High Performance +23 dBm Miniature PM Ho-Doped Fiber Amplifier at 2100 nm

Alexandre Amavigan [1], Shivaraman Asoda [1], Robert E. Tench [1], Jean-Marc Delavaux [1], Thierry Robin [2], Benoit Cadier [2], and Arnaud Laurent [2]

[1] Cybel LLC, 1195 Pennsylvania Avenue, Bethlehem, PA 18018 USA
[2] iXblue Photonics, 22300 Lannion, France

robert.tench@cybel-llc.com

Current progress in infrared LIDAR, atmospheric sensing, and DWDM transmission system experiments highlights the need for large bandwidth, high dynamic range polarization-maintaining (PM) optical amplifiers in the 1900 nm—2100 nm band [1—6]. Amplifiers that can operate efficiently near the high wavelength end of this band at 2090—2100 nm are particularly attractive for many emerging applications. In this paper we present the first simulated and experimental results for a newly developed miniature packaged Ho-doped fiber amplifier that is optimized for operation at 2090—2100 nm and employs high performance single clad PM Ho-doped fiber (iXblue IXF-HDF-PM-8-125).

Our goal in building a packaged PM Holmium-doped fiber amplifier (HDFA) at 2100 nm is to provide a miniaturized device with output powers of > 200 mW CW, high small signal gain, low noise figure, and large OSNR that can be used in many applications as a versatile wideband preamplifier or power booster amplifier. Our novel miniature HDFA package, shown in the photograph of Figure 1, has dimensions of 97 × 78 × 15 mm^3, incorporates full pump control electronics, and communicates via an RS232 interface. The device is fully isolated against external and internal reflections and employs FC/APC connectors for the input and output ports.

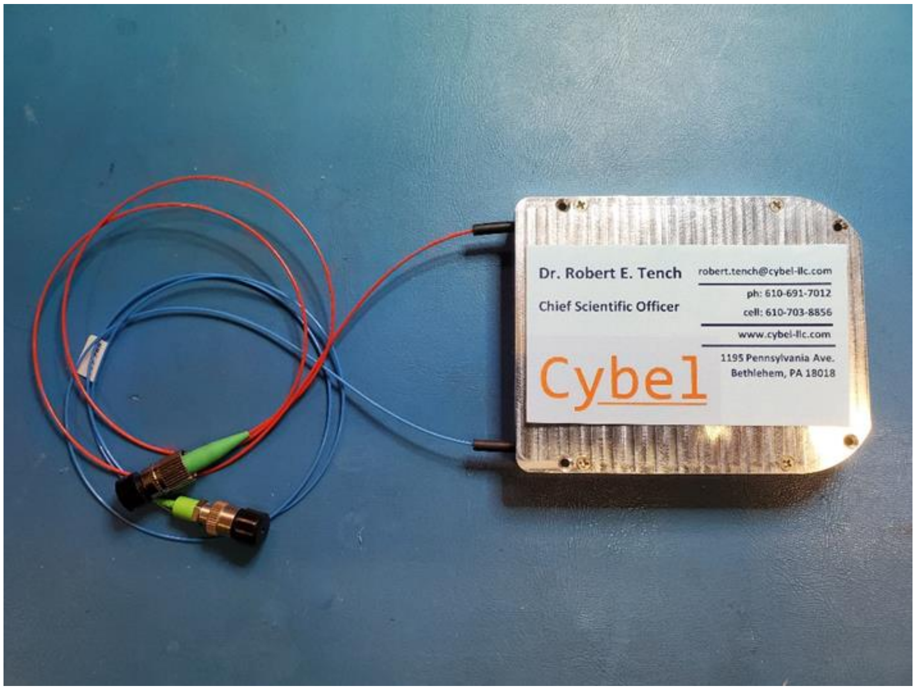

Figure 1. Miniature high wavelength HDFA with dimensions of 97 x 78 x 15 mm^3.

In order to systematically design the +23 dBm PM HDFA, we carried out simulation studies of the co-pumped amplifier architecture shown in Fig. 1. Here the input and output isolators have insertion losses of 1.2 dB, the

WDM has insertion losses of 0.8 dB in both the signal and pump channels, and fiber F1 is from ixBlue (IXF-HDF-PM-8-125). Pump P1 is a multiwatt fiber laser source at wavelengths of 1720-2000 nm.

