All-Fiber ASE Filters for the Design of High-Power Fiber Lasers & Amplifiers

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ASE can constrain the output power of high-performance fiber lasers and amplifiers. This limitation becomes more pronounced when operating near the boundaries of the active fiber's gain region. Fiber laser manufacturers now have access to a new technique to mitigate ASE at its source, boosting laser output power, stability, and overall system robustness.

Introduction

Amplified Spontaneous Emission (ASE) poses significant challenges in many fiber laser and amplifier designs, particularly when aiming for high gain, high energy, or emission at wavelengths at the edges of the gain region of the doped active ion in its host material. Various methods have been suggested to eliminate unwanted ASE, which all have significant drawbacks. A large core-to-cladding ratio and short gain fiber lengths can enhance gain at shorter wavelengths, but a larger core degrades beam quality, and a smaller cladding restricts the pump power that can be injected. Optical fibers with a W-type refractive index profile can suppress ASE at longer wavelengths, but they are usually limited to small core diameters. Incorporating an isolator within an amplifier has been proposed, but it is ineffective because it only removes counter-propagating ASE. Introducing a dichroic filter directly into the cavity has also been explored, but its free-space approach typically introduces high losses and cannot handle high power levels.

FBG-Based All-Fiber ASE Filter

Chirped Tilted Fiber Bragg Gratings (CTFBGs) have demonstrated significant effectiveness in suppressing stimulated Raman scattering in multi-kilowatt fiber lasers. These filters can be inscribed in nearly all types of optical fibers with precise control of the extinction band while maintaining low insertion loss. indie has released the ASE Shield series of ASE filters, made with indie's exclusive tilted FBG filter technology. indie's ASE Shield CTFBG filters guide the ASE into the cladding of the fiber, where it can no longer be amplified and is safely extracted from the laser, as illustrated in Fig. 1.

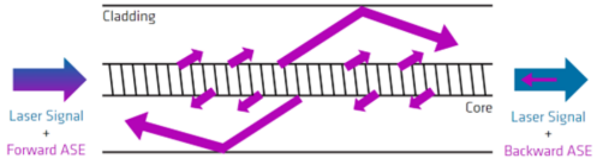

Figure 1: ASE Shield Filter.

In the following sections, applications where ASE filters can be used to significantly enhance fiber laser performances will be reviewed.

ASE Filters for 1018 nm Fiber Lasers

Tandem pumping is recognized as one of the most promising techniques for enhancing the output power of single-mode fiber lasers operating at 1µm. Tandem pumping involves the use of multiple pump sources at cascaded wavelengths. A common configuration of tandem-pumped ytterbium (Yb)-doped fiber lasers uses fiber lasers emitting at 1018 nm as a pump source. This configuration reduces the quantum defect, thereby minimizing thermal load and enabling extremely high output power. Fiber lasers at 1018 nm have also been used to pump diamond Raman lasers to generate 589 nm emission from a frequency-doubled 1178 nm laser.

However, designing a 1018 nm fiber laser poses significant challenges due to strong gain competition from ASE, potentially leading to parasitic lasing and even catastrophic failures. A typical configuration of a 1018 nm fiber laser cavity with an ASE filter is shown in Figure 2. The ASE filter reflects the unwanted ASE into the fiber cladding where it is no longer amplified. To maximize the signal conversion efficiency, the ASE filters must be inserted in between active fiber sections to attenuate the ASE before it gets significantly amplified.

Placing the filter at the fiber laser's output would reduce ASE, but this approach has limitations. While this cleans the output spectrum, the ASE is still generated in the active fiber, reducing the gain and possibly de-stabilizing the cavity, leading to self-pulsing.

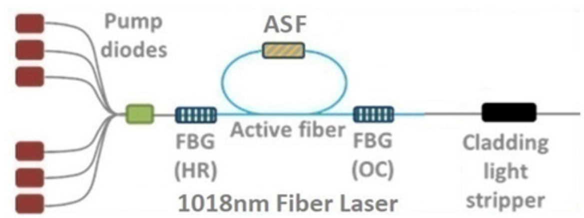

Figure 2: FBG-based filters for 1018 nm fiber laser

Using such ASE filters, an output power exceeding 400 W at 1018 nm was achieved using an Yb-doped 20/400 active fiber. Experimental results showing slope efficiency and output spectrum are shown in Fig. 3.

