High gain in erbium-doped channel waveguides

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Integration of multiple functions on an optical micro-chip is going to revolutionize the exploitation of optics for various applications such as communication, optical sensing, and biomedicine. One of the enabling functions is amplification at 1.5 µm [1]. Rare-earth-doped amplifiers typically deliver a net gain per unit length of only a few dB/cm [2]. In spiral-shaped channel waveguides a total internal net gain of 20 dB was demonstrated [3].

The rare-earth-doped potassium double tungstates $KY(WO_4)_2$, $KGd(WO_4)_2$, and $KLu(WO_4)_2$ are widely investigated laser materials [4]. They are especially suited for optical amplification due to the high transition cross-sections of rare-earth ions in these materials. Moreover, the large inter-ionic distance between neighboring rare-earth sites may allow for higher erbium concentrations without the detrimental effect of energy-transfer upconversion (ETU). Recently an internal net gain of ~1000 dB/cm was demonstrated in ytterbium-doped channel waveguides [2].

Here we report optical gain at 1.53 µm in $KGd_xLu_yEr_{1-x-y}(WO_4)_2$ channel waveguides doped with five different Er^{3+} concentrations. When pumping the Er^{3+} ions at 980 nm, a record-high internal net gain of 13 dB/cm is experimentally demonstrated, despite the fact that the intrinsic propagation losses in these surface waveguides were as high as 4 dB/cm. Using buried channel waveguides, which typically exhibit intrinsic propagation losses of only 0.2 dB/cm, and optimizing the erbium concentration and waveguide length, for a reasonable 500 mW of launched pump power a high total gain of ~40 dB can be achieved.

Crystalline layers of $KGd_xLu_yEr_{1-x-y}(WO_4)_2$ (KGLEW) with five different Er^{3+} concentrations of 0.48, 0.95, 1.9, 3.81, and 6.36 × 10^{20} cm^{-3}, lattice matched by appropriate Gd^{3+} and Lu^{3+} concentrations were grown by liquid-phase epitaxy onto undoped $KY(WO_4)_2$ substrates [13]. Rib channel waveguides were microstructured by Ar^+ etching parallel to the N_g axis in the $N_m - N_g$ plane of the crystalline layer, hence the optical modes propagate with a polarization of either $E||N_m$ or $E||N_p$. The channel width and thickness each range from 3–8 µm. A rib height of ~1.5 µm was chosen, resulting in fundamental-mode profiles with dimensions < 10 × 10 μm^2. For determining the macroscopic ETU parameter W_{ETU}, we measured the luminescence-decay curves in channel waveguides with all five Er^{3+} concentrations, each at 4 different values of the pump power. The extracted concentration-independent donor-donor and donor-acceptor microscopic parameters are $C_{DD} = 5.4 \times 10^{-39}$ cm^6/s and $C_{DA} = 4.9 \times 10^{-40}$ cm^6/s, respectively, from which W_{ETU} was calculated as a function of doping concentration.

Figure 1 shows the internal net gain as a function of waveguide length at the optimum Er^{3+} concentration of 3.81 × 10^{20} cm^{-3}. The maximum experimental internal net gain per unit length was ~13 dB/cm for short waveguide lengths, which compares very favourably with results in other host materials. For a simulation of optimized optical gain we assume intrinsic propagation losses of 0.2 dB/cm at 1.5 µm, as can be achieved in buried channel waveguides. With an erbium concentration of 3.81 × 10^{20} cm^{-3}, for a length of ~3 cm a record-high total internal net gain of ~40 dB is predicted, thereby underlining that erbium-doped potassium double tungstate channel waveguides are extremely high-performing amplifiers at 1.5 µm.

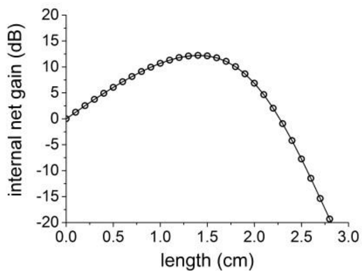

Fig. 1 Internal net gain as a function of length for an erbium concentration of 3.81 × 10^{20} cm^{-3}.

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