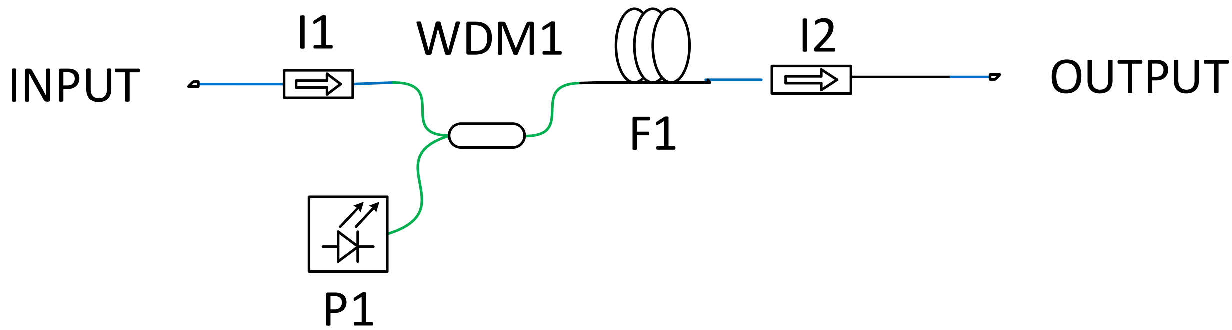

Figure 2. Schematic Diagram of Co-Pumped PM HDFA for Simulation Studies

Our first simulation study is for signal output power as a function of fiber length for three representative pump wavelengths of 1860 nm, 1940 nm, and 2005 nm. The results of this simulation study are shown in the plot of Fig. 2. Here we see that the optimum pump wavelength is 1860 nm and the optimum fiber length is 2—2.2 meters. 1940 nm and 2005 nm pump wavelengths clearly yield much lower output powers for this amplifier design.

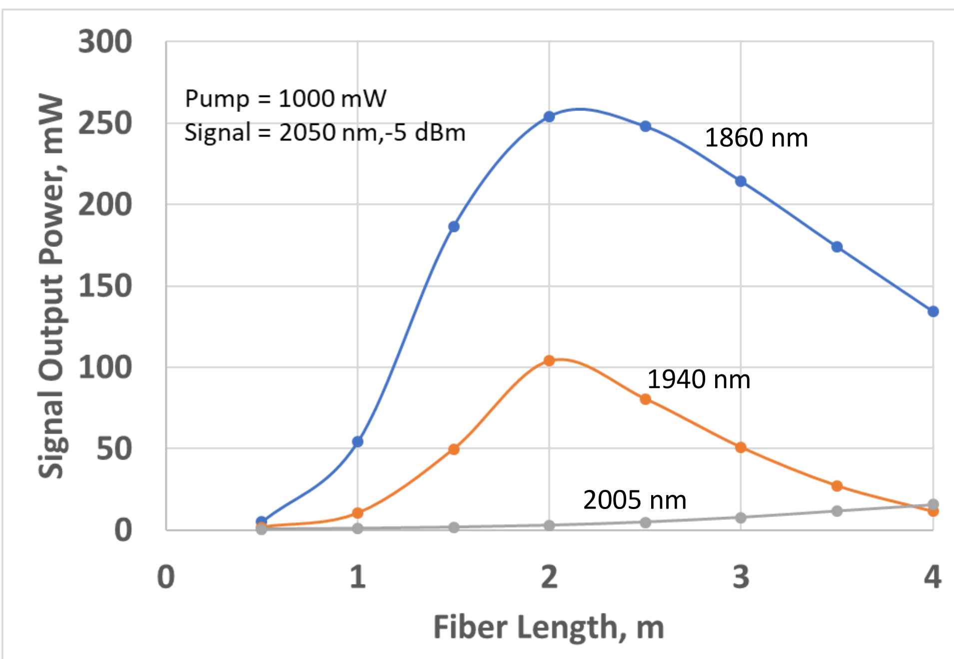

Figure 3. Simulated Signal Output Power as a Function of Active Fiber Length, for Three Representative Pump Wavelengths

In Figure 4, we graph the signal output power as a function of pump wavelength for both co- and counter-propagating amplifier configurations. We see that the counter-propagating pump yields significantly more output power, and the optimum pump wavelength is 1860—1880 nm.