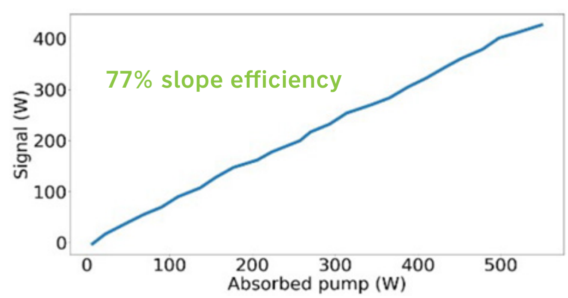

Figure 3a: Slope Efficiency - Experimental Results with 20/400 Yb fiber

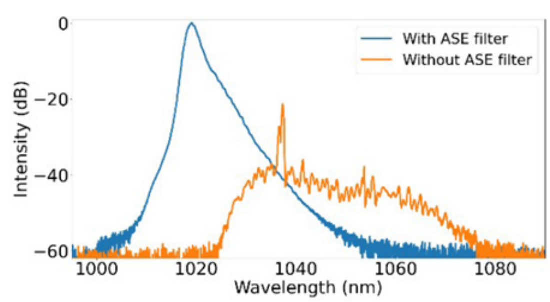

Figure 3b: Output Efficiency - Experimental Results with 20/400 Yb fiber

ASE Filters in Spectral Beam Combining Applications

Spectral beam combining (SBC) is presently the favored approach for high-power fiber lasers for use in directed energy (DE) or in applications demanding exceptional beam quality. The more wavelengths or channels that can be combined, the higher achievable output power. However, the wavelength band below 1040 nm has not been extensively used up to now, mostly limited by ASE. indie's ASE Shield opens the band from 1025 nm up to 1040 nm and adds several new channels to significantly increase the overall laser output power. An illustrative spectral combining system using FBG-based fiber lasers is shown below. The ASE filter will typically be inserted in the laser cavity of the power amplifier stage as illustrated in Figure 4.

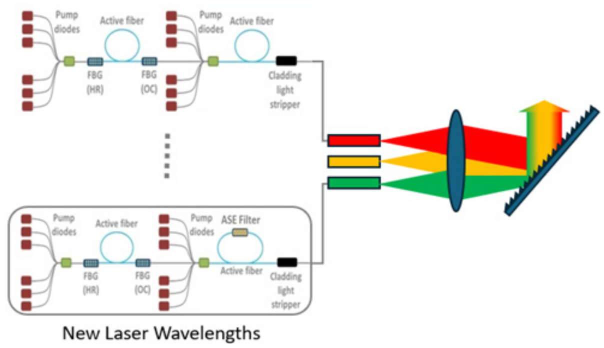

Figure 4: ASE Filters in Spectral Beam Combining

ASE Filters for Er/Yb Co-Doped Fiber Lasers and Amplifiers

High-power lasers and amplifiers operating in the 1.5 µm band are widely used in various applications, such as CATV/ telecom amplifiers, surveying or geospatial LIDARs, gas sensing, skin treatments, free-space optical communications, satellite communications, etc. Er/Yb co-doped active fibers are the preferred choice for increasing absorption and the extractable output power.

However, one important challenge in using Er/Yb co-doped fibers is the unwanted ASE from Yb ions in the 1 µm band that can lead to parasitic lasing or self-pulsing effects, potentially causing unstable operation or even permanent damage to the amplifier or laser. A typical EYDFA amplifier is illustrated in Figure 5. An ASE filter is spliced within the active fiber section of the power amplifier stage to increase the amplifier output power, its stability and robustness.

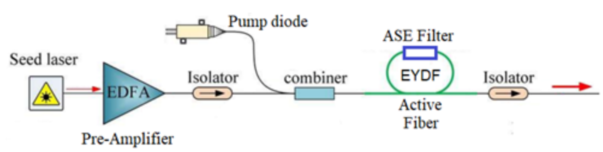

Figure 5: Typical Er/Yb Co-Doped Fiber Amplifier (EYDFA)

Conclusion

ASE constrains output power in high-performance fiber lasers and amplifiers, especially when operating far from the active fiber's peak gain. indie's ASE Shield, utilizing exclusive tilted FBG filter technology, suppresses ASE by rejecting it into the fiber cladding. There, it can no longer be amplified and is safely extracted from the laser. This innovation enables fiber laser manufacturers to significantly boost output power and stability by reducing ASE at its source.