A 10GHz tunable laser system for multi-isotope laser cooling, trapping and optical control

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Introduction

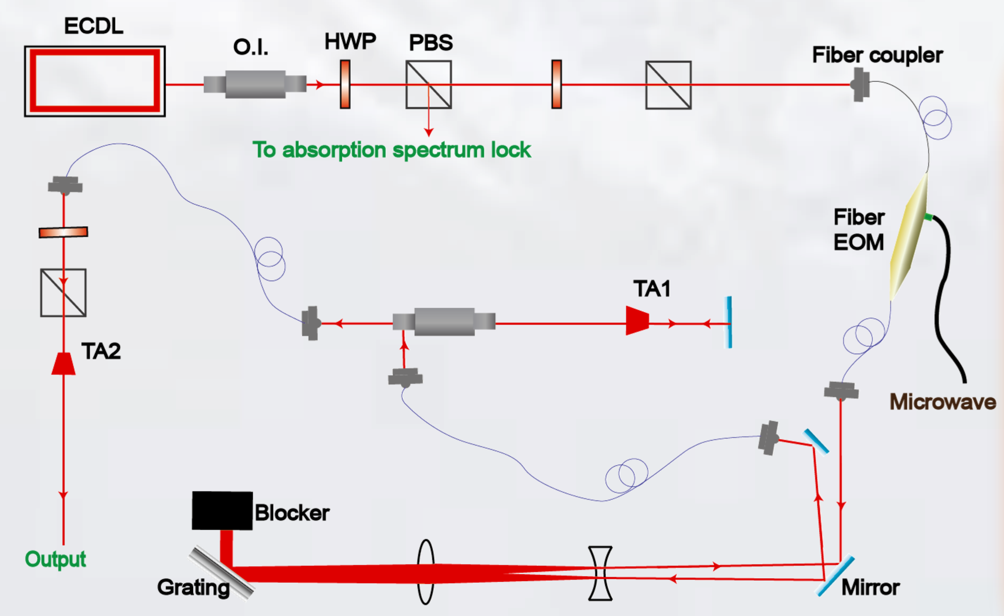
To produce laser-cooled atomic sample and for its applications in precision measurements, multiple lasers with frequencies separated by a few GHz are usually required to simultaneously fulfill different functions.

- Chirped laser slowing
- Magneto optical trap of multiple isotopes
- Efficient polarization gradient cooling
- Photo association control
- Light pulse atom interferometry

The GHz-level frequency separation is too large to be conveniently achieved by regular modulation methods. Usually, several lasers are needed to realize the functions. The complex setup and locking schemes may lead to compromised stability of the setup.

In this work, we develop a compact and robust laser system with a modulation bandwidth of 11GHz (FWHM) to fulfill all the requirements. The system is based on fiber-EOM modulation followed by spectrum-filtering and optical amplifications. The system is tested in daily operation of Fudan Ultracold lab, as well as in a mixer MOT experiment discussed in this work.

Optics setup



Schematic diagram of optics setup

A 780nm Laser from an external cavity diode laser (ECDL) is modulated by a fiber-EOM. The output beam is expanded to 10 mm waist and then diffracted by a large (50mm × 50mm) grating (2400 lines/mm). A single mode fiber picks up the requiring sideband and the modulated light is seeded into a double pass Tapered amplifier (TA). The output is further amplified by a second TA to 1W.

Key points and challenges

- Fiber-EOM： A wide-band phase-modulation device widely used in telecommunication applications. Based on electric-optical effect, the device has a bandwidth of up to 40GHz.
- Grating filter: The EOM output contains a series of frequency components. This beam is expanded and diffracted by a large area grating. The desired frequency component is picked up by a single mode fiber
- TA double pass: Unfortunately, fiber-EOM has a low power throughput of a few miliwatts at NIR. We amplify this low power seed with a semi-conductor optical amplifier in a double-pass configuration.

Bessel expansion of the modulated term

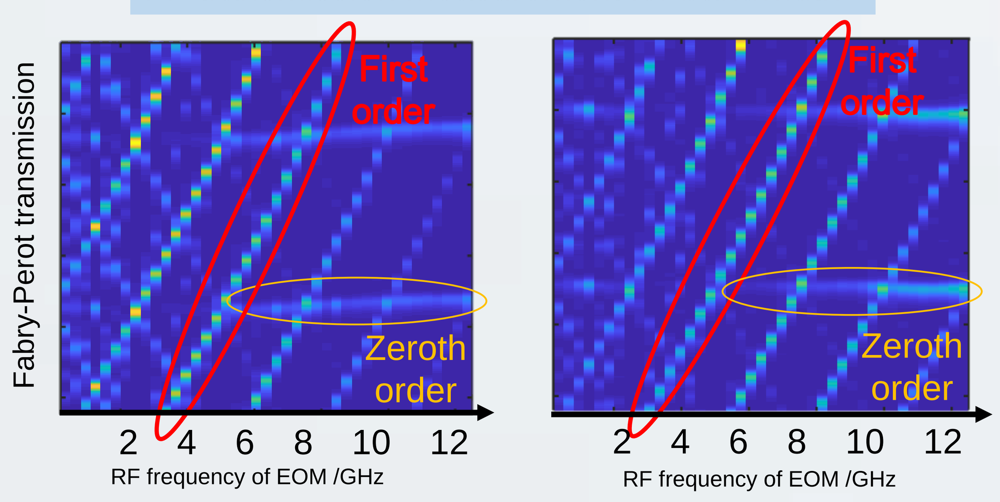
$$E_l(t) = A_l e^{i(\omega t+\phi)} \sum_{n=-\infty}^{\infty} i^n J_n(b) e^{in(\omega_m+\phi_m)}$$

