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Pump-polarization dependence of the bipolarization emission in ytterbium lasers

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Ytterbium lasers are widely used for femtosecond pulse generation, in particular for dual-comb spectroscopy. Indeed, in the case of quasi-isotropic active media such as Yb:YAG or Yb:CaF₂, two eigenstates with orthogonal polarizations can oscillate simultaneously, corresponding to two frequency combs with adjustable repetition rates [1]. In order to balance the powers of the two modes, one may wonder if the use of a polarized pump could create a gain dichroism, as it has already been demonstrated in neodymium lasers. To this aim, we have performed experimental studies on Yb-doped solid-state lasers, that were supported by a two-mode rate-equation model taking into account the pump-induced gain anisotropy.

The CW laser used is shown in Fig.1(a). The active medium is a 2 mm-thick Yb:YAG crystal (<111>-cut, 5% at. doped) placed between two plane mirrors M₁ and M₂ (output coupling 1%). The laser emits a 120 mW TEM₀₀ mode at 1030 nm for a typical pump power of 1.5 W at 940 nm. The pump polarization is linear and its orientation α_p with respect to x is controlled by a half-wave plate (HWP). When rotating HWP, we observe a strong periodic energy exchange between the two eigenstates (see Figs.1(b)-(c)). We have observed a significant gain dichroism induced by the polarized pump. For example, when $\eta = 2.7$, the power ratio is of the order of 10 at $\alpha_p \equiv 0^\circ$ (mod 90°). We point out that the power balance is obtained for $\alpha_p \equiv 45^\circ$ (mod 90°), in agreement with the fact that our cavity has no loss dichroism.

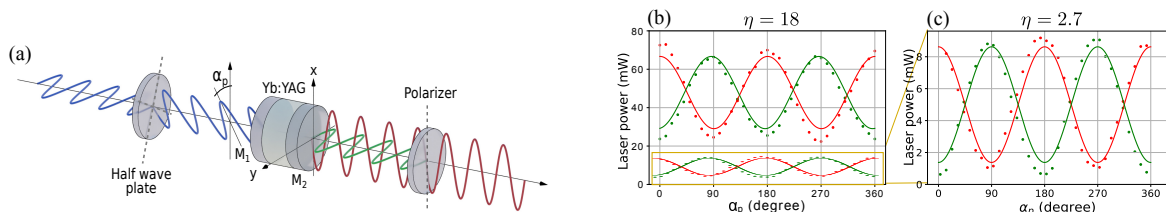


Fig. 1 (a) Illustration of the Yb:YAG laser experimental setup. Powers I_x (in red) and I_y (in green). The points (resp. solid curves) represent the experimental (resp. theoretical) results: (b) $\eta = 18$ and (c) $\eta = 2.7$.

To model the laser with a minimal number of parameters, we consider two super-modes characterized by their intensities $I_{x,y}$ interacting with two population inversion reservoirs $n_{x,y}$. The stationary solutions are found to be $\hat{I}_{x,y} = \eta \left(1 \pm \varepsilon \frac{1+\beta}{1-\beta} \cos 2\alpha_p \right) - \frac{1}{1+\beta}$ where η is the excitation degree, ε the pump-induced gain anisotropy parameter, and β the cross-saturation coefficient that couples the two modes. Figs.1(b)-(c) show a very good agreement between the model and the observations for different values of η [2]. Here, $\varepsilon = 0.08$ and $\beta = 0.64$.

We now compare the preceding results from the Yb:YAG laser to those obtained with a diode-pumped Yb:CaF₂ bulk laser. The latter consists of a 5-cm long plano-concave (1% output coupling) cavity containing a 4 mm-long Yb-crystal (3%-at. doped) close to the plane mirror. It typically emits 25 mW at 1050 nm for about 500 mW of absorbed pump power at 976 nm. Two orthogonal eigenstates oscillate, polarized along the crystal cut directions. A very different pump-polarization dependence on the eigenstate powers is found with respect to the Yb:YAG case. Indeed, while the observations are qualitatively the same, we note that the pump-induced anisotropy appears to be very weak, with a contrast of about 5% at $\eta \approx 2$, yielding $\varepsilon = 0.004$ only. Hence, the Yb:CaF₂ laser polarization states are quite independent of the pump polarization. This can be physically attributed to the high clustering effect in the CaF₂ host [3] that leads to a fast isotropisation of the gain by energy transfers among neighboring ions.

This work can be extended to any host materials. Depending on the chosen host, the gain anisotropy induced by the pump orientation could leverage eventual loss anisotropies in the more complex cavities used for short pulse generation, in order to optimize the simultaneous oscillation of dual combs in Yb lasers.

References

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