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WL4 Gain and noise figure variations of an erbium doped fiber amplifier for pump wavelengths between 1460 and 1510 nm

RICHARD S. VODHANEL, A. YI-YAN, Bellcore, 331 Newman Springs Rd., Red Bank, NJ 07701-7040; B. ENNING, Fachhochschule Flensburg, Flensburg, F. R. Germany; R. I. LAMING, U. Southampton, Optical Fibre Group, Southampton SO9 5NH, U.K.

Recently, 978-nm diode pumping of an erbium doped fiber amplifier has produced the highest gain coefficient of 3.9 dB/mW.[1] However, pumping with 1.48-μm laser diodes[2] is also important because of the more mature technology for fabricating high power InGaAsP laser diodes. High optical gain is generally desirable, but a low noise figure is also important for use as a preamplifier. To optimize the amplifier performance and compare with 978-nm pumping, we measured the gain and noise characteristics of an erbium doped fiber amplifier for pump wavelengths between 1460 and 1510 nm.

The fiber amplifier was pumped in a copropagating configuration with a tunable color center laser having a narrow spectral width of 0.1 nm. The fiber amplifier consisted of a 15-m long germanosilicate erbium doped fiber characterized by a relative index difference of 0.01 and a λ_{cutoff} at 1050 nm. A low input signal power level of −34 dBm was chosen to avoid gain saturation of the amplifier. The input polarization states of the signal and pump light were controlled so that the use of a polarizer following the amplifier resulted in over 30-dB attenuation of the residual pump with <0.5-dB loss of signal.

Figure 1 shows the amplifier gain at 1536 nm for different pump wavelengths and pump powers, as measured with an optical spectrum analyzer. A maximum gain of 29.6 dB was obtained with 54 mW of pump power, with ~2-dB variation in gain for pump wavelengths between 1460 and 1490 nm. At lower pump powers of 34 and 21 mW, the gain was reduced, and in the 21-mW case there was a more pronounced variation with pump wavelength with the peak gain occurring at near 1480 nm.

The noise of the fiber amplifier was measured at the signal wavelength using a heterodyne receiver. Figure 2 shows the relative receiver output power levels at different pump wavelengths and for a pump power of 54 mW. The local oscillator-spontaneous (LO-SP) beat noise, which was the dominant noise, and the spontaneous-spontaneous (SP-SP) beat noise both had pronounced peaks near 1475 nm. The corresponding gain, which was obtained by comparing the heterodyne signal levels measured with and without the amplifier, was nearly constant for pump wavelengths between 1465 and 1490 nm with a maximum value of 30.3 dB. The heterodyne gain results (Fig. 2) were within 1 dB of those measured with the optical spectrum analyzer (Fig. 1) over the entire pump laser wavelength range.

With a pump power of 54 mW, the heterodyne carrier-to-noise ratio (CNR) varied by ~7 dB for pump wavelengths between 1465 and 1505 nm. The origin of this unexpected result is not understood at present. It is not attributed to spontaneous emission reflected back to the amplifier from the pump laser. A reflection which depended on the pump wavelength with a minimum return loss of ~15 dB at 1475 nm would be required. A source for such a reflection could not be identified.

The amplifier noise figure was obtained by comparing the CNR measured with the amplifier with that obtained without the amplifier. When the LO-SP noise is the dominant noise, the CNR can be represented as[3]

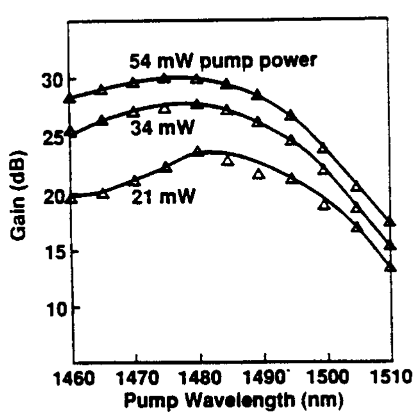
$$\mathrm{CNR} = \frac{L_{in} G L_{out} \eta_c \eta_d i_s i_l}{eB_e i_l + eB_e i_l \cdot 2(G-1) N_{sp} L_{out} \eta_c \eta_d}, \tag{1}$$

