multiwatt pump sources in the 1950 nm band.

and suppress spurious lasing. Signal and pump powers are measured internally for stages 1 and 2. Spectra are measured with a Yokogawa AQ6375B OSA.

3. **Experimental Results** Figure 2 shows P_{out} for one stage vs. pump power P_{P1}, as a function of P_s with a linear fit. A maximum P_{out} of 1.0 W is achieved for P_s of +22.7 dBm and a 1952 nm pump power P_{P1} = 1.6 W. Figure 3 plots the evolution of P_{out} for the two stage HDFA vs. P_{P2} as a function of P_s with a linear fit. A maximum output power of 3.5 W is obtained for P_s = 22.7 dBm. Output powers of 1 W can be achieved for an input of -10 dBm, demonstrating the high performance of the two stage HDFA. The evolution of G for one stage and two stages vs. P_s is plotted in Figure 4. A maximum G of 22 dB is observed for one stage and a maximum gain of 43 dB is measured for two stages. The 10 dB gain compression point for the two stage HDFA occurs for P_s = 2 dBm with P_{out} = 2.7 W. The two stage amplifier has a dynamic range larger than 25 dB (P_s = -20 to + 5 dBm). The inset in Figure 4 shows the output spectrum at P_{out} = 3.5 W with an experimental OSNR of 58 dB/0.1 nm. From the output spectrum we can estimate a useful operating bandwidth of 60 nm. Figure 5 shows the evolution of slope efficiency η as a function of P_s for one and two stages, where $\eta = \Delta P_{out} / \Delta P_p$. A maximum η of 70% is observed for the two stage amplifier.

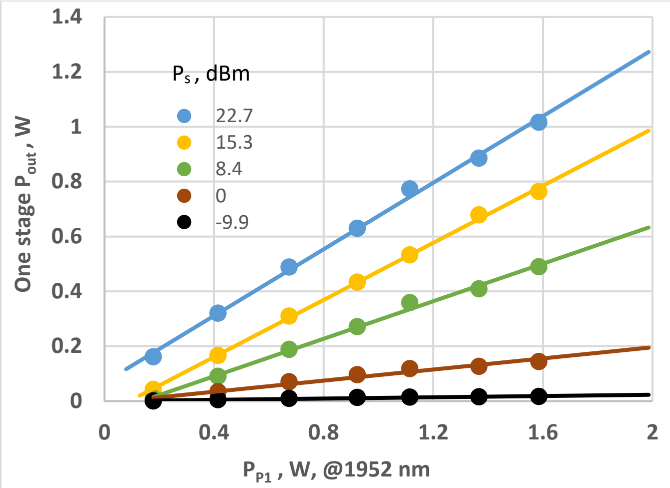

Figure 2. One Stage P_{out} vs. P_{P1} for Different P_s Levels

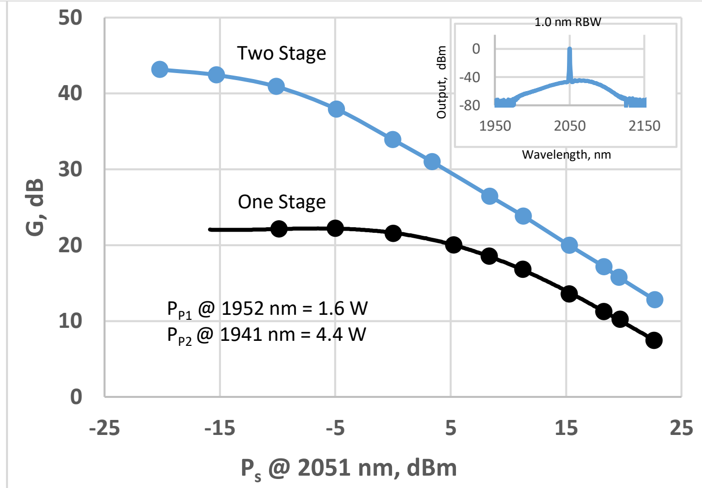

Figure 4. G vs. P_s for Different P_p Levels

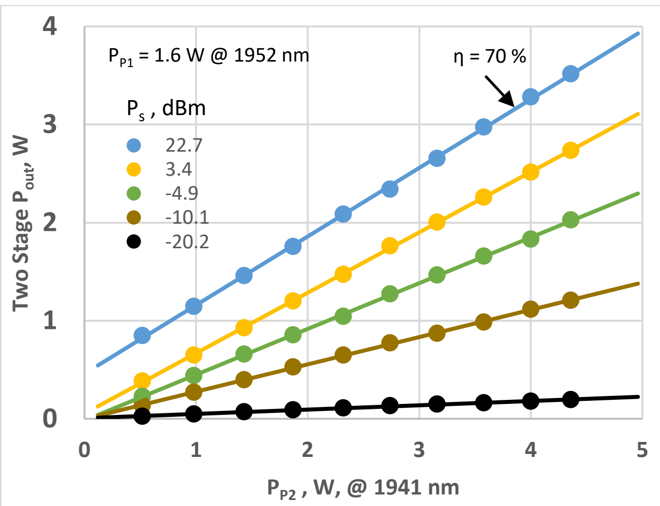

Figure 3. Two Stage P_{out} vs. P_{P2} for Different P_s Levels

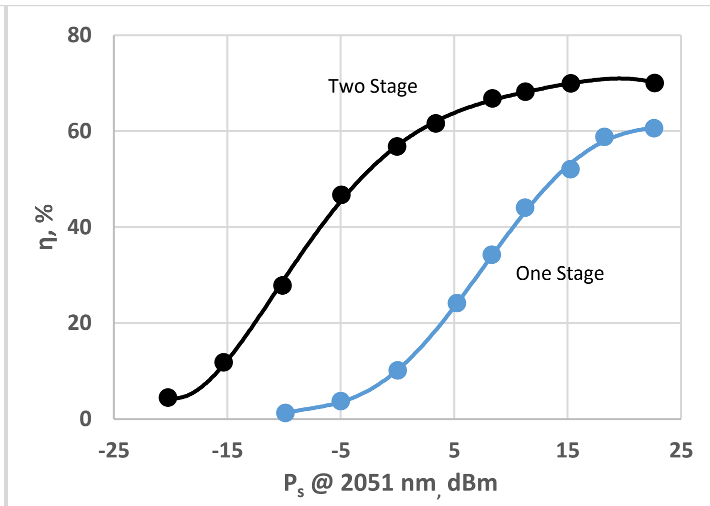

Figure 5. η vs. P_s for One Stage and Two Stage Configurations

4. Summary We have reported the design and experimental behavior of one- and two-stage PM HDFAs at 2051 nm signal wavelength. Our two stage HDFA offers a unique combination of performance which includes G = 43 dB, P_{out} = 3.5 W, OSNR = 58 dB, a dynamic range larger than 25 dB, and a bandwidth of 60 nm. Our power measurements reveal a 70% optical-optical slope efficiency for the fiber which is the highest value reported for PM HDFAs. Our next studies will be to optimize the amplifier configuration for λ_s and P_{out}, and to investigate noise figure values. The high performance and design flexibility of the two-stage PM HDFA make it useful for many applications such as LIDAR and coherent lightwave systems.

5. Acknowledgement We gratefully acknowledge Eblana Photonics for single frequency DM laser sources in the 2000 nm band.

6. References

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