Application of an Er: Doped Fiber Comb for Sr Lattice Clock

Meng Fei[1] Cao Shiying[1] Zhao Guangzhen[2] Zhao Yang[1] Fang Zhanjun[1]

[1] *Divsion of Time and Frequency Metrology, National Institute of Metrology, Beijing* 100029, *China*

[2] *Department of Precision Instrument, Tsinghua University, Beijing* 100084, *China*

Abstract For measurement of the ^{87}Sr lattice clock probe laser frequency and controlling the red cooling laser and lattice magic wavelength etc, a frequency comb based on a mode-locked erbium fiber laser is built and locked to H-maser. The measurement realizes strong output at desired wavelengths, including 689, 698 and 813 nm (acquire at different time in one branch). The total visible spectrum power is about 120 mW and the power in the single frequency is more than 200 μW within 2 nm (full width half maximum). The beat signal between the comb tooth and the external laser with a signal-to-noise ratio is up to 30 dB (300 kHz resolution bandwidth). The tracking stability is better than 60 mHz at 1 s.

Key words fiber optics; metrology; fiber frequency comb; spectrum expansion; laser stabilization

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掺铒光纤光梳在锶晶格钟中的应用研究

孟 飞[1] 曹士英[1] 赵光贞[2] 赵 阳[1] 方占军[1]

[1] 中国计量科学研究院时间频率所, 北京 100029

[2] 清华大学精密仪器系, 北京 100084

摘要 为了测量 ^{87}Sr原子光晶格钟的钟激光频率和控制红冷却激光及光晶格激光的绝对频率,实验建立了一套掺铒光纤光学频率梳系统,并将其锁定到了氢钟参考信号上。光梳的可见光测量部分对 689、698 及 813 nm 等特定波长功率进行了优化(在同一扩谱支路中不同时获得),其输出光谱功率大于 120 mW,单点频率下的功率在 2 nm 宽度时大于 200 μW。实验得到的外激光和光梳梳齿拍频信号信噪比大于 30 dB(在分辨率带宽 300 kHz 时观测),锁定后频率跟踪秒级稳定度优于 60 mHz。

关键词 光纤光学; 计量标准; 光学频率梳; 光谱扩展; 激光稳频

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1 Introduction

Compared with Ti: sapphire comb, fiber frequency combs have the advantages of small size, low price, easy maintenance, high stability and environmental robustness, which make them useful in many fields, such as frequency metrology[1-4], precise measurement of optical spectroscopy, absolute distance measurement, and ultrastable microwave generation.

A ^{87}Sr optical lattice clock at NIM[5-6] is developed. For measurement of the clock transition frequency and controlling the red cooling laser and lattice magic wavelength etc, a fiber frequency comb based on a mode-locked erbium fiber laser[7-9] is built. The efficient visual optical spectrum expansion technology and the optical offset-locking loop is used in this equipment.

2 Er:doped fiber frequency comb

The fiber frequency comb is shown in Fig.1. DFD: digital frequency discriminator, Amp.: low noise amplifier, PPLN:

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作者简介: 孟 飞(1979—),男,硕士,副研究员,主要从事光学频率梳方面的研究。E-mail: mfei@nim.ac.cn

periodically poled MgO∶LiNO$_3$ (fan-out type), Cpl. :fiber coupler, AL: aspheric lens, Syn. : microwave synthesizer. This oscillator employs nonlinear polarization rotation (NPR) as the mode-locking mechanism and is operated at a repetition rate of 128 MHz at a central wavelength of 1560 nm. The average output power is more than 50 mW.

