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New stabilization method of atomic clock with detecting the maximization of coherent-population-trapping resonance signal

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1. Background

In recent years, IoT and relating sensing mobility devices have already been widely exploited in commonplace. Accordingly the numbers of devices connected to the Internet have been rapidly increasing. Such inclination is expected to strain availability of series of bandwidths of wireless network to a great extent in the near future.

One approach to mitigate the problem is conceivably to enhance the accuracy of location identification of each devices by further developments of highly precise time synchronization. Furthermore, improving spatial multiplexing technique of wireless communication by sophisticated directional radio transmission is also presumed to be a valid solution.

To achieve more accurate time synchronization, chip-scale atomic clocks which can be installed into IoT devices and mobility devices have been developed[1)]. In atomic clock based coherent-population-trapping (CPT), 2 kinds of controlled parameters, a laser's wavelength and modulation frequency generating its sidebands, are essential factors for its stable operation. In the case of typical atomic clock, modulation frequency is stabilized by detecting CPT resonance signal. The wavelength of laser is stabilized by detecting absorption lines obtained from alkali metal cell.

However, when alkali metal cells like MEMS based chip-scale gas cells are targeted, to make stabilizations of these factors becomes significantly difficult because both detectable signals of CPT resonance and absorption lines are exceedingly tiny.

In addition, it is known that, in the case of atomic clocks consisted of rubidium gas, frequency value of peak absorption line and maximum CPT resonance are different2). Which means, CPT resonance frequency is not in its optimal stabilization condition under the conventional stabilization method.

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As an effective proposal to solve these issues, we propose a novel method that simultaneously stabilizes modulation frequency and laser wavelength by maximizing the CPT resonance signal without detection of absorption lines.

2. Methods

Block diagram of the proposed technique is shown in Fig.1.

Feedback loop 1 stabilizes modulation frequency output from the RF generator, and feedback loop 2 stabilizes laser wavelength. Output signal of RF generator is phase-modulated (PM)[3)]. CPT resonance signal is detected by lock-in amplifier (LA)1 with synchronized signal from PM. For stabilization, carrier frequency of the RF generator is controlled, then output signal of LA1 becomes zero. At the same time, output signal of the detector becomes twice of the one of PM's frequency. Amplitude of the CPT resonance signal is detected by LA2 based on second harmonic frequency from PM as a reference signal. Laser current is amplitude-modulated (AM) with frequency of 1.23 kHz, sufficiently smaller than frequency of phase modulation, 98.7 kHz. While frequency content of PM is filtered-out, frequency content of AM is output from LA2 with proper setting of low pass filter in LA2. Synchronous detection is performed by AM's synchronous signal at LA3. When the

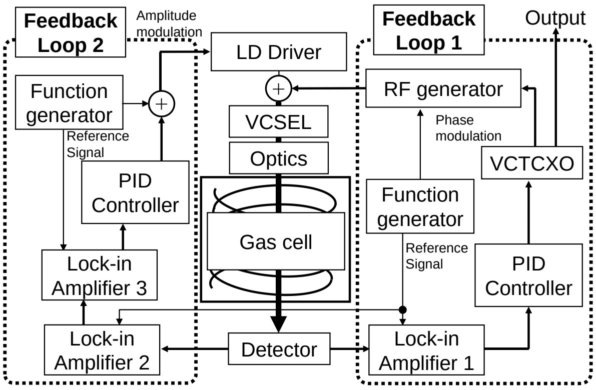

Fig.1 Block diagram of proposed stabilization system.

CPT resonance is maximized, output of lock-in amplifier 2 is also maximized, then output of lock-in amplifier 3 becomes zero. In whole sequences, laser wavelength is stabilized by feedback control based on the output signal of LA3.

As a c s onsequence, modulation frequency and laser wavelength can be stabilized by CPT resonance signal, only.

