Dual frequency emission in a compact semiconductor laser for coherent population trapping cesium atomic clocks

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Coherent population trapping (CPT) has been demonstrated as an interesting technique for miniature atomic frequency references [1,2] and quantum information. It is based on the coupling of the two hyperfine ground states of an alkali atom – namely cesium (^{133}Cs) for atomic clocks – through excitation to a common atomic level by two phase-coherent laser fields nearly resonant with the atomic transitions. The frequency difference between the two laser fields is tuned at the atomic frequency splitting in the microwave range, equal to 9.192 GHz for ^{133}Cs atoms. Outputs powers in the mW range and narrow-linewidth emission (<500 kHz) are required for the two laser beams. Dual-frequency operation of an optically-pumped vertical external cavity semiconductor laser (VECSEL) has been proposed as a simple and compact solution [3] and presents many advantages. First, this configuration takes benefit of the intrinsically strong correlation between the two laser lines which share the same cavity; second, the frequency difference, which is proportional to the intracavity phase anisotropy, may be tunable from few tens of MHz to a few THz. Finally, the low relative-intensity-noise of VECSELs on a wide spectral range is of particular interest for this application, as it should provide a high-purity RF beat-note phase spectrum.

The laser cavity was composed by a semiconductor chip and a 15mm concave output mirror with a transmission of 0.5% at 852 nm. In order to obtain two cross-polarized adjacent longitudinal modes distanced by 9.192 GHz, a 10-mm long compact cavity was designed, corresponding to a free-spectral-range of 12 GHz. The semiconductor chip is grown on a 350 µm-thick GaAs substrate and it comprises 7 GaAs quantum wells embedded in $Al_{20\%}Ga_{80\%}As$ barriers grown on a high-reflectivity Bragg mirror [4]; it is pumped with a fiber-coupled laser diode emitting up to 1 W at 670 nm. The dual frequency emission is achieved thanks to a 500 µm-thick birefringent YVO_4 plate which induces a lateral separation of 50 µm of the ordinary and extraordinary polarizations in the semiconductor chip. An uncoated silica etalon is used to tune the central wavelength and to force the single-frequency emission at each polarization. The laser cavity design has focused on compactness as well as high mechanical and thermal stability. The pump optics, the semiconductor chip and the laser cavity elements are integrated in a compact casing. This limits mechanical and acoustic vibrations as well as air temperature fluctuations inside the external cavity. The temperature of the whole setup is stabilized to 15°C with a Peltier element.

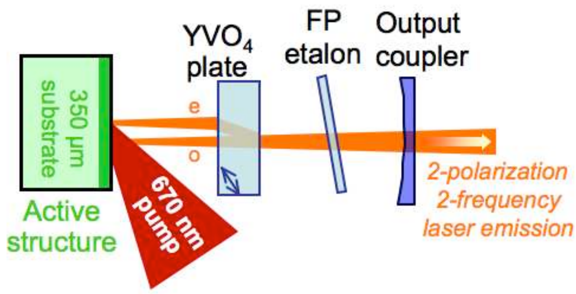

Fig. 1 Experimental setup of the dual frequency VECSEL.

The maximum output power reaches 10 mW on each polarization with all the elements in the cavity. The dual-frequency emission is evidenced in the RF beat-note spectrum obtained by mixing the cross-polarized lines. Finally, the laser line is stabilized onto an atomic hyperfine transition of the Cs D_2 line at 852.14 nm; the laser frequency at the ordinary polarization is locked to the side of a Doppler-free saturated absorption line through a low-bandwidth (f <1kHz) servo loop on the piezoelectric transducer glued onto the output coupler.

In the next future, the addition of an intracavity electro-optic modulator will allow to phase-lock the frequency difference Δν at 9.2 GHz and to stabilize it to Cs hyperfine splitting.

References

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