Suppression of stimulated Raman scattering in a cladding pumped amplifier with an Yb-doped filter fiber

J. M. Fini, M. D. Mermelstein, M. F. Yan, R. T. Bise, A. D. Yablon, P. W. Wisk, and M. J. Andrejco
OFS Laboratories, 19 Schoolhouse Rd., Somerset, NJ 08873
fini@ofsoptics.com

Abstract: A cladding-pumped, high-power amplifier was built incorporating a star-shaped, Yb-doped filter fiber. Pulsed amplifier measurements demonstrate strong suppression of stimulated Raman scattering accomplished by a special index profile with an up-doped ring.

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1. Introduction

Stimulated Raman scattering (SRS) and other nonlinear noise sources are a main obstacle in the development of high power amplifiers and lasers. We have recently proposed incorporating distributed SRS filtering into the gain fiber by coupling noise wavelengths into index-matched cladding structures [1-3]. This can be accomplished with a very simple structure with a standard core and a raised-index cladding ring. Evidence of filtering at desired wavelengths has already been observed. In this paper, we incorporate a star-shaped, Yb-doped filter fiber into a cladding-pumped amplifier. Suppression of SRS is clearly observed in pulsed amplification, along with partial ASE filtering, demonstrating the effectiveness of this recent filter fiber design for high-power applications.

2. Filter fiber design

A filter fiber [3] was fabricated with an Yb-doped core and one cladding ring. The preform was ground to a star shape and coated with low-index polymer to give a modified fiber [Fig 1(a)] suitable for cladding-pump absorption. The measured index profile [Fig. 1(b)] was designed to achieve gain-suppression through index-matched core-ring coupling: The raised index core and ring features each guide light, and at the "signal" wavelength (1080nm), the core-guided fundamental is only weakly coupled to the ring. Signal light then remains well confined to the gain medium and is efficiently amplified [schematic, Fig. 1(c)]. However, at wavelengths where the effective index of core and ring modes are the same [dashed lines in Fig. 1(d)], light will efficiently couple between the core and ring. Gain filtering occurs because these noise wavelengths have less power overlapping the gain. Numerical mode solutions for a radially symmetric fiber [Fig. 1(e)] show the continuous transition from core-guided to ring-guided modes, with intermediate gain-suppressed mixed modes. This fiber resembles concentric-ring bandgap structures [4], but guides with a conventional core; neither guidance nor filtering result from bandgap mechanisms.

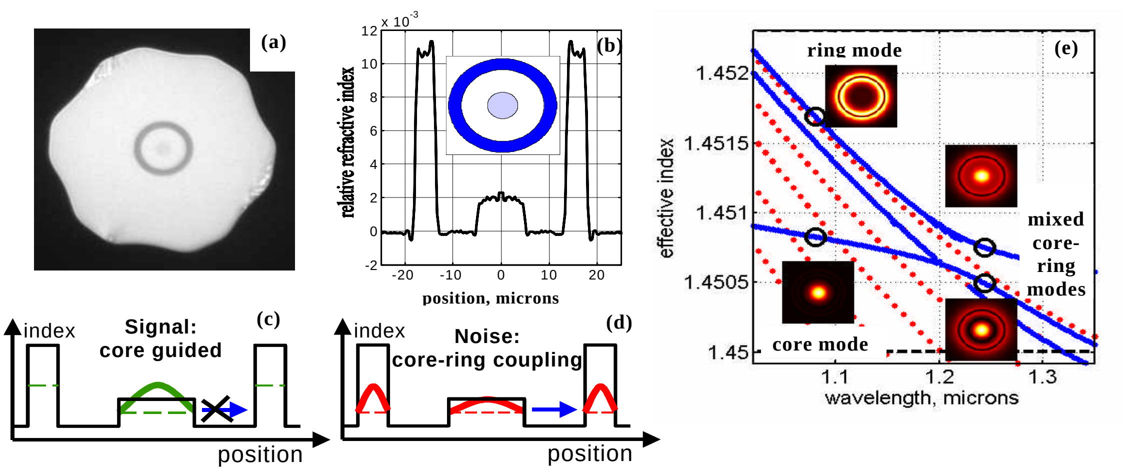

Fig. 1. A filter fiber was fabricated with resonant coupling between core and ring. At a "signal" wavelength (1080nm), light is confined in the gain-doped core. Gain suppression of "noise" wavelengths arises as light couples from core to ring.

