Efficient Intracavity Frequency Doubling of a High Power Diode Laser Generating Light at 423nm

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Abstract

In this work an efficient system generating blue light (at 423nm) is reported. A high power, broadband, diode laser is injected by a single-mode diode laser, generating up to 300mW of useful power at 846nm. Using a 1cm long Potassium Niobate ($KNbO_3$) crystal, the frequency of the laser is doubled generating up to 54mW of useful power of blue light a t423nm. The crystal is placed in an external bow-type ring cavity that enhances the fundamental power increasing the efficiency of the doubling process. The doubled laser can be used to cool and trap neutral Calcium atoms as well as for spectroscopy of these atoms.

1 - Introduction

High resolution atomic and molecular spectroscopy requires single-mode and tunable lasers. Diode lasers, particularly attractive because of their low cost and long lifetime, generally do not fit this requirement, but can be forced to oscillate single-mode when used in extended cavity configurations. Although their tuning range is acceptable for most applications, they are available only in certain wavelength regions. In particular, laser cooling and trapping of alkaline-earth atoms, as Calcium, is one example that requires tens of miliwatts of single-mode laser power in blue-violet region.

Calcium is a particularly interesting element because of a very narrow optical transition, which makes it a candidate to a unified frequency-time-length standard [1]. Certainly, one of the biggest technical challenges in building a diode-based magneto optical trap (MOT) for Ca is the generation of single-frequency radiation at 423nm [2]. Since there are no suitable 423nm semiconductor source yet available, the better choice to generate enough cw power is frequency doubling of a laser diode in an external build-up cavity. This solution requires a powerful single-mode laser source at the fundamental wavelength (846 nm). Injection locking is a useful technique for amplifying the output power of a tunable external cavity diode laser. The injection-locked output retains the spectral properties of the injected signal while offering high powers.

2 - Experimental Setup and Results

It can be seen in the figure 1 the experimental setup of our system. The master laser, a single mode extended cavity diode laser (SDL 54222-H_1), injects the salve laser, a high power diode laser (SDL – 8630), which can delivery up to 300mW of useful infrared light.

The master laser is used in an alternative extended cavity configuration [3]. The cavity is made of a thin glass plate placed 16cm away from the collimating lens. Between the lens and the thin plate a prism is placed to disperse spatially the light. The glass plate can be tilted tuning the wavelength of the master laser. Approximately 18mW is injected in the slave laser. After the isolators, the total power of the master laser is 300mW at 846nm. The light of both lasers can be analyzed by a Fabry-Perot (F.P.) cavity which guarantees that the lasers are single mode. Besides the Fabry-Perot cavity we can analyze the spectrum of the lasers with an Optical Spectrum Analyzer.

The light emitted from the slave laser enters in the doubling cavity where it is placed the nonlinear $KNbO_3$ crystal. The ring cavity consists of two plane mirrors (the first with a transmission of T = 2.3% at 846 nm and the second to have a reflection R = 99,8% at 846 nm) and two curved with radius curvature of 10 cm each (the output mirror have a reflection R = 99,3% at 846 nm and a transmission at blue light R = 55%). The free spectral range of the cavity is 470 MHz. The fundamental power is enhanced by the cavity, which build-up factor is 70 times. When the blue light is generated this factor is reduced to 14 times for the second harmonic generation creates losses to the fundamental harmonic. The noncritical type-I phase-matching is achieved by varying the crystal temperature up to -12^{o}C. The doubling cavity is kept resonant with the laser frequency electronically. The stabilization is made using the Hänsch-Coulliaud technique [2].

The single pass efficiency of the 1cm long $KNbO_3$ is given by the following expression

$$P(2\omega) = \eta P^2(\omega)$$

where η=-0.01W^{-1}. A maximum of P_{blue} = 54 mW of blue light emission (unidirectional) was generated with P_{NIR} = 245 mW of incident pump power, an optical conversion efficiency of 22%.

