Long term, stable, 115W output from an Erbium fiber amplifier pumped by a Raman fiber laser

Andrew Grimes *[a], Venkatapuram S. Sudarshanam[a], Anand Hariharan[a], Jeffrey W. Nicholson[a]
[a] OFS Labs, 19 Schoolhouse Road, Somerset, New Jersey 08873
*agrimes@ofsoptics.com

ABSTRACT

We report on the development of an Erbium amplifier operating at 1550 nm with an output power of 115 W for 500 hours and power variation of less than 1% when run under an open loop, constant-current configuration. To achieve this level of stability, a Raman pump laser system was configured to optimize the output from a Raman resonator and the output wavelength filtering was staggered to prevent any degradation of downstream components, in particular the amplifier WDM that couples the pump and signal. The power level of this amplifier configuration is adequate for a ground-based transmitter to satellites in geosynchronous orbit at 37,000 km.

Keywords: Fiber lasers, High power fiber lasers, Laser sources, Raman fiber lasers, Raman lasers

The Erbium doped fiber amplifier (EDFA) core-pumped in-band by a Raman fiber laser (RFL) has unique advantages [1]. Core pumping shortens the active fiber length compared to cladding pumping which increases nonlinear thresholds. In addition, core pumping allows for significant scaling in the mode-field diameter [2]. Finally, in-band pumping an EDFA with an RFL operating at 1480 nm distributes the quantum defect from 9xx nm pump wavelength to 15xx nm signal wavelength among multiple laser modules, reducing the thermal load of the amplifier gain fiber, which is important for reliability.

Achieving long-term stability from an EDFA pumped by an RFL with output above 100 W has proven difficult in practice. 1390 nm radiation produced in a high-power RFL has been shown to cause irreversible degradation in 1480/1550 biconical fused fiber wavelength-division multiplexers (WDM) [3]. The 1480/1550 nm WDM is a critical component required for pumping a high-power EDFA with an RFL as the WDM is needed to couple the RFL and the seed laser to the EDFA. Furthermore, the WDM filters power from the RFL that would overlap in wavelength with the seed laser and be amplified as noise in the amplifier. In this work we show that at RFL power levels of 150 W it is insufficient to only filter out the power at 1390 nm and that out-of-band power in the other Stokes components can also cause WDM degradation.

The RFL in this investigation, shown in Figure 1, was designed to produce a total output power (without any output WDMs) of 170 W, with 158 W of in-band power at 1480 nm in SMF-28e fiber. Two tilted Bragg gratings (TBGs) were spliced directly at the output reduced power in the penultimate Stokes at 1390 nm by approximately 25 dB. Two TBGs were used as a best effort attempt to decouple the known issues with power at 1390 nm by reducing the power in this band below detectable levels. The output of the TBGs were then spliced to separate WDMs with different wavelength spacing where the WDM was tested for both its efficacy to filter out-of-band power from the RFL and its long-term power stability.

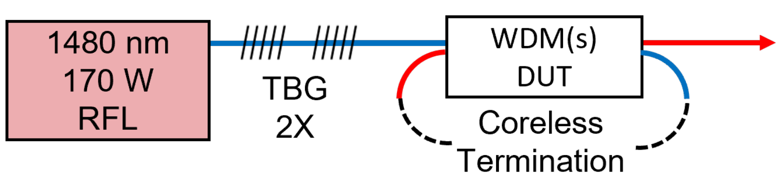

Figure 1 Configuration of the RFL

As seen in Figure 2 (a) the output stability of the RFL shows a direct relation with the spacing of the WDM, where a decline began after 100 hours, and the slope of the decline is influenced by the WDM wavelength spacing. This slope lessens with wider spacing until the WDM spacing reaches 120 nm, where no degradation is seen. Next, the output of the WDM with wide spacing, 1480/1600 nm, was coupled into a WDM with the narrow spacing, 1480/1550 nm, needed for the Raman laser to be coupled to the EDFA. With this configuration, the Raman laser showed no decline in output power for 1000 hours of testing. The order of the WDMs was found to be critical in achieving stable output power from the high-power RFL. The first WDM in this chain had a wider spacing of 120 nm and reduced the out-of-band power by 8 W. The second WDM had a narrower spacing of 70 nm and further filtered the out-of-band power by 3.5 W. The final output power from the RFL system was 156 W with 99% in-band spectral purity as shown by the optical spectra in Figure 2 (b).

