DIODE PUMPED TUNABLE SINGLE-FREQUENCY Nd:YGLF LASER

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Abstract

Solid state diode pumped, high output power, single frequency is obtained with a thin Nd:GdYLiF gain medium inside a short laser ressonator and a coupled Fabry Perot cavity. The size control of the cavity allows the selection of the spatial hole burning modes. Adjusting the effective reflectivity of the coupled Fabry-Perot cavity we are capable to enhance single frequency operation and tune the cavity frequency. We achieve a single frequency, continuous output power of 200 mW for 1.5 Watt of diode pump power.

Introduction

A solid state laser can oscillate on many longitudinal modes depending on the cavity size and the gain medium profile. In some applications, a single frequency laser emission is necessary. The development of single frequency stabilization techniques is important to many scientific and technologic areas. Optic sources of great spectral purity and stability are a very important subject to fundamental physics, communication applications, high resolution spectroscopy and atmospheric high resolution laser Doppler LIDAR [1,2,3,4,5].

Diode pumped solid state lasers are suitable for applications which claim portable systems because of their high capacity for miniaturization. Another advantage is their high spectral stability in comparison with lamp pumped lasers, whose cooling system difficults the goal of obtaining a single frequency [6,7].

There are different techniques to achieve solid state laser single frequency operation. They are ring laser [8,9], microchip laser [10,11] and the use of intracavity frequency selection devices like etalons [12]. In ring lasers, the travelling wave impedes spectral hole burning in the gain medium whereas in a microchip the separation between adjacent longitudinal modes is bigger than the gain width. The absorption efficiency of diode laser pumping techniques enables the use of very small gain mediums. Microchips are small gain media, who frequently have the cavity mirrors coated directly on their beam entrance and exit faces in order to generate longitudinal modes with very large frequency separation as explained above. This technique is only suitable for crystals with large absorption.

The Nd:YGdLiF, used in this work has a large linewidth (400 GHz) [13]. Therefore, single frequency operation is possible only for crystals with less than 0,3 mm length. In order to absorb 95% of the incident radiation, the gain media would need an absorption coefficient of 100 cm^{-1}. Nd:YLF has an absorption coefficient of roughly 10 cm^{-1} for 1.5 mol% doping level and cannot be doped beyond that level. The isostructural Nd:YGdLiF has the advantage of a higher segregation coefficient and therefore might be more indicated for the task of single frequency generation with microchip techniques.

Therefore, in this work a crystal, long enough for a efficient pump absorption, was used inside a small cavity. As this cavity is not capable of generating single frequency, a coupled cavity with plane parallel mirrors was attached to the principal cavity. This Fabry-Perot cavity allows to control the effective reflectivity of the oscillating frequencies by changing the distance of its mirrors and their reflectivities.

Theory

The frequency separation of a cavity is given by its free spectral range, which depends mainly on the cavity length. If the cavity is short enough so that the free spectral range is larger than the linewidth, only the mode at line center (figure 1) will oscillate, whereas the adjacent frequencies will not.

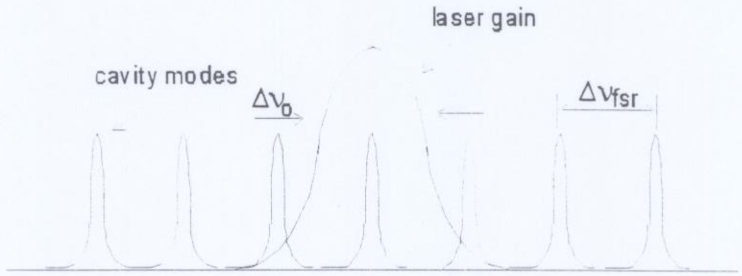

Figure 1: Diagram of the microchip's longitudinal modes.

For larger standing wave cavities, the adjacent frequencies have enough gain to oscillate and additional mode selection techniques are necessary to guarantee single frequency oscillation. This is because the first mode to lase establishes itself at the gain center and creates, due to the standing wave cavity, a spatial modulation of the population inversion inside the gain media. At the nodal points of the stationary electromagnetic field of this mode, there are not exploited atoms in the upper laser level which can contribute to the development of new modes. This is named *spatial hole burning* (SHB).

Obviously, a new SHB- mode must also be a cavity mode in order to oscillate. Whereas the SHB modes are determined by the crystal length and the distance between crystal and the nearest mirror [14], the cavity longitudinal modes emitted are determined just by the principal cavities' length. Therefore, by tuning this cavities' length it is possible to impede a second SHB-mode to lase even if it would experience spatially gain inside the active media.

Adjusting the effective reflectivity of the coupled Fabry-Perot cavity we are capable to enhance single frequency operation and tune the cavity frequency(figure 2). For two mirrors, R_1 and R_2, the effective reflectivity is [15]:

$$R_{eff} = \frac{(\sqrt{R_1} - \sqrt{R_2})^2 + 4\sqrt{R_1 R_2}\, sin^2(\delta/2)}{(1 - \sqrt{R_1 R_2})^2 + 4\sqrt{R_1 R_2}\, sin^2(\delta/2)} \quad \text{where} \quad \frac{\varphi}{2} = \frac{2\pi n d}{\lambda}.\cos\theta$$

where d is the distance between the mirrors, λ is the wavelength, n is the refraction index and θ is the incident angle.