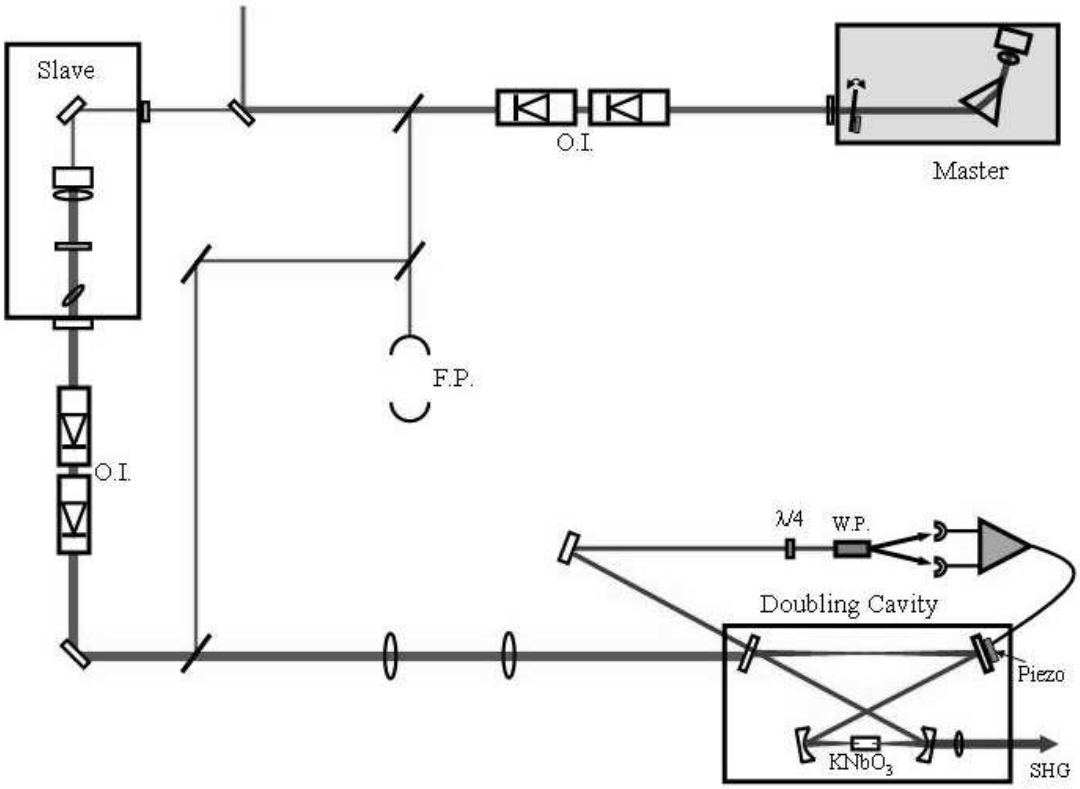
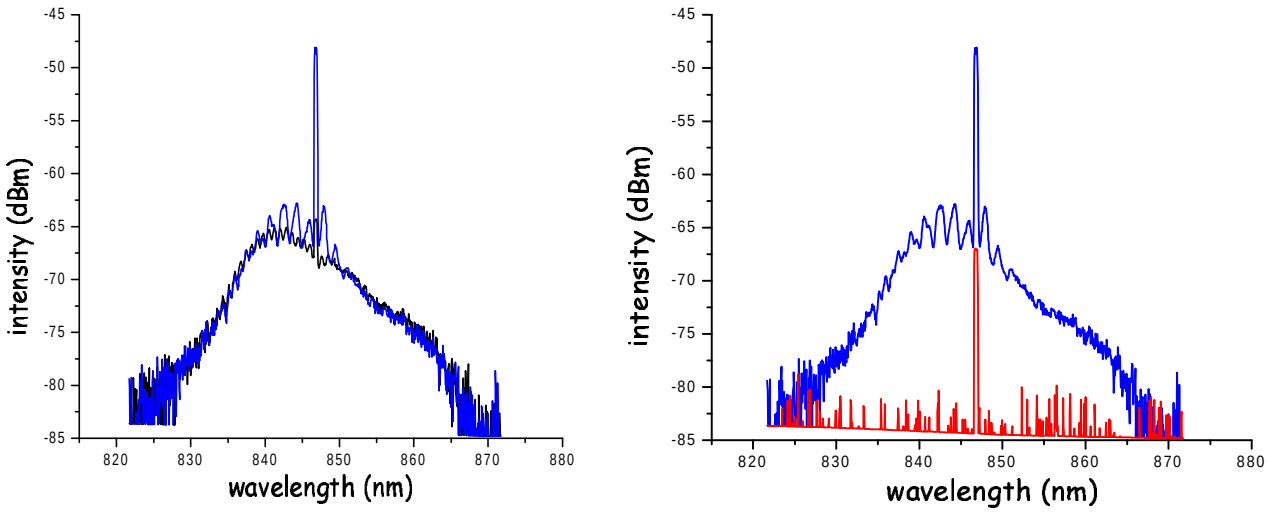


Figure 1: Experimental setup. The extended cavity master laser injects the high power slave laser. O.I. are the optical isolators. F.P is the Fabry-Perot analysis cavity. The stabilization of the doubling cavity is made electronically by acting in the "piezo". The error signal is generating by the quarter wave plate and the Wolastron prism (W.P.).