3. Results

Fig.2 indicates measured signals of LA2 and LA3 when laser current is still varied. Vertical Cavity Surface Emitting Laser (VCSEL) is used as a laser light source, and its wavelength changes in proportion to driving current of VCSEL. Output signal of LA2 measures a change in the amplitude of CPT resonance as laser's driving current varies, and LA3 outputs zero signal at its maximum. The same signal is input to the laser driver equipped with PID controller to stabilize laser's driving current and wavelength.

Fig.3 shows measurement results of Allan standard deviation. Rectangle-plotted curve is the result obtained by our proposed method. Compared to circle-plotted curve, the measurement result without laser wavelength stabilization, long-term stability is significantly improved. These data indicates that the feedback control in our proposed method using only CPT resonance is well effective. In the comparison with crosshairs-plotted curve, the measurement result of conventional stabilization method, the short-term stability at 1 second is improved in our proposal method, which may imply the improvement in signal-to-noise ratio of CPT resonance signal in the proposal method. In addition, the proposed method shows the better result in the sense of long-term stability, too.

4. Conclusion

We proposed a novel method, without detecting absorption lines, stabilizing the wavelength of laser and modulation frequency in a state of maximum CPT resonance signal. The proposed method shows satisfactory measurements and comparisons results of Allan standard deviation. By the proposed method, maximizing the signal of the CPT resonance, desirable and practical performance of chip-scale CPT-based atomic clocks is strongly anticipated.

One concern is, the proposed method requires one more set of lock-in amplifier than the conventional method.

However, in the case of chip-scale atomic clocks which will be embedded into IoT or related mobile devices, each lock-in amplifiers are probably required to be implemented as a form of integrated circuit like FPGA. Therefore, addition of one more set of lock-in amplifiers is not considerable issue.

Thus, the proposed method is still one of the promising candidate to be applied to commercial tip-scale atomic clocks in near future.

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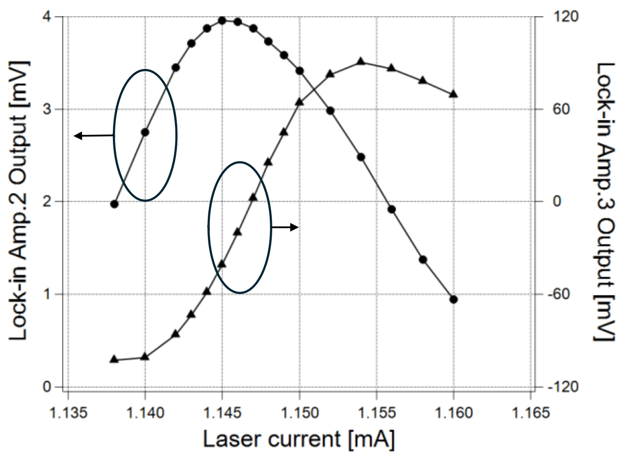

Fig.2 Output signals of LA2 and LA3 with laser drive current varied.

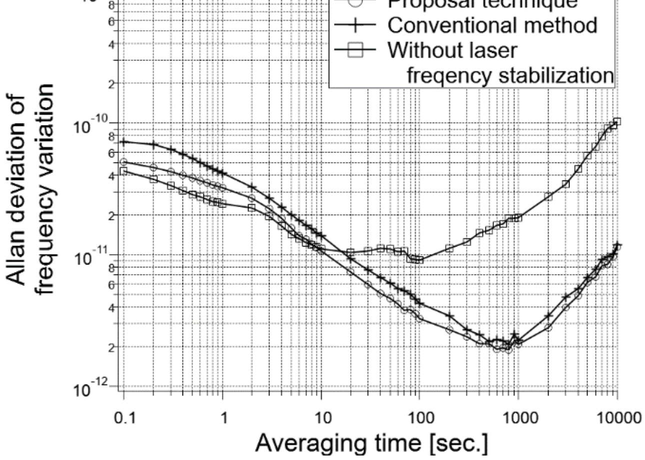

Fig.3 Measurement results of Allan standard deviation.