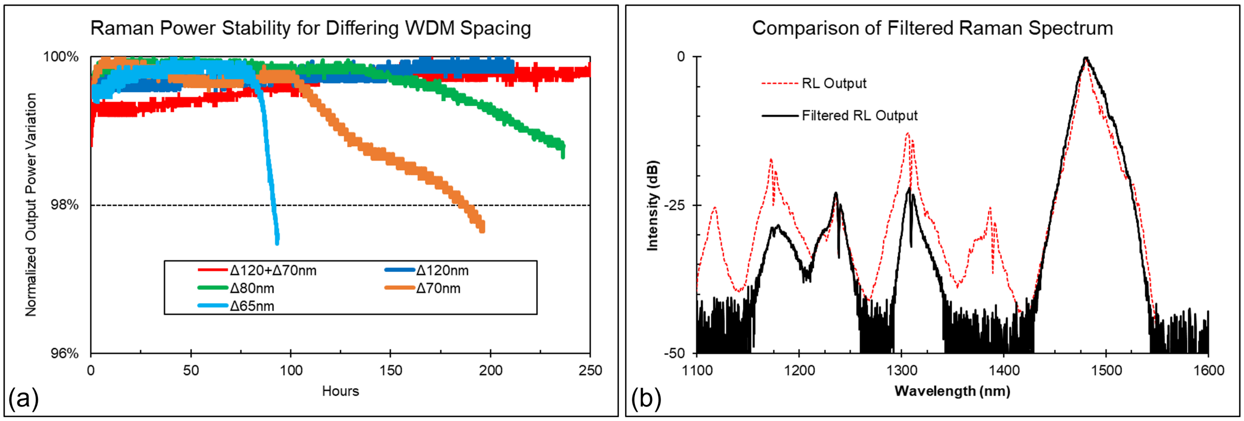

Figure 2 (a) Comparison of the output stability from the RFL after WDMs with different spacing (b) RFL output spectrum before and after final filtering

While filtering the 1390 nm is necessary for stability due to OH absorptions, the power in other out of band wavelengths can still negatively impact the WDM via internal heating, possibly influenced by how the fiber is secured to its submount and causing a decline in the output power stability. We currently attribute the increase in output power stability to the fact that a WDM with wider channel spacing will have a less sensitive design and therefore be more stable if any absorption or mechanical stresses occur. Having the wider spaced WDM followed by narrowly spaced WDM distributes the heat load caused by out-of-band power and thus protects the more sensitive, narrowly spaced WDM.

After validating the stability of the Raman laser followed by the WDM pair, the Raman laser was then used to pump an EDFA in a configuration shown in Figure 3 (a). The output of the RFL was 147 W, generating 115 W at 1545 nm from the EDFA. The 115 W output spectrum is shown in Figure 3 (b). The power remained stable at 115 W over the 500-hour test, Figure 3 (c).

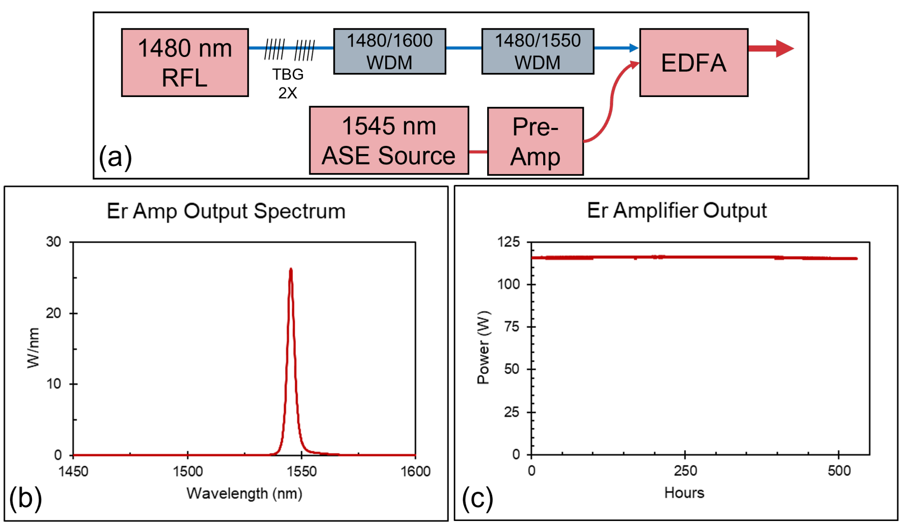

Figure 3 (a) RFL pumped EDFA configuration (b) 115 W output spectrum from the EDFA (c) Power stability from the EDFA over 500 hours

One potential application of the amplifier would be as a ground-based transmitter to satellites in low earth or geosynchronous (GEO) orbit [4]. The power needed for a ground-based uplink compared to a downlink from a satellite is known to be asymmetric with a conceptual analogy described as the “shower curtain” effect [5]. This effect can be understood as the distance from the disturbance caused by turbulence and other deleterious effects in the atmosphere from the emitter. As the ground-based transmitter starts out in the atmosphere, the output beam is distorted from the aperture of the transmitter, and the beam continues to be distorted for the 30 km it travels through the atmosphere until it reaches the stratosphere. However, the beam from the satellite in GEO orbit propagates for 37,000 km before it encounters the atmospheric distortion for its final 30 km of travel. This results in a downlink beam that is only three times larger than the diffraction limit at the ground-based receiver, while the uplink beam is several orders of magnitude larger than the diffraction limit at the satellite in GEO orbit. An adaptive optical system that corrects for distortion to the downlink beam will greatly reduce the arbitration from the atmosphere to the uplink beam, but the adaptive optics correct for the averaged astigmatism, and correct for a part of the atmosphere that has moved away [6], there will be some uncorrected distortion to the uplink beam that will reduce the power received by the satellite.

In conclusion, we have demonstrated a highly reliable, high power EDFA pumped by an RFL. Given the power level and stability, this configuration appears suitable for non-stop operation for many of thousands of hours where it could be used for applications such as long-range LIDAR, an uplink for a ground-based transmitter to satellites in GEO orbit, or any other applications where high-power constant uptime is critical in the eye-safe 1550 nm atmospheric transmission window.

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