Control of the bipolarization emission of the Yb:YAG laser by the orientation of the pump polarization

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Outline

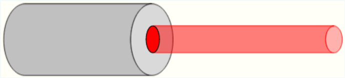
Introduction

Laser

The acronym LASER stands for "Light Amplification by Stimulated Emission of Radiation"

Laser properties

- Coherent
- Focused
- One color(Wavelength)



Early history

- First built in 1960 by Theodore Maiman
- Charles Hard Townes, Arthur Leonard Schalow, etc

Laser Innovations

- Laser pointers
- Medicine
- Telecommunication
- Industry
- Lidar, Radar etc...

Optical frequency comb (OFC)

What is an OFC?

- Optical frequency combs are specialized lasers that act like a ruler for light.
- High-precision spectroscopy and optical clock.

What an OFC can do?

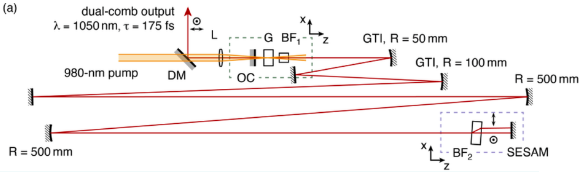
They measure exact frequencies of light; from the invisible infrared and ultraviolet to visible red, yellow, green and blue light quickly and accurately.

Physicists behind the frequency combs

The discovery of frequency combs and their applications by John L. Hall and Theodor W. Hänsch lead to the 2005 Nobel Prize in Physics. [a]

[a] https://link.aps.org/doi/10.1103

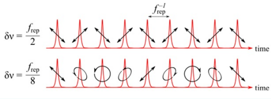
Introduction



- Ytterbium lasers are widely used for femtosecond pulse generation.
- In the case of quasi-isotropic active media such as Yb:YAG or $Yb:CaF_2$, two eigenstates with orthogonal polarizations can oscillate simultaneously[a].

[a] U. Keller, Opt. Express, 28(20) :30275–30288, 2020

Context



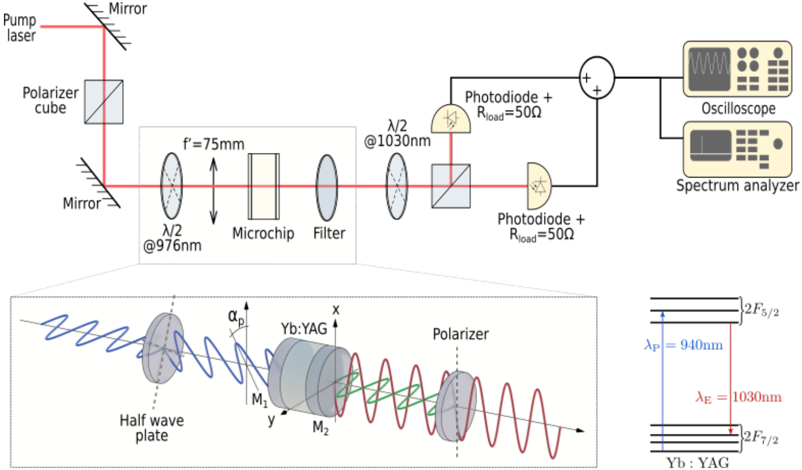
Pulse-to-pulse polarizations inside a mode-lock Nd:YAG laser in our group. [a]

[a] J. Thévenin, Opt. Lett., 2012.

Purpose of the work

- Yb:YAG crystal
- Coupling between the two polarization states?
- Influence of the pump polarization?

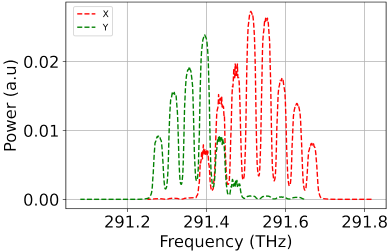
Microchip laser



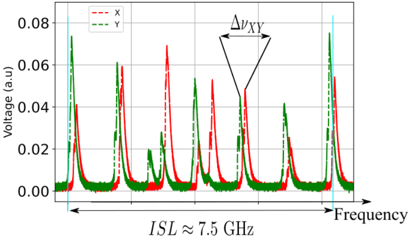
Microchip characteristics

- Thickness of the active medium= 2 mm, $P_{threshold} = 80$ mW.
- For $P_{pump} = 1.5$ W; $P_{laser} = 120$ mW.

Optical spectral analysis



(a) Multimode.



(b) Polarization states observation using the Fabry-Perot cavity.

