Development of a Clock Laser of Ca^+ Ion for the Optical Frequency Standards

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Abstract: A narrow linewidth diode laser is being developed. The laser linewidth is reduced to 66 Hz. The long term frequency drift is reduced 0.5 Hz per second, measured by Gigajet 20W optical frequency comb.

OCIS codes: (140.2020) Diode Lasers; (140.3320) Laser cooling

1. Introduction

We are developing an optical frequency standard based on the $S_{1/2}$ –$D_{5/2}$ quadrupole transition (729 nm) of a single Ca^+ ion confined to the Lamb-Dicke regime [1]-[2]. This standard has a principal advantage on its narrow 0.13 Hz electric quadrupole transition linewidth and a practical advantage on the availability of light sources using only the fundamental waves of compact and robust diode lasers (LD) for a whole process of the cooling, repumping and probing [3]. A clock laser system is being developed with two parts: the first is reducing the linewidth of a diode laser (master laser); and the second is offset locking a slave laser to the stabilized master laser. The long term stability of the laser system is also evaluated by an optical frequency comb.

2. Stabilization of the clock laser

Our master laser system is based on a 5 mW, antireflective coated (AR) laser diode with a center wavelength at 730 nm. The free-running linewidth of the solitary laser is substantially reduced by employing an extended cavity diode laser (ECDL) setup in Littman-Metcalf configuration. In order to compress the spectral linewidth extremely and suppress the frequency drift of the ECDL, the laser is actively stabilized to an ultrahigh-finesse ultralow expansion glass (ULE) Fabry-Perot reference cavity by employing a frequency modulation (FM) sideband technique. We choose an ULE reference cavity whose free spectral range is 1 GHz and finesse is 6×10^4 (it corresponds to a 17 kHz spectral linewidth). It is very important to isolate the ULE reference cavity against acoustic, thermal and mechanical perturbations. We set the ULE optical cavity into a constant temperature vacuum chamber and the vacuum chamber is put on vibration isolation platform (nano-k 250BM-3 type) with an acoustic isolation box.

The laser light is coupled to a polarization maintaining single mode fiber (Fujikura) to obtain a single spacial TEM_{00} mode. Then the laser beam is mode matched to the ULE reference cavity. The reflected light from the cavity is detected, demodulated, amplified, and fed back to the ECDL (master laser). A slow feedback loop (~ several hundreds Hz)-driving the PZT of the ECDL mirror – adjusts the laser frequency to a reference cavity resonance. Fast frequency fluctuations are compensated by superimposing the feedback current signal onto the laser cathode, obtaining a 1 MHz total servo bandwidth. The master laser is stabilized to the ULE optical cavity.

For an evaluation of the linewidth of the master laser, we have measured the heterodyne beatnote between two narrow linewidth master lasers, individually stabilized to two independent ULE reference cavities. Figure 1 shows a beatnote signal of the stabilized lasers. Its linewidth is 94 Hz, it corresponds a 66 Hz linewidth for each laser, assuming the same linewidths.

For the frequency fixed master laser, the frequency of the slave laser is set with an arbitrary RF frequency difference using an optical phase-locked loop. A beatnote between the master and the slave laser is detected by a fast photodiode and an RF frequency is set by a signal generator. The phase difference between the beatnote and the local oscillator is demodulated and fed back to the slave laser. Its offset frequency should be tunable relative to the fixed-frequency of the master laser system in a whole free spectral range of the 1 GHz. The feedback method is similar to that of the master laser. The slave laser is offset locked to the stabilized master laser.

The linewidth of the slave laser has been evaluated by measuring a beatnote signal of the master laser and the slave lasers. The -3dB full linewidth of the beatnote is 1.3 Hz. This value is closed to the resolution of spectrum analyzer (1 Hz, 8560E Hewlett Packard). This shows that the linewidth of the slave laser is practically identical with that of the master laser. A ±500 MHz offset locking has also been confirmed. As mentioned above, the free spectral range is 1 GHz for our ULE cavity. The frequency tuning range covers the whole free spectral range of the ULE reference cavity.

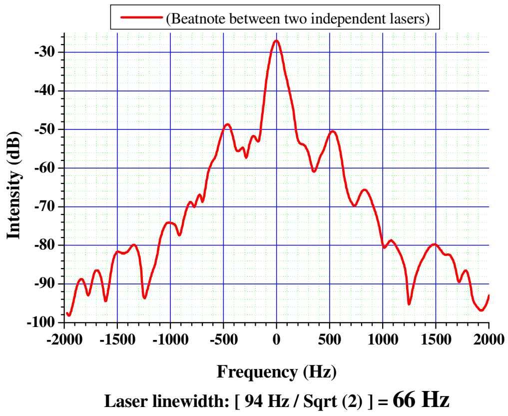

Figure 1: Beat spectrum between two independent diode laser system

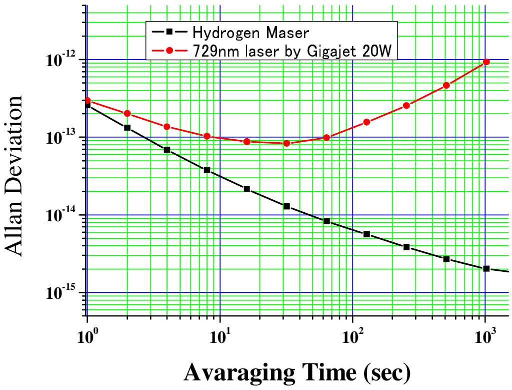

Figure 2: Measured frequency instabilities as given by the Allan deviation for a 729 nm clock laser stabilized to an optical cavity. A hydrogen maser is used as frequency reference for Gigajet 20W optical comb.

We also evaluated the long term stability of the laser system, employing a Gigajet 20W femtosecond laser frequency comb. This comb system is stable and precise, because no photonic crystal optical fiber is used for broadband spectrum. We measured the beat-note frequency between the laser beam and the optical frequency comb. The square root of the Allan variance of the measured beatnote frequency is shown in Fig.2. The measurement shows the frequency stability of 2×10^{-13} in Allan deviation at an averaging time of 1 s. In this measurement, the short term stability limited by that of the hydrogen maser used as the frequency reference. The floor of the Allan variance is 8.3×10^{-14} at an averaging time of 32 s. This measurement shows that the long-term frequency drift is 0.5 Hz per second, by choosing the temperature of the ULE cavity. We have obtained three times smaller drift than before [4].

3. Conclusion

We are developing a clock laser system for a quadrupole transition of a single Ca^+ ion. Presently its linewidth is 66 Hz, the narrowest one by diode laser in this wavelength ever. The floor of the Allan variance is 8.3×10^{-14} at an averaging time of 32 s. The long term stability is improved to be 0.5 Hz / s. For the manipulation and spectroscopy of a single Ca^+ ion, the slave laser frequency is continuously tunable with an RF frequency range of ±500 MHz covering whole free spectral range of the ULE reference cavity. Its linewidth is the same as the stabilized master laser. A clock laser system is being improved further, aiming the linewidth below 1 Hz.

4. References

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