Spectral and noise characterization of a 852 nm dual-frequency VECSEL

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Coherent population trapping (CPT) is a common technique used in compact atomic clocks which requires two-phase coherent laser modes with a frequency difference in the GHz range for alkali atoms [1]. To improve the performance vs size trade-off of Cs atomic clocks, we develop a laser source generating two cross-polarized coherent laser fields at 852 nm. It relies on the dual-frequency and dual-polarization operation of an optically-pumped vertical external-cavity semiconductor laser [2]. This emission is induced by intracavity birefringent components which induce a controllable phase anisotropy within the laser cavity and force emission on two cross-polarized longitudinal modes.

The semiconductor (SC) chip is grown on a 350 µm thick GaAs substrate and includes 7 GaAs quantum wells (8 nm-thick) embedded in $Al_{0.22}Ga_{0.78}As$ barriers, and a high reflectivity Bragg reflector composed of 32.5 pairs of $AlAs/Al_{0.22}Ga_{0.78}As$. The semiconductor micro-cavity, consisting in the Bragg mirror and the air/semiconductor interface, is resonant at the emission wavelength and thus enhances the modal gain. Under continuous pumping, the SC chip delivers up to 8% optical gain. The 10 mm long cavity includes a birefringent YVO_4 plate which induces a 50 µm separation modes inside the semiconductor structure and an electro-optic crystal (MgO:SLT) for continuous tuning of the frequency difference. Additionally, a wedged Fabry-Perot etalon made of a 100 µm-thick YVO_4 is inserted in the cavity. The frequency difference between the cross-polarized modes is tunable by rotating the etalon thanks to its intrinsic birefringence: a 2° angle corresponds to a frequency difference of 9 GHz. And the tuning of the laser central wavelength is achieved by translation of the etalon.

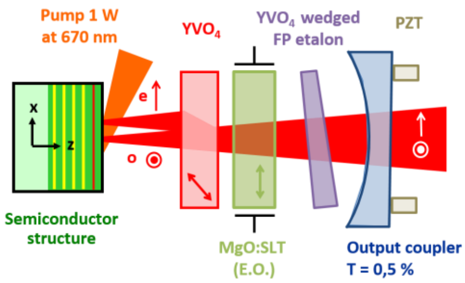

Fig. 1: Laser cavity set-up.

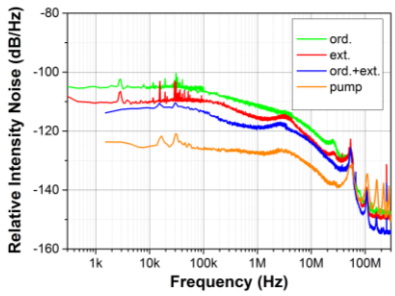

Fig. 2: Laser and pump relative intensity noise.

The laser emission is stabilized using two separated servo-loops. The wavelength of the ordinary polarized mode is locked onto the Cs D_2 line using a saturated absorption set-up with feedback to a piezo-transducer (Fig. 2). Then the frequency difference between the cross-polarized lines is locked on a local oscillator using electronic feedback to the intracavity electro-optic crystal. The detailed characterization of the noise properties is done with both servo-loops operating. The relative intensity noise (RIN) is flat from 100 Hz to 100 kHz at a level of -105/-110 dB/Hz, limited by the pump RIN transfer to the laser (Fig. 2). Intensity noise fluctuations of the two modes are anti-correlated under 2 MHz, the cavity cut-off frequency, and correlated above. The frequency noise is limited by mechanical resonances below 1.5 kHz and by thermal fluctuations induced by the pump source above. The laser linewidth was measured from both frequency noise integration and heterodyne beatnote measurements; it is estimated to 3 MHz at 1 second. Based on those performances, we estimate a theoretical clock stability of $1.6.10^{-12}$ over 1 second, limited by the laser RIN. This limit can be overcome using power stabilization loop or intensity normalization of the CPT signal [3]. With those improvements, we target a clock stability of 3×10^{-13} at 1 second, which would be at the state of the art for CPT atomic clocks.

References

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