1050 dB/cm Gain in a 57.5at.% Yb-doped $KGd(WO_4)_2$ Thin Film at 981 nm

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Rare-earth-doped materials with high gain per unit length are essential for optical amplification on emerging small-footprint integrated optical devices in the fields of optical communication, optical backplanes, as well as optical sensing. Recently, a 47.5at.% Yb^{3+}-doped potassium double tungstate waveguide amplifier was reported with 935 dB/cm gain at 981 nm [1], which is promising for developing high-gain amplifiers with lengths as short as a few millimetres. Here we present the results of perpendicular gain measurements in a ~32 μm-thick thin film of 57.5at.% Yb^{3+}-doped potassium gadolinium double tungstate, $KGd(WO_4)_2$, and analyse the impact of pump-signal-foci mismatch to the gain achievable in our sample.

The $KGd(WO_4)_2$ active layer with an Yb^{3+} concentration of 3.63 × 10^{21} cm^{-3} is grown onto a 1-mm-thick $KY(WO_4)_2$ substrate by liquid phase epitaxy [2]. Gd^{3+} compensates the lattice mismatch induced by the high amount of Yb^{3+} dopants and reduces the stress in the layer [3]. The inset of Fig. 1 shows the energy levels of Yb^{3+} in $KGd(WO_4)_2$ [4]. Based on the room-temperature Boltzmann distributions within each of the two electronic multiplets, a maximum population inversion of ~90% is determined, at which transparency would occur at the 932 nm pump wavelength. The theoretical modal gain, calculated by assuming a perfect pump-signal overlap, is shown in Fig. 1. The upper gain limit of the sample is ~1465 dB/cm, which is ~19% higher than that of 47.5at.% potassium double tungstate [1].

A pump-probe measurement is performed with the sample positioned perpendicular to the optical beams using a continuous-wave Ti:Sapphire pump laser tuned to 932 nm. The 981 nm signal beam is mechanically chopped. The pump and signal beams are combined using a dichroic mirror, polarized to the N_m optical axis of the sample, and focused onto the sample with a ×22 microscope objective. A ×50 long-working-distance microscope objective is used to collect the amplified signal from the other end of the sample. The signal is directed to a spectrometer equipped with a pump filter, detected by a cooled InGaAs detector, and amplified by a lock-in amplifier. The small-signal gain is depicted in Fig. 2. A record-high value of 1050 dB/cm is obtained. A numerical amplifier model taking into account the Gaussian beam propagation is applied to study the detrimental effect on the gain value if the signal focal position is shifted along the propagation axis, and the result is shown in the inset of Fig. 2. Since the thin film does not exhibit a waveguide structure, the gain is greatly reduced when the signal focal spot is shifted by more than ~15 μm. Taking into account the non-ideal beam overlap owing to chromatic lens aberrations in our experiment, we simulated the gain according to the experimental conditions and the result agrees well with the result of the measurement, see Fig. 2.

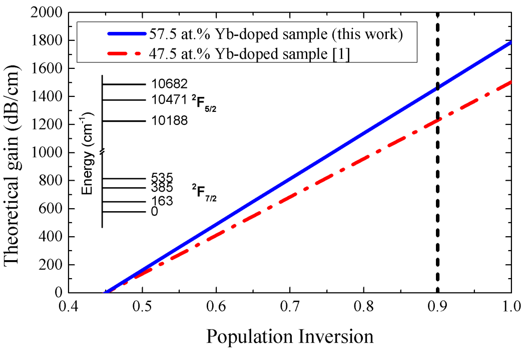

Fig. 1. Theoretical modal gain assuming ideal pump-signal overlap. The vertical dashed line indicates the maximum population inversion at the 932 nm pump. The inset shows the energy levels of $KGd(WO_4)_2:Yb^{3+}$ [5].

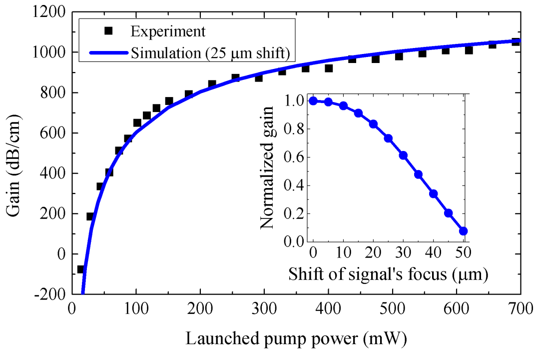

Fig. 2. Measured and simulated gain in 57.5at.% Yb^{3+}-doped $KGd(WO_4)_2$. The inset shows the simulated gain reduction when the focal position of the signal beam is shifted with respect to that of the pump beam.

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