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Spectral Hole Burning for Ultra-stable Lasers

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Ultra-stable laser is an important component of optical lattice clocks which are candidates for the future re-definition of the SI second. Spectral hole burning in rare earth doped crystals can provide narrow atomic transitions based on the absorption of optical frequencies by the doping ions. Ultra-stable lasers achieved by frequency locking a laser radiation on such narrow atomic transitions are expected to exhibit lower fundamental (thermal noise induced) limits compared to traditional system utilizing high finesse Fabry-Perot cavity, due to operation at cryogenic temperature and high mechanical quality factor of the crystal, compared to the amorphous glasses typically used in conventional Fabry-Perot Cavity designs. In our laboratory, we are using the europium doped yttrium ortho-silicate crystal (Eu:YSO), at cryogenic temperature (below 4 K). We have recently reported a double heterodyne detection regime which demonstrates a detection noise compatible with $4\text{x}10^{-16}$ fractional frequency stability at 1s, and we have effectively demonstrated laser fractional frequency stability at 1.7 x 10^{-15} at 1s. We have experimentally evaluated mechanical-deformation-induced frequency shifts of the spectral holes in Eu:YSO, which allows deducing the acceleration sensitivity of the setup, and, in the future, optimizing the design of the crystal mount. We have also quantitatively studied the effect of externally applied electric fields. Furthermore, the sensitivity of the resonant frequency to temperature changes was evaluated. A special environment where the crystal is staying in a cold He gas-filled chamber was implemented. In this environment, temperature changes induce a change of He pressure applied to the crystal. Temperature changes therefore modify the resonant frequency by two processes: direct temperature-sensitivity-induced shift, and, in parallel, pressure-change-induced shift. For a "magic"pressure-temperature couple these two processes can result in a first-order global cancellation of the temperature sensitivity of the frequency of the spectral hole which we have recently shown experimentally.

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