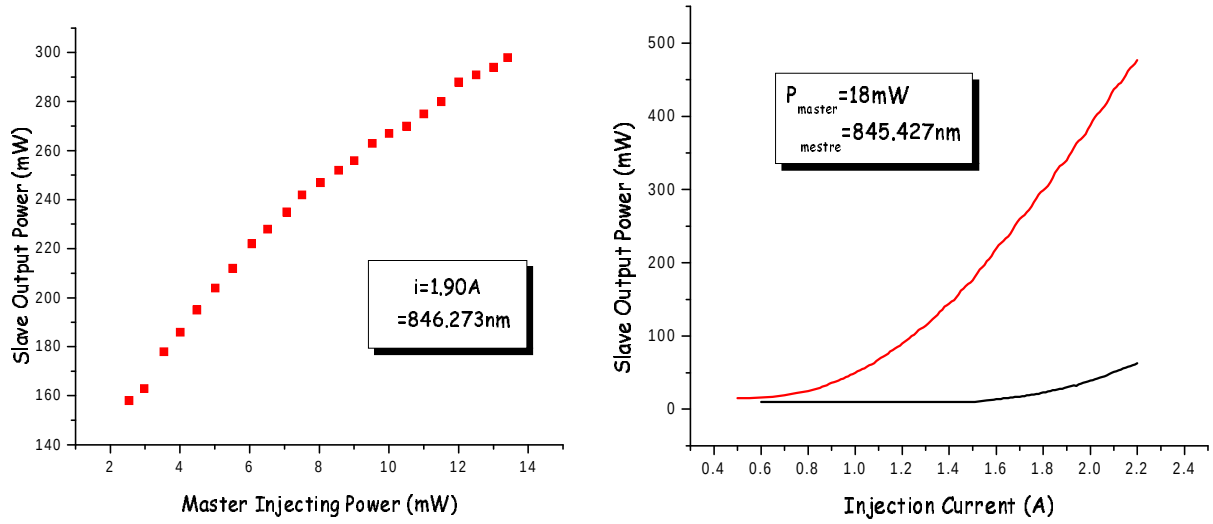
In figure 2 one can see the spectra of the master and the slave lasers. Not only the power of the salve laser is increased with the injection but the emitting laser starts to oscillate single-mode. The mode in which the slave emits is the same of the master laser, as shows the figure 2 (b).



(a) **(b)**

Figure 2: (a) Spectrum of the slave laser been injected by the master laser (blue line) and without injection (black line). (b) Spectrum of the master laser (red line) and the slave laser injected (blue line).

In the figure 3 the effects of the optical injection in the slave laser can be seen. The output power of the slave laser as a function of the injecting power of the master laser is shown by (a). Meanwhile the output power of the slave laser as a function of the injecting current for two cases (injected and without injection) can be seen in (b). The slave oscillation threshold is reduced when the injection takes place.



(a) (b)

Figure 3: (a) Slave output power as a function of the master injecting power. (b) Slave output power as function of the injection current. The black line refers to the case when the laser in not been injected by the master and the red line is the case with injection.

Conclusions

In conclusion, we have shown that the salve laser start to oscillate single mode as the master laser. The high-power injection-locked diode laser was used in conjunction with resonant enhancement cavity to significantly increase the second-harmonic power and conversion efficiency. A maximum of 54 m of useful cw blue light radiation was measured.

Acknowledgements

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References

[1] G. Wilpers, T. Binnewies, C. Degenhardt, U. Sterr, J. Helmcke, and F. Riehle, *Phys. Rev. Lett.* **89** (23): art. no. 230801 DEC (2002);

[2] T. Kurosu, J. Ishikawa, N. Ito, *Appl. Phys. B-Laers and Optics* **63** (3): p. 265 (1996);

[3] D. A. Manoel, R. L. Cavasso-Filho, A. Scalabrin, D. Pereira and F. C. Cruz, *Ops. Commun.* **201** (2002): p.157;

[4] T.W. Hänsch and B. Couillaud *Opt. Commun.* **35** (1980), p. 441.