Gain Characteristics of Er^{3+}-Doped Phosphate Glass Fibres *

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An erbium-doped phosphate glass fibre has been drawn by the rod-in-tube technique in our laboratory. The gain for the Er^{3+}-doped phosphate glass fibre with different pump powers and with different input signal wavelengths is investigated. The 2.2-cm-long fibre, pumped by a single-mode 980-nm fibre-pigtailed laser diode, can provide a net gain per unit length greater than 1.8 dB/cm. The pump threshold is about 50 mW at the wavelength of 1534 nm, and below 70 mW at 1550 nm. The gain linewidth of the Er^{3+}-doped phosphate glass fibre is greater than 34 nm and can cover the C band in optical communication networks.

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It is necessary to integrate the high performance optical amplifier devices into low-cost compact packages for the growth of internet traffics. Currently 10–50 m silica fibres doped with 500-ppm weight Er^{3+} ions are employed in commercial Er^{3+}-doped fibre amplifiers (EDFAs), which require bending fibres to a radius of larger than 50 mm and make it difficult to miniaturize devices. If higher Er^{3+} concentrations are doped in silica glass, the effect of concentration quenching caused by ion clusters will occur.[1] In order to shorten the length of the active fibre to a few centimetres, an Er^{3+} doping concentration greater than 2 wt.% is required. Thus, it is critical to choose an appropriate host material with high solubility of rare-earth ions. Phosphate glass is more attractive as an amplifier material because it combines most required properties, e.g., good chemical durability, high gain, wide band tunability, and low cooperative up-conversion coefficient.[2−4] In particular, phosphate glass exhibits large emission cross sections and high solubility of Er^{3+} ions without cluster formation.[5,6] Recently, many techniques including sol-gel, ion-exchange, and rf sputtering for fabrication of Er-doped phosphate planar waveguide amplifiers have been reported.[7−9] However, planar waveguide amplifiers, compared with fibre amplifiers, have several disadvantages such as polarization sensitivity, optical mode mismatch and high coupling loss with fibres. We believe that the best approach to miniaturize amplifier devices is to improve the gain coefficient of glass fibre.

In this Letter, we demonstrate a fibre amplifier with net gain per unit length greater than 1.8 dB/cm, based on an Er-doped phosphate glass fibre drawn in our laboratory. The gain test is described in detail.

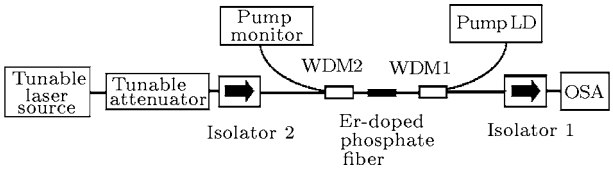


Fig. 1. Schematic diagram of measuring the gain of the Er^{3+}-doped phosphate glass fibre.

The experimental setup of gain test is shown in Fig. 1. The pump source is a single mode 980 nm fibre-pigtailed laser diode, with a maximum output power of 162.0 mW. The Er^{3+}-doped phosphate fibre is backward pumped by a 980-nm laser diode (pump LD) through a fused wavelength division multiplexer (WDM 1) combining 980 nm and 1550 nm with 0.5 dB insert loss. The tunable laser source (TLS) MG9514A is used as the signal source with the wavelength range from 1510 nm to 1640 nm and the output power rang from −30 dBm to +7 dBm. The isolator (Isolator 2) is connected between the TLS and the tunable attenuator (TA). The output signal of the TLS is coupled into the Er^{3+}-doped phosphate fibre through WDM 2. The amplified signal is input into the optical spectrum analyser (OSA) MS9710C through WDM 1. The two isolators (Isolators 1 and 2) ensure the signal along the right directions. The Er^{3+}-doped phosphate fibre (EDPF) used in this experiment was fabricated by the rod-in-tube technique. In the process of fibre drawing, argon gas was used to prevent the fibre from water in air until the fibre was cooled to room temperature. An Er^{3+}-doped phosphate glass fibre with the core diameter of 30 μm and the cladding diame-

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ter of 125 μm was obtained. The inset in Fig. 2 shows a cross section view of the EDPF. No plastic coating was applied to the phosphate glass fibre. A 2.2-cm phosphate glass fibre was enclosed into a homemade ceramic tube and its two end-faces were polished.