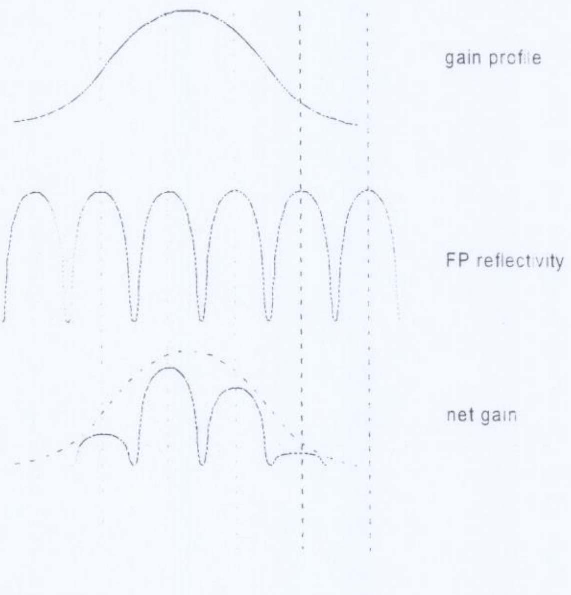

Figure 2: Laser gain modulation by a FP.

The maximum effective reflectivity was chosen to be close to the optimum reflectivity of the cavity, so that the lasing frequencies are always on a reflectivity maximum. The distance between the transmission maximums has to be large enough for no other SHB modes to lase but at the same time should not be much smaller than the gain bandwidth (FWHM) so that a reasonable tuning range is possible.

Beyond the above single frequency selection techniques, we also limited the pump power.

Experimental setup

In this work a high power diode laser emitting at 792 nm was used, that is one of the absorption frequencies of neodymium. The pump beam was set according to figure 3, what allows the spatial coincidence between pump and cavity modes. The pump beam has M^2 of 43x62 and beam waist of 135x160μm.

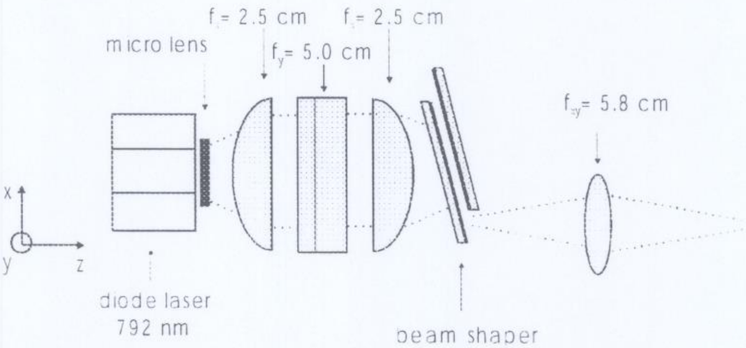

Figure 3: Diode and its focusing optics.

The cavities pump mirror had 20 cm of radius of curvature and the crystal length was 2.9 mm. The optimum output reflectivity is 88%, according to experimental measures. We therefore used two plane mirrors for the FP with 70 % and 47 % reflectivity, as shown in figure 4.

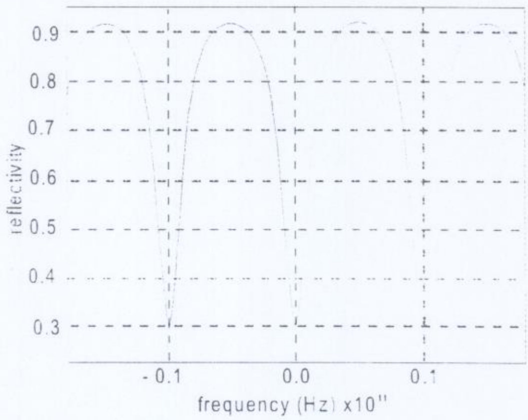

Figura 4: Reflectivity versus frequency for a Fabry-Perot with 70% and 47% reflectivity mirrors and 1.5 mm distance.

The laser frequencies were analyzed by a Burleigh HiFase scanning etalon and their frequency amplitudes observed on an oscilloscope.

Results

Single frequency operation can be observed in figure 5. The two larger peaks represent the same frequency, ν_0, which appears two times due to the scanning range being larger than $c\ 2\nu_0$. The distance between the two peaks is equal to the free spectral range of the scanning etalon. The smaller peaks to the right are secondary reflections.

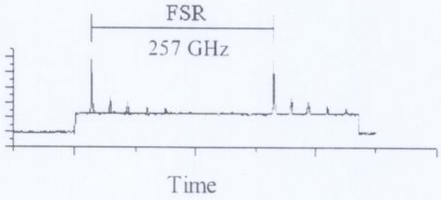

Figure 5 Single frequency operation as seen on the oscilloscope.

Because we work with a large linewidth emission crystal, we had to limit the pump power to avoid more than one frequency. As a result we achieved at the beginning only 50 mW of output power. With the mode selecting techniques we could increase the input power to 1.5 Watt obtaining a useful, single frequency output power of 200 mW.

Without the coupled cavity we usually had 3 to 5 SHB modes as seen in figure 6 with the first mode to lase at gain center.

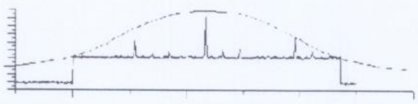

Figure 6: Etalon scan showing three SHB modes.

Using the net gain modulation of the coupled cavity, we could now tune the principal SHB mode. In a second pass, using the interferometric cavity length control of the principal cavity, we eliminated the other SHB modes. Single frequency operation was maintained routinely for a period of 10 minutes, after that mechanical and thermal instabilities stopped the regime.

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