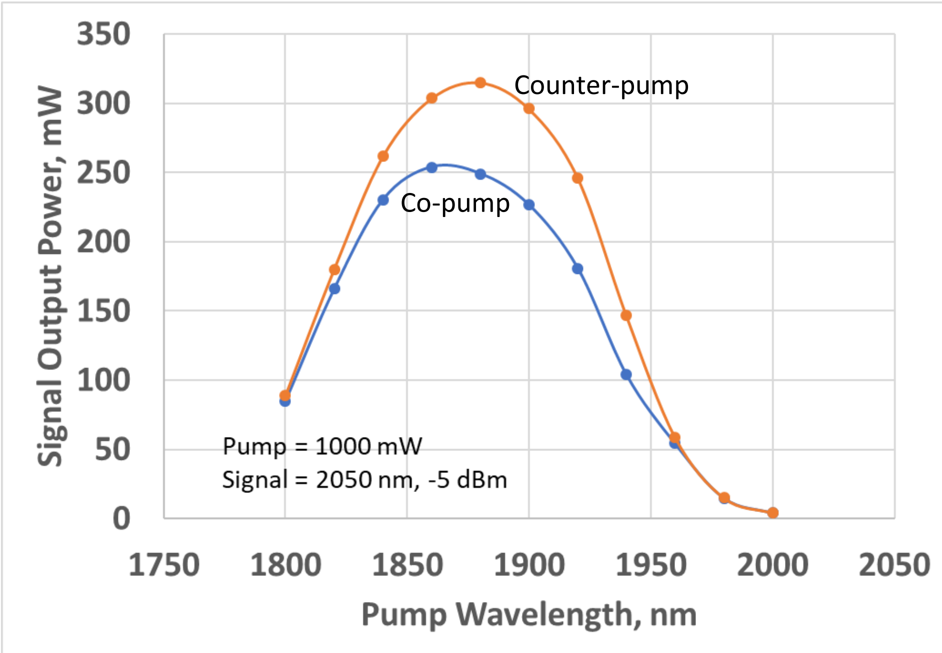

Figure 4. Simulated Output Signal Power as a Function of Pump Wavelength for Co-and Counter-Propagating Amplifiers

In Figure 5 we plot simulated signal output power as a function of signal wavelength for co- and counter-pumped amplifier configurations. We see that the maximum output power is greater than 300 mW for the counter-pumping configuration. Significant output power is generated at 2090 nm.

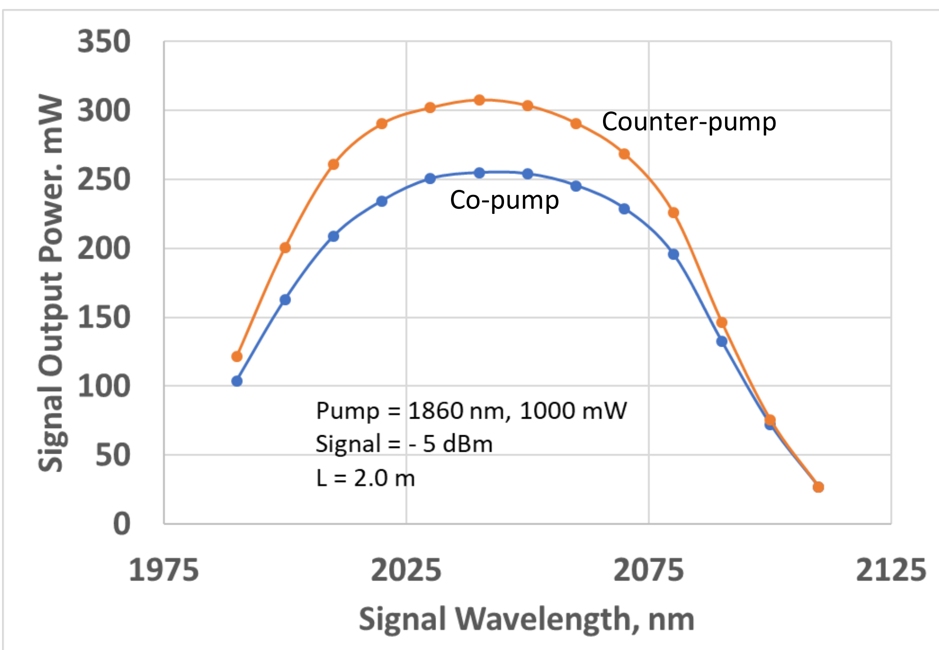

Figure 5. Simulated Output Signal Power as a Function of Signal Wavelength for Co- and Counter-Propagating Amplifiers

Figure 6 plots the signal output power at 2050 nm as a function of fiber length for both co- and counter-pumping configurations. Here we see that a fiber length of between 2 and 3 meters yields good output power for both co- and counter pumping.