Observations

- On Y: 10 stable modes (6 intense and 4 less intense)
- On X: 8 stable and intense modes
- Measurement of the spectral separation $\Delta\nu_{XY}$
- Stress birefringence in the crystal: $\Delta n = 1.41 \times 10^{-6}$

Experimental results

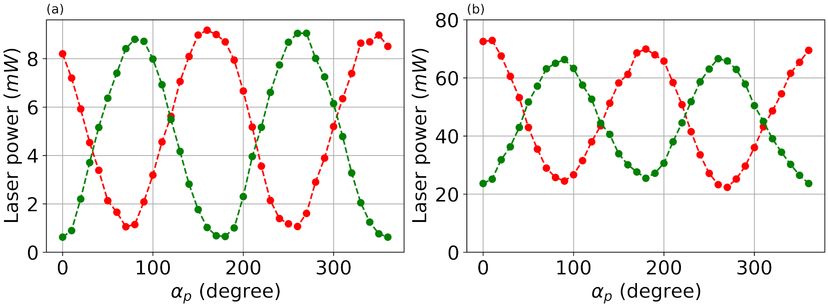


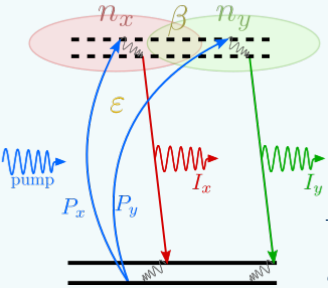
Figure 3: Powers P_x (in red) and P_y (in green).

Observations

- Oscillation of the laser in two polarization states: linear and orthogonal.
- Control of the gain anisotropy $\Rightarrow$ Promotion of one polarization state or another.

Model

Evolution equations of $I_{x,y}$ et $n_{x,y}$



$$\frac{dI_x}{dt} = \kappa\left(n_x + \beta n_y\right) I_x - \Gamma_x I_x \quad (1)$$

$$\frac{dI_y}{dt} = \kappa\left(n_y + \beta n_x\right) I_y - \Gamma_y I_y \quad (2)$$

$$\frac{dn_x}{dt} = \gamma_{\parallel} P_x - \left[\gamma_{\parallel} + \zeta\left(I_x + \beta I_y\right)\right] n_x \quad (3)$$

$$\frac{dn_y}{dt} = \gamma_{\parallel} P_y - \left[\gamma_{\parallel} + \zeta\left(I_y + \beta I_x\right)\right] n_y \quad (4)$$

Pumping anisotropy[a]

[a] T. Chartier, Appl. Phys. B, 70(1) :23–31, 2000.)

$$P_{x,y} = P\left(1 \pm \varepsilon \cos\left(2\alpha_p\right)\right) \quad (5)$$

Normalization and expression of the excitation degree

$$\hat{I}_x = I_x/(\gamma_{\|}/\zeta) \quad \text{and} \quad \eta = P/P_{th} \tag{6}$$

Stationary solutions(important parameters ε, β and η)

$$\hat{I}_{x,y} = \eta \left(1 \pm \varepsilon \frac{1+\beta}{1-\beta} \cos 2\alpha_p \right) - \frac{1}{1+\beta} \tag{7}$$

We can now measure the good parameters for the model.

Cross saturation coefficient[a]

[a] M. Brunel, A. Amon, and M. Vallet. Opt. Lett., 30(18) :2418–2420, 2005.

$$\beta = \frac{\Omega_R - \Omega_L}{\Omega_R + \Omega_L} \approx 0.64 \pm 0.02 \text{ and } \varepsilon = 0.084$$

Comparison between the model and the experimental results

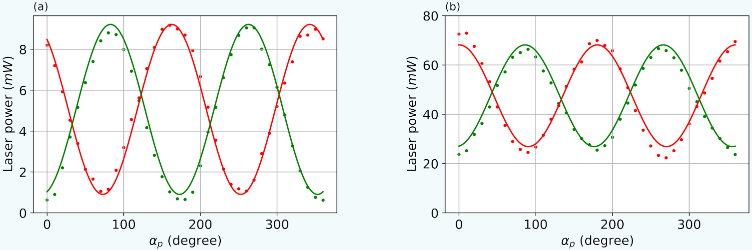
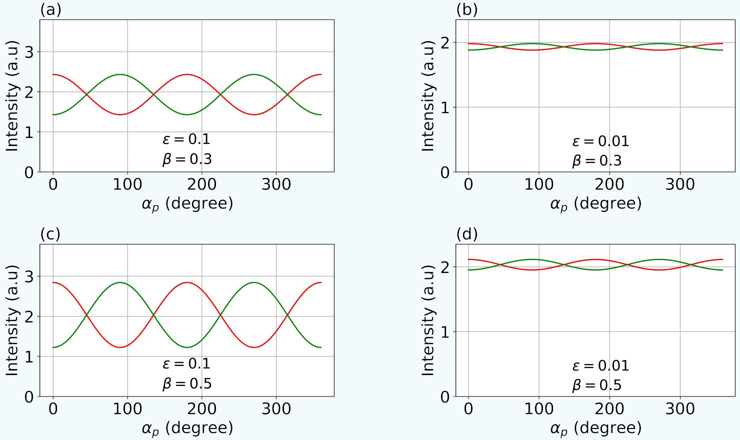