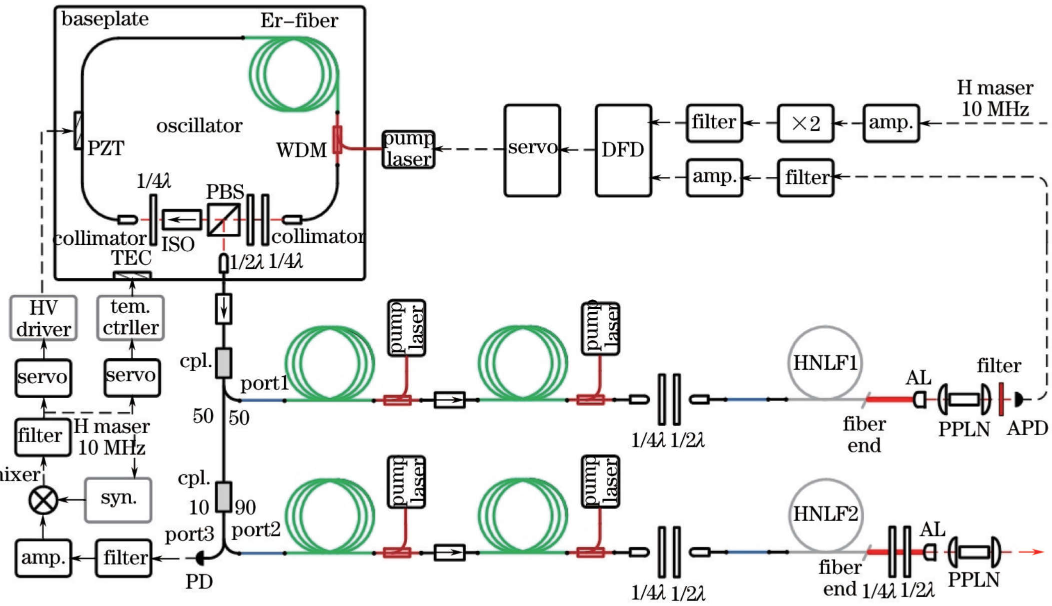

Fig.1 Schematic diagram for the frequency stabilization of the fiber comb

The output from the oscillator is split into two parts by a fiber coupler and sent to the self-referencing and the measurement branches respectively.

In the self-referencing arm, the optical pulses are amplified to more than 300 mW by two stage amplifier and are compressed to approximate 160 fs before broadened to cover an octave-spanning spectrum from 1100 nm to 2200 nm in HNLF. The beat signal f_{ceo} is detected by a collinear self-referencing interferometer, which employs a 2 mm long periodically poled MgO∶LiNO$_3$ crystal and an InGaAs APD. The signal-to-noise ratio (S/N) of the offset signal is typically 35 dB [300 kHz resolution band width (RBW)].

The measurement arm is expanded from IR spectrum to visible range and realized strong output at desired wavelength, including 689, 698 and 813 nm, which meet requirements of the ^{87}Sr lattice clock. The total spectrum power after amplification is about 200 mW and the power in single frequency is more than 200 μW within a full width half maximum (FWHM) of 2 nm. The spectrum is shown in Fig.2. The S/N of the beat signal between the comb tooth and the external laser is up to 30 dB (300 kHz RBW). The continuous wave (CW) laser's output power is more than 1 mW.

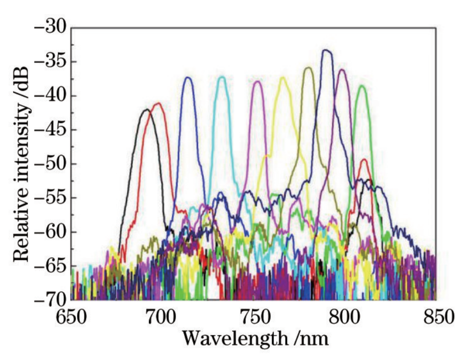

Fig.2 Expansion visible spectra after HNLF (no acquire at the same time in one branch)

The 7th harmonic of the comb repetition rate frequency is locked to a low phase noise synthesizer which is referenced to the NIM H-maser. The residual fluctuation of the stabilized signal f_{rep} is 0.49 mHz (1σ,1s gate time), corresponding to a relative instability of 4.9×10^{-13}[7]. The locking servo system controls both the ring laser cavity length and the laser baseplate′s temperature. This fiber comb is continuously locked over one month in the lab condition.

3 External CW laser frequency stabilization

The beat note between the output from the measurement arm and the external CW laser (813 nm ECDL) is about 20MHz with a S/N up to 30 dB (300 kHz RBW). The CW laser is a home-made ECDL with Littman configuration, and the output power for beating is more than 1 mW. An optical phase-locked loop is employed to lock the laser (813 nm ECDL) frequency to the comb tooth as shown in Fig.3. Syn.: microwave synthesizer, Grating: 1800 lines grating, Optical filter: 2 nm (FHWM), PBS: polarization beam splitter.

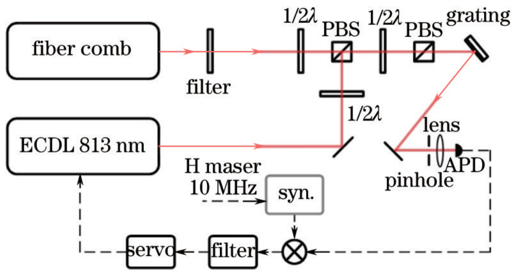

Fig.3 Schematic diagram for the frequency stabilization of the CW laser

The beat note signal and a local 20 MHz signal that referenced to the H-maser mixed by a digital phase discriminator[7,10] . The error signal which feeds back to the laser controls the diode current and the cavity piezo voltage.