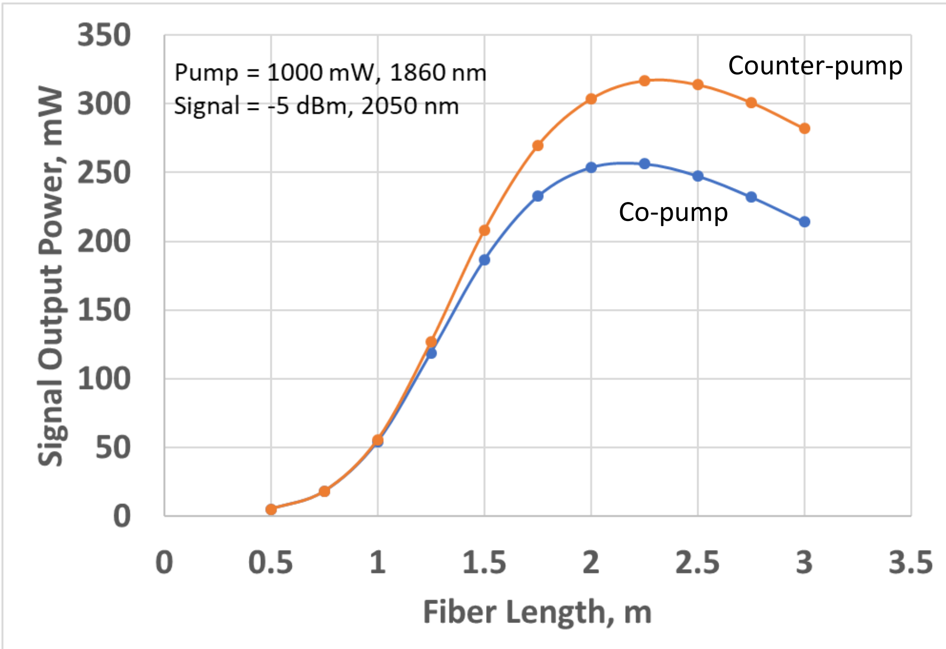

Figure 6. Simulated Signal Output Power as a Function of Fiber Length for Co- and Counter-Propagating Amplifiers

In Figure 7 we plot the signal output power as a function of pump power for both co- and counter-pumping, and for 1860 nm and 1940 nm pump wavelengths. Here we observe that the 1860 nm pump wavelength is far more efficient than 1940 nm, and that counter-pumping yield significantly more output power than copumping.

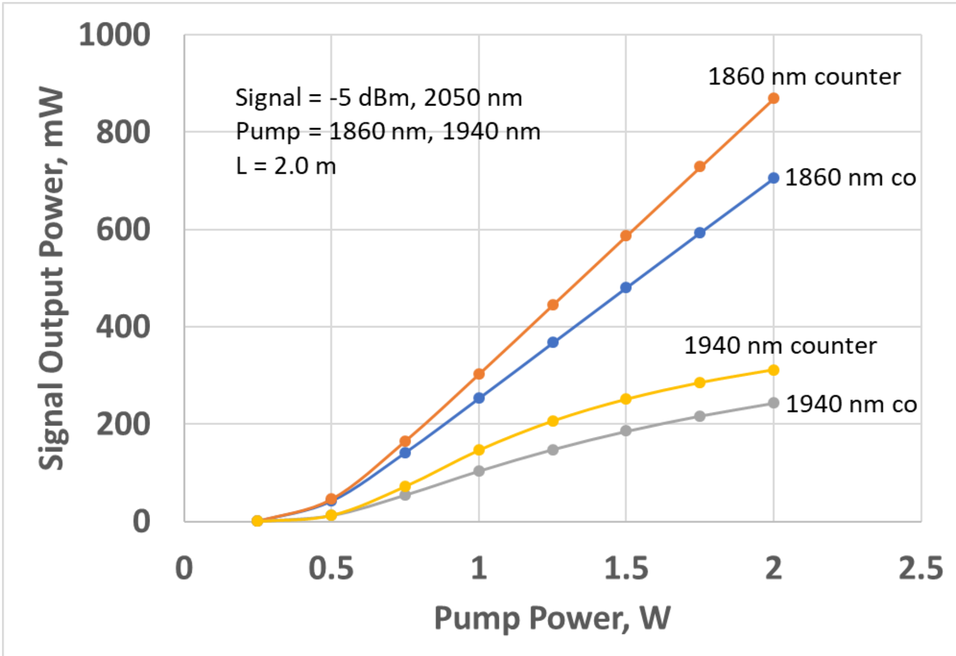

Figure 7. Simulated Signal Output Power as a Function of Pump Power for Two Representative Pump Wavelengths and Co- and Counter-Pumped Amplifiers