Figure 4: Powers P_x (in red) and P_y (in green). The points (resp. solid curves) represent the experimental (resp. theoretical) results. (a) $\eta = 2.7$ and (b) $\eta = 18.3$.

- Nice agreement between the theory and the experiment.

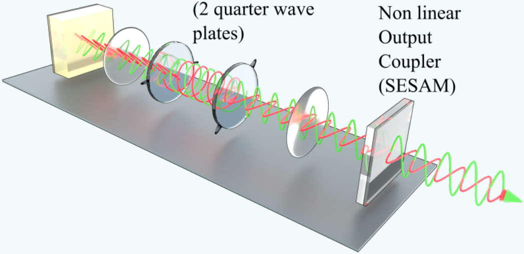
Exploration of the model



For a given value of β, the contrast between the two polarization intensities decreases when the pump anisotropy coefficient decreases.

Actual experiments: mode-lock Yb:YAG laser

Laser setup



Mode-locked laser

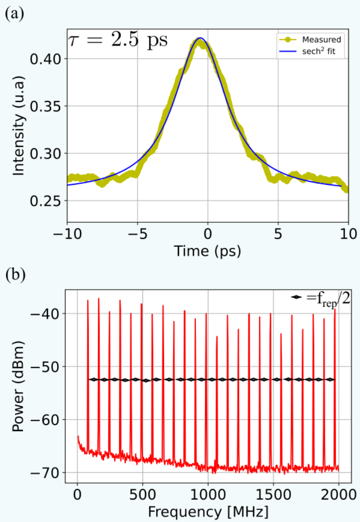
- $w_{SESAM} = 20\mu m$
- $w_{Yb:YAG} = 17\mu m$
- $P_{threshold} = 2.82$ W
- $< P >= 90$ mW

Combs characteristics

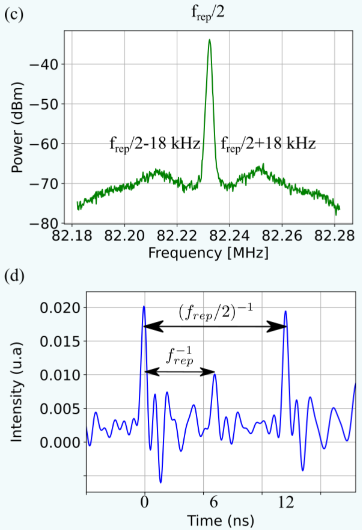
- $T_{rep} = 6$ ns
- $f_{rep} = 164.44$ MHz
- FWHM (f_{rep})= 17 Hz
- FWHM ($f_{rep}/2$)= 8 Hz

Results

Autocorrelation trace



Locking regime



Conclusions

- The orientation of the pump polarization is an effective tool for controlling the relative powers in a dual-polarized Ytterbium laser.
- First measurement of the cross saturation coefficient $\beta = 0.64 \pm 0.02$ in a Ytterbium laser.
- Calculation of the pump anisotropy parameter $\varepsilon = 0.084$ in a Ytterbium laser.
- Good agreement between the theory and the experiment.
- Extension of the principle to a dual frequency comb.

Perspectives: projects planned for the thesis work

- Generation of a polarization sequences.
- Implementation of the most stable mode locking regime.
- New crystal of Yb:CaF_2(CIMAP at CAEN), diode pumping.

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Future projects in Africa

Activities towards students

- Inspire young African students to enter scientific fields.
- Caravan of exhibition and scientific demonstrations.
- Scholar orientation.
- Training students on Optics and Photonics.
- Scientific activity in school for disabled students.
- Visit to companies.
- Organize televised debates between young scientists and heads of companies and institutions.

Scientific demonstrations in Togo

Scholar orientation