For eliminated tracking stability of the locked external laser, the measured residual frequency fluctuations of the 20 MHz signal is shown in Fig.4(a), which shows one standard deviation of 53.7 mHz.

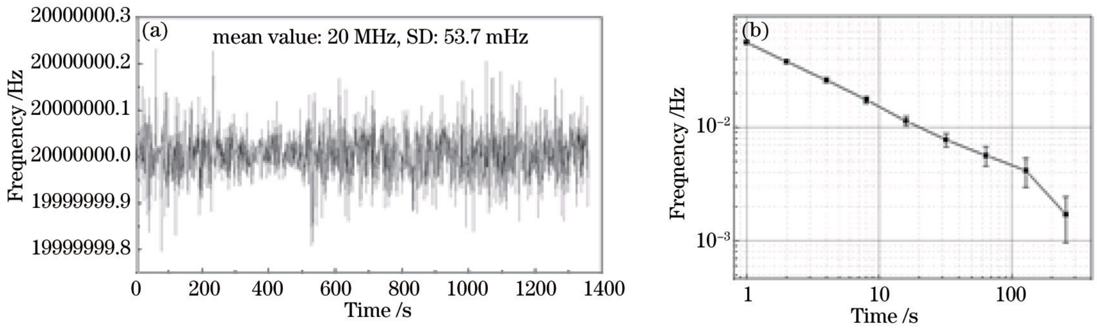

Fig.4 (a) Residual fluctuations of the beat signal between comb tooth and CW laser (in-loop, gatetime:1s); (b) calculated frequency stability

4 Conclusion

A home-made Er: doped fiber frequency comb is demonstrated which is employed to measure and control the laser absolute frequency for Sr optical lattice clock. It is realized that the power increasing at special frequency points within the comb′s output expanded spectrum. The external CW laser frequency is locked faithfully to the comb tooth.

The further work contains multi-frequency locking simultaneously and comb teeth linewidth reduction.

References

1 Florian Adler, Konstantinos Moutzouris, Alfred Leitenstorfer, *et al.*. Phase-locked two-branch erbium-doped fiber laser system for long-term precision measurements of optical frequencies[J]. Optics Express, 2004, 12(24): 5872-5880.

2 Ryu H Y, Lee S H, Lee W K, *et al.*. Absolute frequency measurement of an acetylene stabilized laser using a selected single mode from a femtosecond fiber laser comb[J]. Opt Express, 2008, 16(5): 2867-2873.

3 H S Margolis, G P Barwood, G Huang, *et al.*. Hertz-level measurement of the optical clock frequency in a single $^{88}Sr^{+}$ ion[J].

Science, 2004, 306(5700): 1355−1358.

4 Lin Baike, Cao Shiying, Zhao Yang, *et al*.. A compact iodine−stabilized solid−state laser at 532nm[J]. Chinese J Lasers, 2014, 41(9): 0902002.

5 Lin Yige, Wang Qiang, Li Ye, *et al*.. Magnetic field induced spectroscopy of ^{88}Sr atoms probed with a 10 Hz linewidth laser[J]. Chin Phys Lett, 2013, 30(1): 014206.

6 Zhao Yang, Li Ye, Peng Yu, *et al*.. Stable second harmonic generation 461 nm blue radiationby PPK TP crystal[J]. Acta Optica Sinica, 2009, 29(9): 2473−2478.

赵 阳, 李 烨, 彭 瑜. 用周期极化KTP晶体高效倍频获得稳定461 nm激光[J]. 光学学报, 2009, 29(9): 2473−2478.

7 Meng Fei, Cao Shiying, Cai Yue, *et al*.. Study of the femtosecond fiber comb and absolute optical frequency measurement[J]. Acta Phys Sin, 2011, 60(10): 100601.

孟 飞, 曹士英, 蔡 岳. 光纤飞秒光学频率梳的研制及绝对光学频率测量[J]. 物理学报, 2011, 60(10): 100601.

8 Cao Shiying, Meng Fei, Lin Baike, *et al*.. Precise frequency control of an Er−doped fiber comb[J]. Acta Phys Sin, 2012, 61(13): 134205.

9 Cao Shiying, Meng Fei, Lin Baike, *et al*.. Experimental study on detection of the high signal−to−noise ratio of the carrier−envelope offset frequency in an Er−doped fiber femtosecond laser[J]. Acta Phys Sin, 2012, 61(6): 064208.

10 Li Luming, Tang Wenzhuo, Hu Zhenyan, *et al*.. Realization of optical phase locked loop at 9.2 GHz between two independent diode lasers[J]. Chin Phys Lett, 2008, 25(9): 3253−3256.

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