Growth of Yb^{3+}, Lu^{3+}, Gd^{3+} co-doped $KY(WO_4)_2$ thin layers

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Rare-earth-ion-doped $KY(WO_4)_2$ (KYW) is an important candidate for solid-state lasers. Its high refractive indices of the order of 2.0 make it attractive also for applications as integrated optical devices. Liquid phase epitaxy was employed for growing mono-crystalline KYW thin films co-doped with Yb^{3+}, Lu^{3+}, and Gd^{3+}. Concentrations of the optically inert co-dopants Lu^{3+} and Gd^{3+}, which decrease or increase the KYW lattice parameters, respectively, were optimized for lattice matching with the KYW substrate. Lu^{3+} was partially replaced by Yb^{3+} to achieve active optical doping from a few up to 20%. Optimized growth conditions provided crack-free layers.

Introduction

Due to its high refractive index of the order of 2.0, good thermal conductivity, and the possibility of doping with different rare-earth ions, monoclinic $KY(WO_4)_2$ (KYW) is a highly promising material for high-power solid-state lasers [1,2]. Doping with Yb^{3+} provides high absorption and emission cross sections [2]. In thin-film geometry, this material is also suitable for waveguide lasers [3]. Co-doping the layer with appropriate amounts of Lu^{3+} and Gd^{3+} resulted in $KY(WO_4)_2$:Yb (1.7 at%) thin films with increased refractive index contrast, thus reducing the required layer thickness for waveguiding, while simultaneously providing lattice matching between layer and substrate [4]. For thin-disk laser applications, highly Yb-doped KYW layers are needed. This can be achieved by either growing KLuW:Yb layers on KLuW substrates because of the similar ion radii of Yb and Lu [5] or co-doping a KYW:Yb layer with Gd for compensating the induced lattice mismatch with respect to the KYW substrate. In this paper, we report the liquid phase epitaxy (LPE) of crack-free KYW:Yb (2.4 mol%) layers co-doped with Lu and Gd and crack-free KYW:Yb (20 mol%) layers co-doped with Gd.

Experiment and Results

LPE with a vertical dipping method [3] was employed for the growth of layers onto pure KYW [010] substrates of size 1×1 cm^2. The following compositions were grown in $K_2W_2O_7$ solvents: $KYb_{0.024}Gd_{0.13}Lu_{0.246}Y_{0.6}(WO_4)_2$ and $KYb_{0.20}Gd_{0.13}Y_{0.67}(WO_4)_2$. The incorporation of Yb and Lu ions induces tensile strain, while the incorporation of Gd ions leads to compressive strain [6], i.e., adjusted amounts of Yb and/or Lu ions, on the one hand, and Gd ions, on the other hand, can compensate each other [4]. Calculation of the lattice mismatch helped us to achieve layer growth with small lattice mismatch of $f = 0.04625$ %, as confirmed by X-ray diffraction measurements. The mono-crystallinity of the layers was achieved at a low supersaturations by slow growth rates. In this way, crack-free layers of KYW:Yb co-doped with Gd and Lu of thickness 3-5 µm and KYW:Yb codoped with Gd of thickness 30-40 µm were grown (Figs. 1a and b).

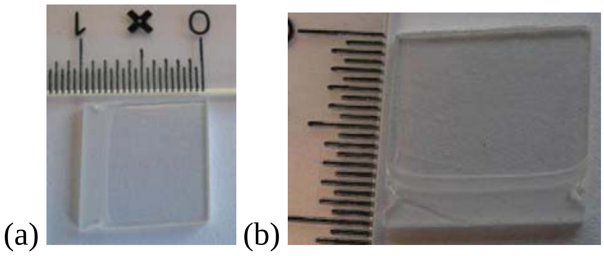

Fig. 1. Crack-free co-doped crystals of (a) KYW:Yb (2.4 mol%), Lu (24.6 mol%), Gd (13 mol%) and (b) $KY(WO_4)_2$:Yb (20 mol%), Gd (13 mol%)

Conclusions

LPE was successfully employed for the growth of co-doped KYW layers. The concentrations of Yb, Lu, and Gd were optimized for lattice matching with the KYW substrate, leading to crack-free layers. 3-5 µm thick layers of KYW:Yb (2.4 mol%) co-doped with Gd and Lu and 30-40 µm thick layers of KYW:Yb (20 mol%) co-doped with Gd were grown. These results form a basis for the fabrication of KYW:Yb, Lu, Gd thin layers suitable for solid-state lasers and integrated optical devices.

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References

[1] N.V. Kuleshov, A.A. Lagatsky, V.G. Shcherbitsky, V.P. Mikhailov, E. Heumann, T. Jensen, A. Diening, and G. Huber, “CW laser performance of Yb and Er,Yb doped tungstates”, Appl. Phys. B **64**, 409 (1997).

[2] N.V. Kuleshov, A.A. Lagatsky, A.V. Podlipensky, V.P. Mikhailov, and G. Huber, “Pulsed laser operation of Yb-doped $KY(WO_4)_2$ and $KGd(WO_4)_2$”, Opt. Lett. **22**, 1317 (1997).

[3] Y.E. Romanyuk, C.N. Borca, M. Pollnau, S. Rivier, V. Petrov, and U. Griebner, “Yb-doped $KY(WO_4)_2$ planar waveguide laser”, Opt. Lett. **31**, 53-55 (2006).

[4] F. Gardillou, Y.E. Romanyuk, C.N. Borca, R.P. Salathé, and M. Pollnau, “Lu, Gd co-doped $KY(WO_4)_2$:Yb epitaxial layers: Towards integrated optics based on $KY(WO_4)_2$”, Opt. Lett. **32**, 488-490 (2007).

[5] S. Rivier, X. Mateos, O. Silvestre, V. Petrov, U. Griebner, M.C. Pujol, M. Aguilo, F. Diaz, S. Vernay, and D. Rytz, “Thin-disk Yb:KLu(WO4)2 laser with single-pass pumping”, Opt. Lett. **33**, 735-737 (2008).

[6] K.H. Hellwege and A.M. Hellwege, eds., *Numerical Data and Functional Relationships in Science And Technology*, Landolt-Börnstein Series III/7, Part f (Springer-Verlag, 1977).