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

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Monoclinic crystals of $KY(WO_4)_2$ (= KYW) doped with different rare-earth ions are among the highly promising materials for building compact solid-state lasers, see Ref. [1] and Refs. therein. Due to its high refractive index on the order of 2, good thermal conductivity, and versatility in doping with rare earth ions, $Yb^{3+}$ in particular, KYW crystals are ideally suited for high-power laser applications. In thin-film geometry, this material is also suitable for waveguide lasers [2,3]. Co-doping the layer with appropriate amounts of $Lu^{3+}$ and $Gd^{3+}$ resulted in $KY(WO_4)_2$:$Gd^{3+}$, $Lu^{3+}$, $Yb^{3+}$ (1.7 at%) thin films with significantly increased refractive index contrast with respect to the undoped KYW substrate, thus reducing the required layer thickness for waveguiding, while simultaneously providing lattice matching between layer and substrate [4]. On the other hand, for thin-disk laser applications highly $Yb^{3+}$-doped KYW layers are needed. This can be achieved by either growing KLuW:$Yb^{3+}$ layers on undoped KLuW substrates because of the similar ion radii of $Yb^{3+}$ and $Lu^{3+}$ [5] or co-doping a KYW:$Yb^{3+}$ layer with $Gd^{3+}$ for compensating the induced lattice mismatch with respect to the KYW substrate. In this paper, we report the liquid phase epitaxy (LPE) growth of 3-5 µm thick KYW:$Gd^{3+}$, $Lu^{3+}$, $Yb^{3+}$ layers for $Yb^{3+}$ concentrations of 1.2, 1.7, and 2.4 mol% and 30 to 40-µm-thick KYW:$Gd^{3+}$, $Yb^{3+}$ (20 mol%) layers (Fig. 1a). The concentration of the dopants $Yb^{3+}$, $Lu^{3+}$, and $Gd^{3+}$ in the grown film were determined by laser ablation inductively coupled plasma - mass spectrometry (LA-ICP-MS). Difference between the solution and the concentrations determined by LA-ICP-MS are summarized in Fig. 1b.The growth conditions were optimized, leading to crack-free layers for all investigated $Yb^{3+}$ concentrations. X-ray investigations have confirmed the high crystallinity of the films.

Based on the $Gd^{3+}$, $Lu^{3+}$ co-doped thin films, planar waveguide lasers operating on the $Yb^{3+}$ transition at 1025 nm were demonstrated. Due to the co-doping, resulting in high refractive-index difference between film and substrate, very thin waveguides with strong light confinement were obtained, thus allowing for a pump threshold of laser operation as low as 18 mW. The highest slope efficiency versus absorbed pump power and output power were 82.3% and 195 mW, respectively. Laser experiments with $Gd^{3+}$ co-doped, highly $Yb^{3+}$ doped thin films in thin-disk laser configuration are currently in progress.

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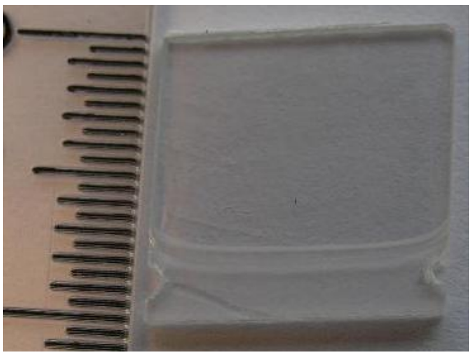
(a) 

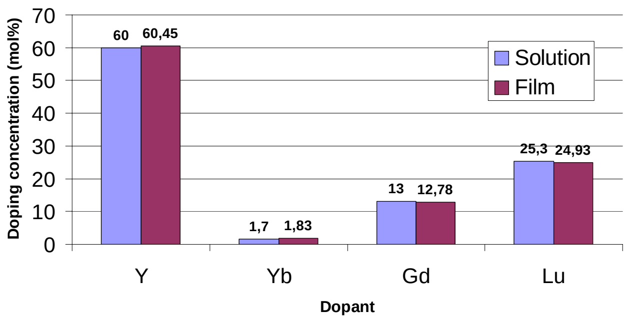
(b) 


**Figure 1: (a) Crack-free $KY(WO_4)_2$:Yb (20 mol%), Gd (13 mol%) thin film; (b) ICP-LA-MS results**

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