In this experiment, the warm-up time of TLS must be greater than 2 hours so that the signal source worked well in power and wavelength stabilization. Then we set the input signal via changing the power level of the TLS and the attenuation value of the TA. The signal gain was measured through the OSA. The inherent loss at 1534 nm due to the erbium absorption is estimated to be about 4.0 dB/cm. As shown in Fig. 2, the gain increases when the launched pump power increases. The threshold of pump power is about 50 mW at 1534 nm, and below 70 mW at 1550 nm. A net gain of 4.01($\pm$0.2) dB is achieved for the 2.2-cm-long fibre at 1534 nm, i.e. net gain per unit length greater than 1.82($\pm$0.1) dB/cm, which is approximately two orders of magnitudes larger than that of commercial silica fibres.[10] It should be emphasized that the pump power illustrated in Fig. 2 is the nominal power before coupling into the phosphate fibre. The effective power coupled into the phosphate fibre is about 100 mW. As the pump power increases, the gain saturation is still not reached in our experiment. We expect a larger gain by increasing the pump power. In addition, the fluorescence lifetime for the $^4I_{13/2} - {}^4I_{15/2}$ transition of Er^{3+} ions is 6.1 ms, which is shorter than 8.3 ms before the fibre drawing. This difference indicates that contamination or impurity can be introduced in the fabrication process of the fibre preform. Our on-going efforts are to improve the coupling efficiency, to draw a single mode phosphate glass fibre, and to eliminate the contamination or impurities during the glass melting and fibre drawing processes.

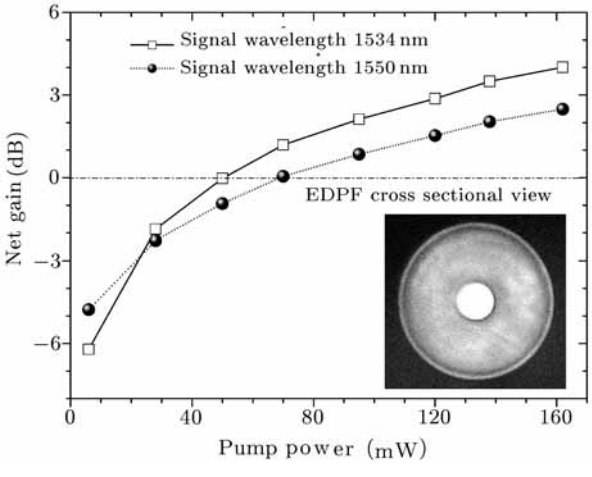


Fig. 2. Net gain vs launched pump power. Inset: the Er^{3+}-doped phosphate glass fibre with the core diameter of 30 μm and the cladding diameter of 125 μm.

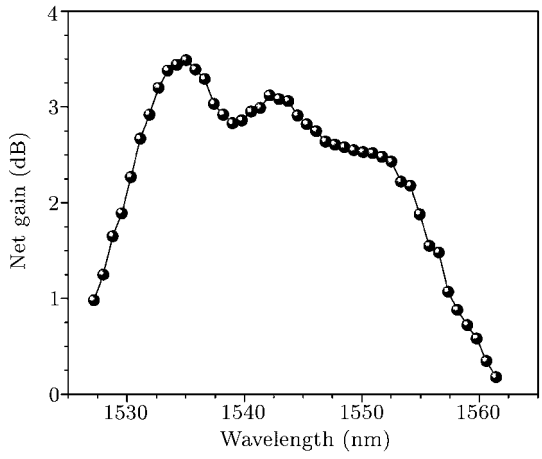


Fig. 3. Net gain vs signal wavelength.

Figure 3 shows the gain versus signal wavelength. When the pump power is fixed at 150.0 mW, the gain dependence on wavelength can be measured. The gain linewidth of the Er^{3+}-doped phosphate glass fibre is greater than 34 nm (1528–1562 nm) and can cover the C band in optical communication networks.

In conclusion, we have drawn an erbium-doped phosphate fibre via the rod-in-tube technique in our laboratory. The gain of the phosphate fibre with different pump powers and with different input signal wavelengths has been experimentally investigated. The results show that the erbium-doped phosphate fibre can provide a net gain per unit length greater than 1.8 dB/cm, and a gain linewidth greater than 34 nm. It is expect to achieve a larger gain per unit length by means of increasing the coupling efficiency, improving the fibre drawing process, and decreasing the diameter of the fibre core.

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