With these simulations in mind, we then constructed an experimental counter-pumped PM HDFA as shown in Figure 8. Here the component insertion losses are the same as in Figure 2 and the pump is also the same as in Figure 2.

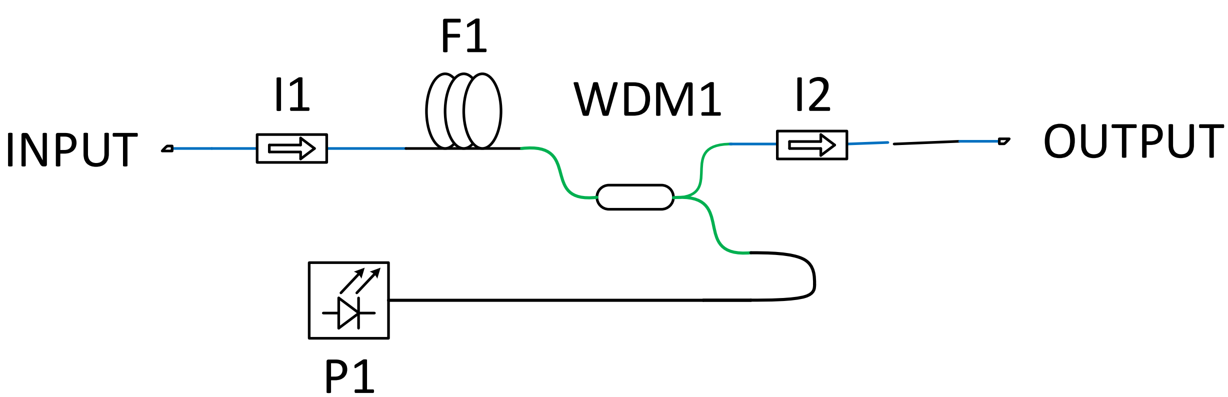

Figure 8. Experimental Counter-Pumped HDFA Architecture

Figure 9 plots the experimental and simulated signal output powers as a function of pump power for the counterpumped amplifier in Figure 8. Here the signal wavelength is in the high wavelength band at 2092 nm. We observe that the experimental and simulation results agree very well, validating our in-house simulation capabilities for PM HDFAs. A maximum output power of 730 mW is achieved for a pump power of 2.3 W.