3. Cladding-pumped laser with distributed SRS filtering

Gain filtering and SRS suppression were confirmed with several types of measurements. The ASE for a short, core-pumped fiber gives a fairly direct indication of the gain spectrum, and Fig. 2(a) highlights differences in these spectra between the (1m) filter fiber and a reference fiber (with no ring) fabricated for comparison. The filter fiber shows reduced gain in the SRS band ~1135nm and a sharp dip near 1070nm, but negligible suppression at 1080nm. Multiple spectral features agree qualitatively with models once fiber asymmetry is included. Figure 2(b) shows ASE for a 24m, cladding-pumped amplifier includes spectral shaping due to Yb absorption, and confirms a sharp rolloff of gain in the SRS band, ~17dB below the reference fiber.

SRS suppression was demonstrated in a pulsed, cladding-pumped amplifier [Fig 2 (c-e)]. The SRS peak generated around 1135nm in a 16m filter fiber [Fig. 2(d)] was more than 40dB below the signal for all measured average output signal powers up to 0.85W, compared to 23dB below the signal for the reference fiber [Fig. 2(e)]. Input pulses had 100ns width, a 10kHz repetition rate, and a peak power 0.33W. The amplifier was run at gains ranging from 25 to 35 dB generating a maximum average output power of 0.85 W (maximum peak power of 850 W). The amplifier is primarily limited by ASE noise at the high gain of 35 dB. Introduction of an intermediate amplifier stage will reduce the gain burden of the final stage permitting operation at the SRS limit. The ringless and ring pulsed fiber amplifiers exhibited slope efficiencies of 0.42 and 0.35, respectively. This particular amplifier configuration was primarily limited by ASE noise, not SRS, and so the filter fiber does not have better overall slope efficiency (35%) than the reference fiber (42%). In an SRS-limited regime, the SRS suppression should give the filter fiber an overall advantage. A notch in the ASE around 1070nm demonstrates that one can simultaneously filter out SRS and ASE components, unlike fibers that filter by fundamental-cutoff [5]. Redesign of the fiber should offer greater efficiency for both SRS-limited and ASE-limited applications.

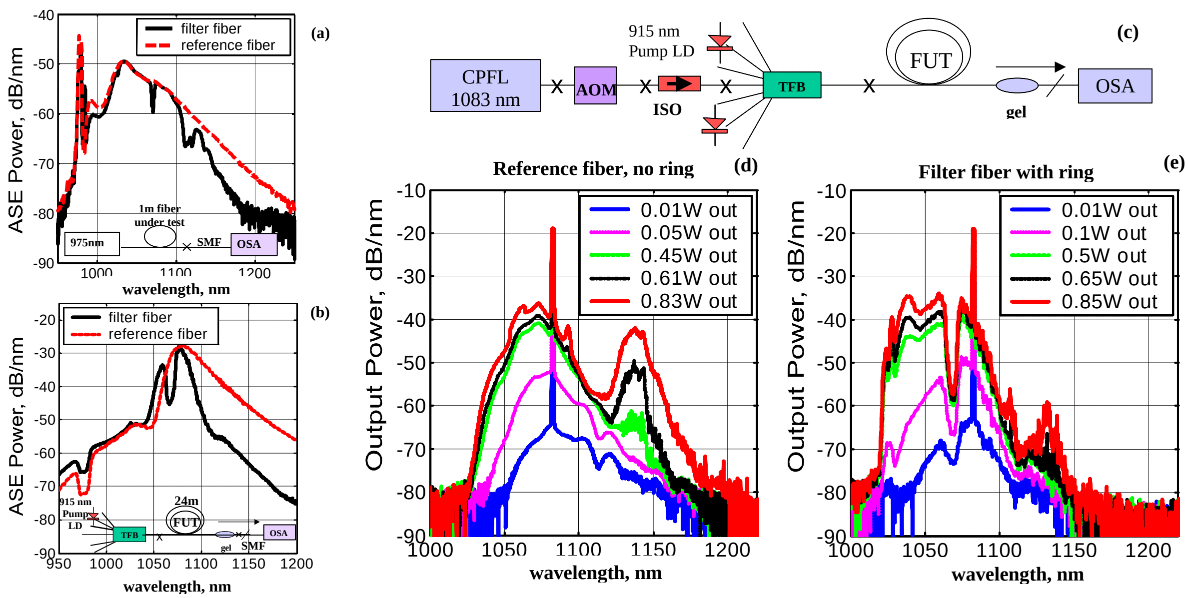

Fig. 2. Amplified spontaneous emission spectra for core-pumped (a) and cladding-pumped (b) amplifiers indicate gain suppression of SRS wavelengths for the filter fiber relative to a reference fiber with no ring. Pulsed amplification measurements (c-e) demonstrate strong suppression of SRS by the filter fiber. The pulsed amplifier utilizes a cladding-pumped fiber laser (CPFL), an acousto-optic modulator for pulse carving, a tapered fiber bundle (TFB) for combining signal and pump radiation, an index matching gel to remove cladding light and an optical spectrum analyzer (OSA) to measure the output spectra.

4. References

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