where G is the amplifier's gain, L_{in} and L_{out} are the input and output losses set by adjustable attenuators, N_{sp} is the population inversion parameter of the amplifier, η_c is the coupler efficiency (=0.5), η_d is the detector quantum efficiency (=0.42), e is the electron charge, B_e is the electrical bandwidth, and i_s and i_l are the photocurrent equivalents of the optical signal and LO powers. With $L_{in}GL_{out}$ set to unity to give the same heterodyne carrier level with and without the amplifier, the degradation in the heterodyne CNR due to the amplifier noise is given by $(1 + 2N_{sp}\eta_c\eta_d/L_{in})$. The amplifier noise figure $2N_{sp}$ was measured very carefully using this technique at the single pump wavelength of 1485 nm with an estimated uncertainty of ±0.5 dB. The dependence of the noise figure on pump wavelength at pump powers of 54 and 21 mW was obtained from the variation in CNR derived from data such as in Fig. 2.

Figure 3 shows the fiber amplifier noise figure dependence on pump wavelength. With 54 mW of pump power, a noise figure of 12 dB was obtained at 1475 nm, corresponding to the maximum in the LO-SP beat noise and maximum gain of 30 dB. The minimum figure of 5.2 dB was obtained at a pump wavelength of 1500 nm where the gain is ~7 dB below the maximum value. With a lower pump power of 21 mW, a minimum noise figure of 5.2 dB was also obtained at a pump wavelength of 1500 nm, and there was much less variation in the noise figure. However, the maximum gain was also reduced ~7 dB.

These results are important for determining the wavelength and power requirements for a diode laser pump source of erbium doped fiber amplifiers. For postamplifiers and line amplifiers, where maximum gain is the objective, the best pump wavelength for this amplifier is 1480 nm and the spectral spread can be 10 nm. However, when amplified spontaneous emission is the dominant system noise, such as for a fiber preamplifier, it is necessary to sacrifice 7 dB of gain to operate the amplifier with a low noise figure.

1. R. I. Laming *et al.*, "Highly Efficient 978 nm Diode-Pumped Erbium-Doped Fiber Amplifier with 24 dB Gain," in *Postdeadline Papers, Seventh International Conference on Integrated Optics and Optical Fiber Communication*, Kobe, Japan (1989), paper 20PDA-4.
2. M. Nakazawa, Y. Kimura, and K. Suzuki, "Efficient Er^{3+}-Doped Optical Fiber Amplifier Pumped by a 1.48 μm InGaAsP Laser Diode," Appl. Phys. Lett. 54, 295 (1988).
3. N. A. Olsson, "Lightwave Systems with Optical Amplifiers," IEEE/OSA J. Lightwave Technol. LT-7, 1071–1082 (1989).



WL4 Fig. 1. Fiber amplifier gain vs pump wavelength.

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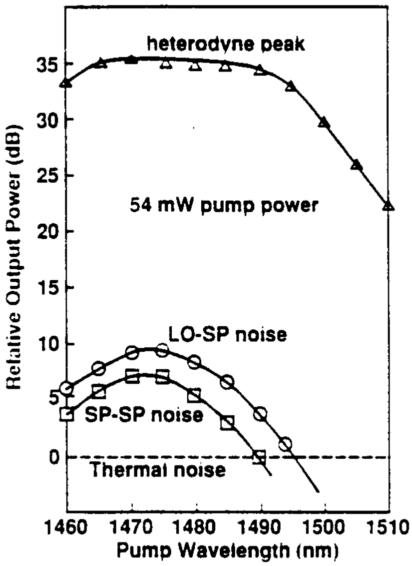
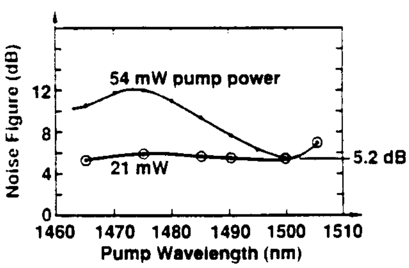


WL4 Fig. 2. Relative receiver output power levels at the intermediate frequency.



WL4 Fig. 3. Fiber amplifier noise figure vs pump wavelength.