

# Growth of $\text{Yb}^{3+}$ , $\text{Lu}^{3+}$ , $\text{Gd}^{3+}$ co-doped $\text{KY}(\text{WO}_4)_2$ thin layers

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*Rare-earth-ion-doped  $\text{KY}(\text{WO}_4)_2$  (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  $\text{Yb}^{3+}$ ,  $\text{Lu}^{3+}$ , and  $\text{Gd}^{3+}$ . Concentrations of the optically inert co-dopants  $\text{Lu}^{3+}$  and  $\text{Gd}^{3+}$ , which decrease or increase the KYW lattice parameters, respectively, were optimized for lattice matching with the KYW substrate.  $\text{Lu}^{3+}$  was partially replaced by  $\text{Yb}^{3+}$  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  $\text{KY}(\text{WO}_4)_2$  (KYW) is a highly promising material for high-power solid-state lasers [1,2]. Doping with  $\text{Yb}^{3+}$  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  $\text{Lu}^{3+}$  and  $\text{Gd}^{3+}$  resulted in  $\text{KY}(\text{WO}_4)_2:\text{Yb}$  (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  $\text{KLuW}:\text{Yb}$  layers on  $\text{KLuW}$  substrates because of the similar ion radii of Yb and Lu [5] or co-doping a  $\text{KYW}:\text{Yb}$  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  $\text{KYW}:\text{Yb}$  (2.4 mol%) layers co-doped with Lu and Gd and crack-free  $\text{KYW}:\text{Yb}$  (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  $1 \times 1 \text{ cm}^2$ . The following compositions were grown in  $\text{K}_2\text{W}_2\text{O}_7$  solvents:  $\text{KYb}_{0.024}\text{Gd}_{0.13}\text{Lu}_{0.246}\text{Y}_{0.6}(\text{WO}_4)_2$  and  $\text{KYb}_{0.20}\text{Gd}_{0.13}\text{Y}_{0.67}(\text{WO}_4)_2$ . 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).

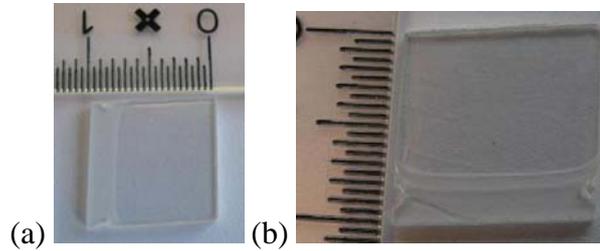


Fig. 1. Crack-free co-doped crystals of (a) KYW:Yb (2.4 mol%), Lu (24.6 mol%), Gd (13 mol%) and (b) KY(WO<sub>4</sub>)<sub>2</sub>:Yb (20 mol%), Gd (13 mol%)

## 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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