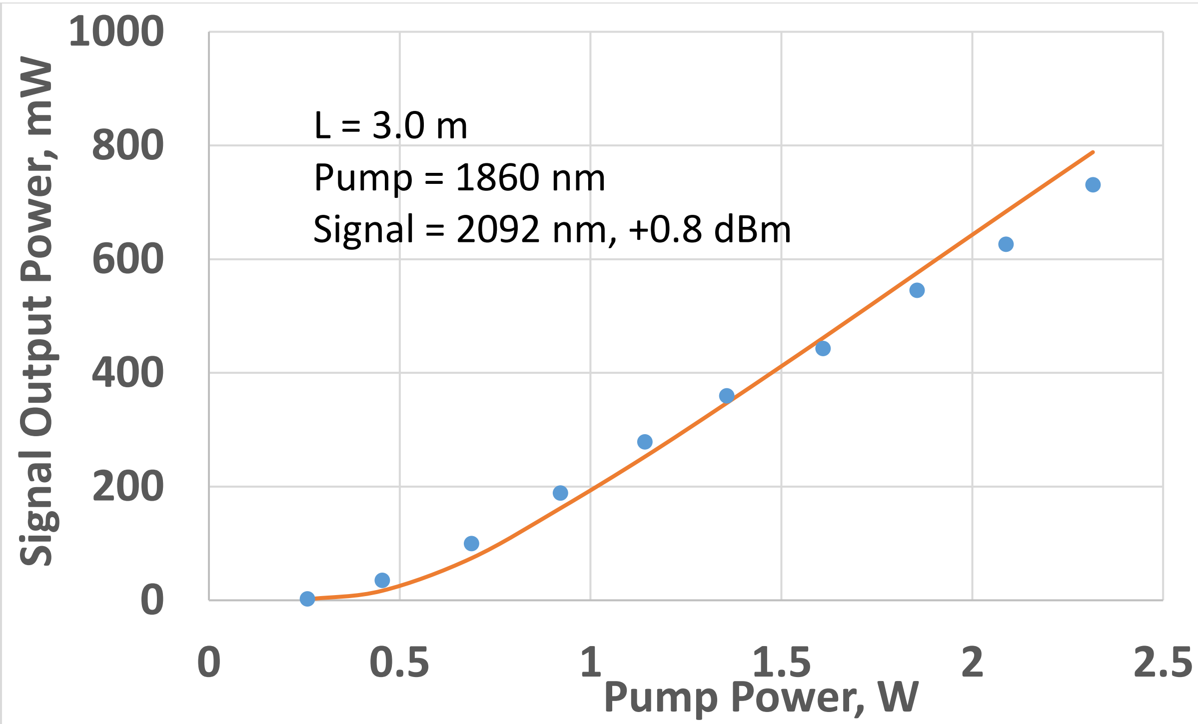

Figure 9. Comparison of Experimental and Simulated Performance of Counter-Pumped PM HDFA

Recalling the pump power limit of 1.0 W that can be achieved in the subminiature package of Figure 1, we summarize in Table 1 below the relevant performance characteristics for the packaged amplifier. For 1 W of pump power, we achieve 215 mW of fiber coupled output power, meeting our performance target of + 23 dBm at 2092 nm signal wavelength.

Parameter	Value
Amplifier Configuration	Counter-Pumping
Fiber Length	L = 3.0 m
Pump Power at 1860 nm	1000 mW
Fiber Coupled Signal Output Power at 2092 nm	215 mW

Table 1. Summary Output Power Performance of Experimental Co-Pumped PM HDFA with 1 W Pump Power

In summary, we have designed and built a subminiature packaged PM HDFA capable of + 23 dBm output power at the high signal wavelength of 2092 nm. Our novel and innovative design will have many immediate applications in LIDAR, DWDM communications systems, mid-infrared wavelength generation, and space and satellite communications systems in the 2100 nm wavelength band.

References:

[1] R. E. Tench, Clement Romano, Glen M. Williams, Jean-Marc Delavaux, Thierry Robin, Benoit Cadier, and Arnaud Laurent, “Two-Stage Performance of Polarization-Maintaining Holmium-Doped Fiber Amplifiers,” IEEE Journal of Lightwave Technology 37, 1434—1439 (2019).

[2] Robert E. Tench, Clement Romano, and Jean-Marc Delavaux, “Shared Pump Two-Stage Polarization-Maintaining Holmium-Doped Fiber Amplifier,” IEEE Photonics Technology Letters 31, 357—360 (2019).

[3] R. E. Tench et al., “In-Depth Studies of the Spectral Bandwidth of a 25 W 2 μm Band PM Hybrid Ho- and Tm-Doped Fiber Amplifier”, J. Lightwave Technol., vol 38, pp. 2456—2463 (2020).

[4] A. Hemming, N. Simakov, A. Davidson. M. Oermann, L. Corena, D. Stepanov, N. Carmody, J. Haub, R. Swain, and A. Carter, “Development of high-power Holmium-doped fibre amplifiers,” Proc. SPIE 8961, Fiber Lasers XI: Technology, Systems and Applications, 89611A (7 March 2014).

[5] N. Simakov, Z. Li, Y. Jung, J. M. O. Daniel, P. Barua, P. C. Shardlow, S. Liang, J. K. Sahu, A. Hemming, W. A. Clarkson, S-U. Alam, and D. J. Richardson, “High Gain Holmium-doped Fibre Amplifiers,” Optics Express 24, 13946-13956 (2016).

[6] N. Simakov, Z. Li, U. Alam, P. C. Shardlow, J. M. O. Daniel, D. Jain, J. K. Sahu, A. Hemming, W.A. Clarkson, and D. Richardson, “Holmium Doped Fiber Amplifier for Optical Communications at 2.05 – 2.13 μm,” in Proc. OFC 2015, Paper Tu2C.6.