Novel Single Clad Ho-doped Fiber Amplifier with High Slope Efficiency and Low Ion Pairing

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Introduction. Current progress in LIDAR, optical sensing, and space applications, including earth-to-satellite and satellite-to-satellite communications, highlights the need for large spectral bandwidth, high efficiency Ho-doped fiber optical amplifiers (HDFAs) in the eye safe region from 2000 nm—2150 nm band [1—6]. Amplifiers exhibiting high optical-optical power conversion efficiency with low or moderate signal input powers are particularly attractive for SWAP optimization in many emerging applications. In this paper we present the design and experimental results for a 2050 nm band fiber amplifier with high optical-optical slope efficiency and low ion pairing, using a novel high performance single clad Ho-doped fiber from the Naval Research Laboratory (NRL). Here we are reporting a measured optical-optical slope efficiency of 57% using 1 mW input signal power which we believe is the highest slope efficiency measured to date for a single clad copumped HDFA. This efficiency is linked to a low ion pairing coefficient of 4% in the doped fiber derived from our data.

Fiber Data and Experimental Setup. The NRL Ho-doped step-index single clad silica fiber in our experiments has a core diameter of 10 μm, a cladding diameter of 92 μm, a refractive index difference of 1.2×10^{-2}, and a numerical aperture of NA = 0.186. The Ho ion concentration in the core is 0.7%-wt, and the peak absorption coefficient is 51 dB/m at 1940 nm. Using the measured absorption coefficient as a function of wavelength and other relevant parameters, we have simulated [7,8] the performance of this fiber in the single stage copumped amplifier architecture shown in Figure 1. Here the Ho-doped fiber is F1, isolators I1 and I2 in the signal path prevent feedback from external reflections and establish unidirectional operation, the pump source is P1, and the wavelength division multiplexer WDM1 couples the input signal and the pump source into F1 with low loss.

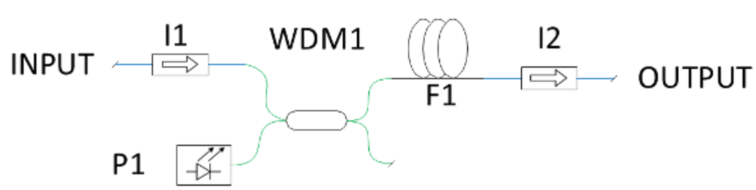

Figure 1. Optical Architecture for the HDFA using NRL Ho-doped fiber

Simulation Studies of Fiber Length Optimization. For our initial simulation studies, the pump wavelength of P1 is 1860 nm, the pump power is 0—2.5 W, and the input signal is 1 mW (0 dBm) at a wavelength of 2050 nm. Signal powers and pump powers are measured at the input and output of the active Ho-doped fiber F1. With these pump and signal parameters, and assuming a range of ion pairing coefficients from 0—15%, we determined a simulated optimum length of the NRL fiber for maximum signal output power of 2.2—2.5 m. We therefore chose a fiber length of 2.5 m for our experiments going forward.

Experimental Measurements of Performance of the NRL Ho-doped Fiber. Figure 2 plots the measured signal output power at 2050 nm with F1 = 2.5 m as a function of pump power for the two significantly different pump wavelengths of 1860 nm and 1940 nm. Here we see that the maximum optical-optical slope efficiency of 57% is achieved for 1860 nm pumping. To our knowledge, this is the highest slope efficiency for a single stage copumped Ho-doped fiber amplifier with low signal input powers of 1 mW so far reported in the literature. For comparison, representative values for widely employed Ho-doped fibers are in the range of 40% [7,8]. The NRL fiber therefore exhibits an optical-optical power conversion efficiency about 43% greater than the fibers commonly used to date.

We also note the signal output power for 1860 nm pumping is about 17% greater than the corresponding signal power for 1940 nm pumping. As reported in [7—9], the presence of non-zero ion pairing in a Ho-doped fiber amplifier strongly affects the signal output power that can be achieved as a function of pump power and wavelength, with lower ion pairing corresponding to higher signal output powers. By measuring the ratio (L) of signal output powers for the 1860 nm and 1940 nm pump wavelengths, the degree of ion pairing in the Ho-doped fiber can be accurately determined in a non-destructive manner [7—8]. The simulated dependence of this power ratio L as a function of the degree of ion pairing for the NRL fiber is plotted in Figure 3, and the experimental ratio of 1.17 corresponds to an ion pairing of about 4%. Typical values for today's Ho-doped fibers are 13.5—15% [7-9]. This value of 4% is the lowest and most favorable ion pairing coefficient so far reported, and allows us to have a much better signal to pump efficiency. This improved efficiency will apply across the entire signal bandwidth of the Ho-doped fiber.

Other experimental data, including the signal output power dependence on a wide range of pump wavelengths, will be presented at the conference.

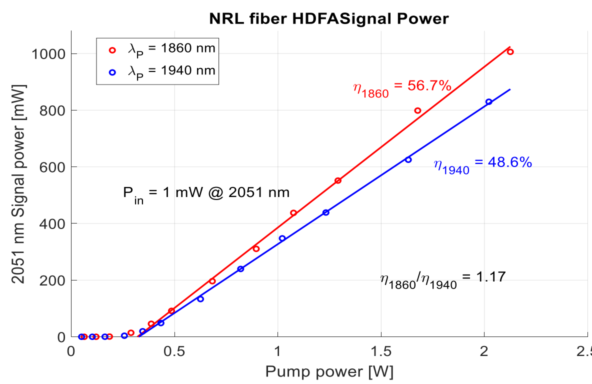

Figure 2. Signal Output Power vs. 1860 nm and 1940 nm Pump Power

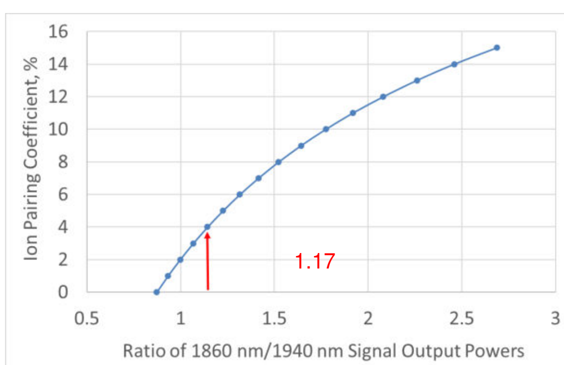

Figure 3. Ion Pairing Coefficient vs. Ratio of 1860/1940 nm Pump Powers

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