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Cs atomic clocks based on coherent population trapping require two phase-locked laser lines with output power in the 10-mW range and a frequency difference of about 9 GHz to provide the microwave interrogation. Stabilization of one laser frequency to the reference laser with a phase-locked loop and high-frequency modulation of a diode laser are the two most frequent solutions. Alternatively, dual-frequency operation of a single laser source might provide the simplest architecture. It is based on the simultaneous emission of two orthogonally-polarized laser beams sharing the same laser cavity, but with a slight anisotropy resulting in the frequency difference. The major advantage of this configuration lies in the fact that the frequency fluctuations of the two beams are strongly correlated. Such dual frequency oscillation has already been observed with rare-earth doped material lasers [1]; recently it has also been demonstrated with a 1-µm vertical-external cavity semiconductor laser (VECSEL), with the benefit of low phase and intensity noise thanks to the class-A regime dynamics of VECSEL [2]. In this work, we describe the first dual-frequency operation of an optically-pumped VECSEL emitting around the Cs D_2 line at 852 nm.

The semiconductor chip is grown on a 350 µm-thick GaAs substrate and is designed to emit at 852 nm [3]. The laser consists in the semiconductor active structure, a 0.5 mm-thick YVO_4 birefringent plate, a 50-µm thick solid etalon and a 50_mm radius of curvature concave output mirror with transmission of 0.5% at 852 nm. The YVO_4 plate forces the laser emission on two cross-polarized spots, distant from 50 µm on the active chip while the etalon guarantees a stable single-frequency operation of each polarization and the tunability of the laser emission. The pump source is 2W-broad-area laser diode coupled into a 100 µm diameter, NA = 0.22, multimode fiber emitting at 670 nm. It is focused on a 100 µm × 130 µm-elliptical spot on the structure. With a cavity length of ~49 mm (free spectral range of 3 GHz), the laser cavity waist is 80 µm in the structure.

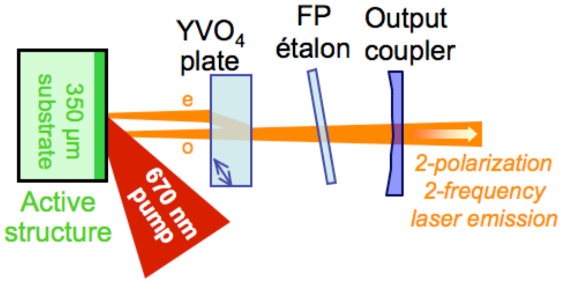

Fig. 1 : Experimental setup of the dual-frequency VECSEL; o,e stands respectively for the ordinary and extraordinary polarized beams.

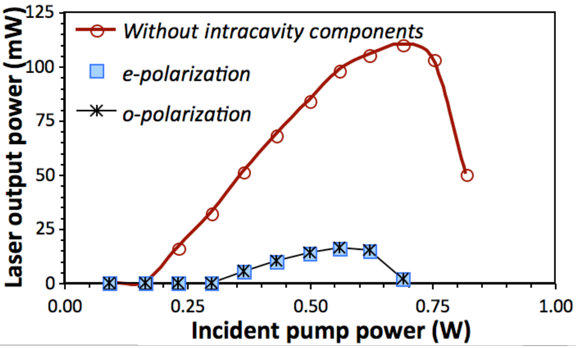

Fig. 2 : Output power *vs* incident pump power for the laser operating around T = 15°C without (circle) and with the birefringent plate and the etalon on each polarization.

Without any intracavity element, the laser output power reaches 110 mW, limited by the strong thermal roll-over of the active structure (Fig. 2). With the birefringent plate and the intracavity Fabry-Perot etalon, the laser emission is purely single-frequency on each polarized beam, with almost equal output power of 16 mW in each (Fig. 2). The strong decrease of the total output power is mainly due to the high losses introduced by the etalon. The frequency difference $\Delta\nu$ is determined by the free spectral range of the laser cavity and by the intracavity phase anisotropy. In this preliminary experiment, $\Delta\nu$ can be adjusted from ~100 MHz to ~40 GHz with the alignment of the intracavity components. Further work to precisely control $\Delta\nu$ with an intracavity electro-optic modulator and to tune it around the 9 GHz microwave transition is under progress.

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