High optical gain in $KGd_xLu_yEr_{1-x-y}(WO_4)_2$ waveguide amplifiers despite energy-transfer upconversion

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A crucial enabling function in integrated optics is amplification of optical signals at 1.5 µm. Whereas rare-earth-doped amplifiers allow for high-speed signal transmission at THz bit rates, typically they deliver an internal net gain per unit length of only a few dB/cm [1]. The rare-earth-doped potassium double tungstates $KY(WO_4)_2$, $KGd(WO_4)_2$, and $KLu(WO_4)_2$ [2] are especially suited for optical amplification due to the high transition cross-sections of rare-earth ions in these materials [3]. Recently an internal net gain of ~1000 dB/cm has been demonstrated in ytterbium-doped thin films [1].

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 of 0.75, 1.5, 3, 6, and 10 at.%, grown by liquid-phase epitaxy (LPE) onto undoped $KY(WO_4)_2$ substrates [4] and microstructured by Ar^+ etching. When pumping at 980 nm, a very 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.

When increasing the erbium concentration and population density of the $^4I_{13/2}$ amplifier level to achieve higher gain, the probability of ETU increases linearly with erbium concentration and quadratically with the $^4I_{13/2}$ population density. 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. The gain was simulated by use of a rate-equation system, thereby confirming that ETU limits the available gain.

Using buried channel waveguides, whose intrinsic propagation losses are only 0.2 dB/cm, and optimizing the Er^{3+} concentration and waveguide length to ~3 cm, for 500 mW of launched pump power a total gain of ~40 dB is predicted, thereby underlining that Er^{3+}-doped potassium double tungstates are extremely high-performing amplifiers at 1.5 µm.

Keywords: rare-earth amplifier, erbium, channel waveguide, potassium double tungstate.

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