Evaluation of an ultra-stable laser system based on a linewidth transfer method for optical clocks

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We have developed Yb and Sr optical lattice clocks at the national metrology institute of Japan (NMIJ) [1,2,3]. The hyperfine-induced electric-dipole $^1S_0$-$^3P_0$ transitions in Yb and Sr have natural linewidths on the order of 10 mHz and are therefore suited to be clock transitions of optical clocks. To observe the clock transition in atoms efficiently, a high-finesse optical cavity is used to narrow the laser linewidth. In order to operate several optical clocks with different atomic species, ultra-stable optical cavities have to be developed for each atom traditionally, so that it requires a great deal of work with technical skill. An attractive way to overcome the difficulties and to save cost for great optical cavities would be to transfer the linewidth and frequency stability to other frequencies using optical frequency combs [4,5]. In this paper, we describe our narrow-linewidth laser system for optical clocks by using a fibre based optical frequency comb, which is stabilised to an ultra-stable Nd:YAG laser operated at 1064 nm.

We have carried out two experiments to characterise the narrow-linewidth laser system as follows: one is beat frequency measurement between the stabilised optical frequency comb and another ultra-stable laser and the other is atomic spectroscopy of the clock transitions in ultra cold Yb and Sr. A diode laser operated at 1.5 μm is stabilised to another optical cavity and then a heterodyne beat between the 1.5 μm laser and the optical frequency comb was detected. The stability of the beat note as measured by the fractional Allan deviation is about 2×10^{-15} at 1 s averaging time, which almost coincides with the estimated thermal noise limit [6]. We have used the clock laser system for atomic spectroscopy and successfully observed the Zeeman components of the $^1S_0$-$^3P_0$ transitions in ^{171}Yb and ^{87}Sr in a homogeneous magnetic field. The observed linewidth of the atomic transitions are about 50 Hz and 10 Hz for ^{171}Yb and ^{87}Sr, respectively, which are limited due to the power broadening and the interrogation pulse width, respectively.

The optical frequency ratio measurements will be important for evaluation of the optical clocks, because optical frequency standards have already surpassed the primary standards. From this point of view, the new narrow-linewidth laser system using the optical frequency comb should be an attractive apparatus and could contribute to process for the re-definition of the SI unit of time.

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