Electric field of light

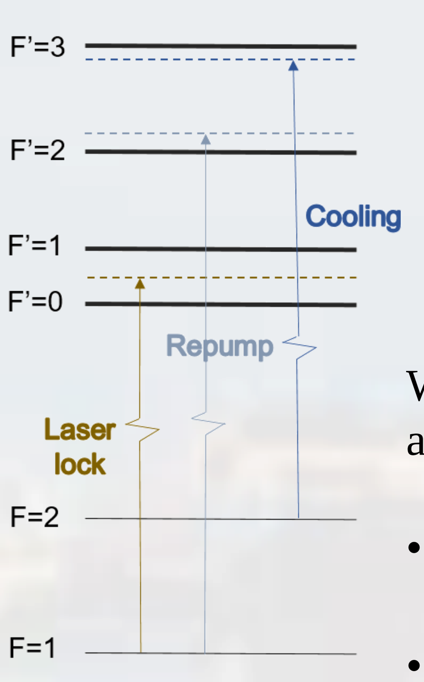
Bandwidth measurement

We measure the ratio of each sidebands by the transmission spectrum of a Fabry-Perot cavity. At each modulation RF frequency, we record the spectrum on the scope. Multiple transmission curves are assembled into a 2D map. we do measurements both before and after the optical amplification. The grating filter has a bandwidth of ~8 GHz(FWHM). Taking advantage of the amplification nonlinearity, the bandwidth is enhanced to ~11GHz after the amplifier.

FP transmission measurement for bandwidth



A novel mixer MOT configuration



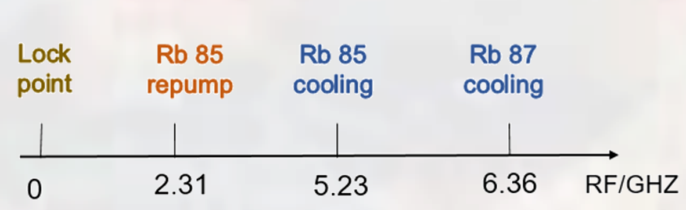
Relevant transitions for ^{87}Rb cooling

MOT(magneto-optical trap) is a common method to produced a cold atom sample. Usually, two frequencies of laser are used to generate a MOT.

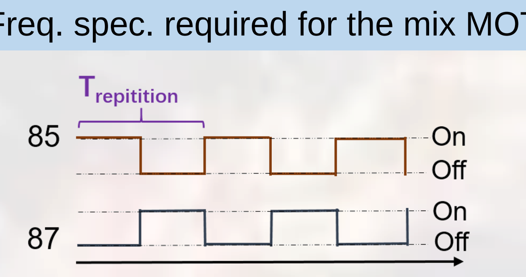
- Cooling laser: red detuning to a cycling transition to keep atoms continuously interaction with it
- Re-pumping laser: reduce the population of non-cycling transition ground state

We switch the frequencies of the laser to alternatively cool the two isotopes.

- Cooling one isotope at a time to avoid cross-talk
- Pulse-timing degree of freedom for future cooling efficiency optimization
- Question to explore: How quick can we switch between the two cooling frequencies?

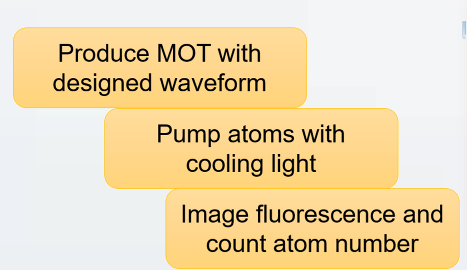


Freq. spec. required for the mix MOT



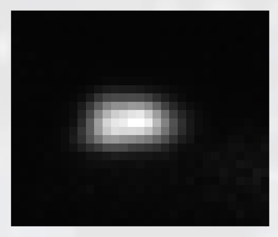
The amp. modulation scheme for the mix MOT

Mixer MOT: experimental results



We alternatively excite ^{87}Rb and ^{85}Rb with cooling pulses. The time period T_{rep} is changed from 1ns up to 10μs. Then we excite the atoms with cooling light and collect fluorescence with a camera. Atom number is calculated from the fluorescence.

Doppler cooling relies on cycling transition. Excitation to non-cycling transition rapidly quench the atom to hyperfine level that do not interact with the cooling laser, leading to inefficient cooling. In addition, the cooling laser needs to be tuned to the red side of the cycling transition for the Doppler cooling effect. We calculate scattering rates for different types of excitations due to multiple sidebands of the interleaved pulses, and use a figure-of-merit R_s to gauge the expected quality of cooling.

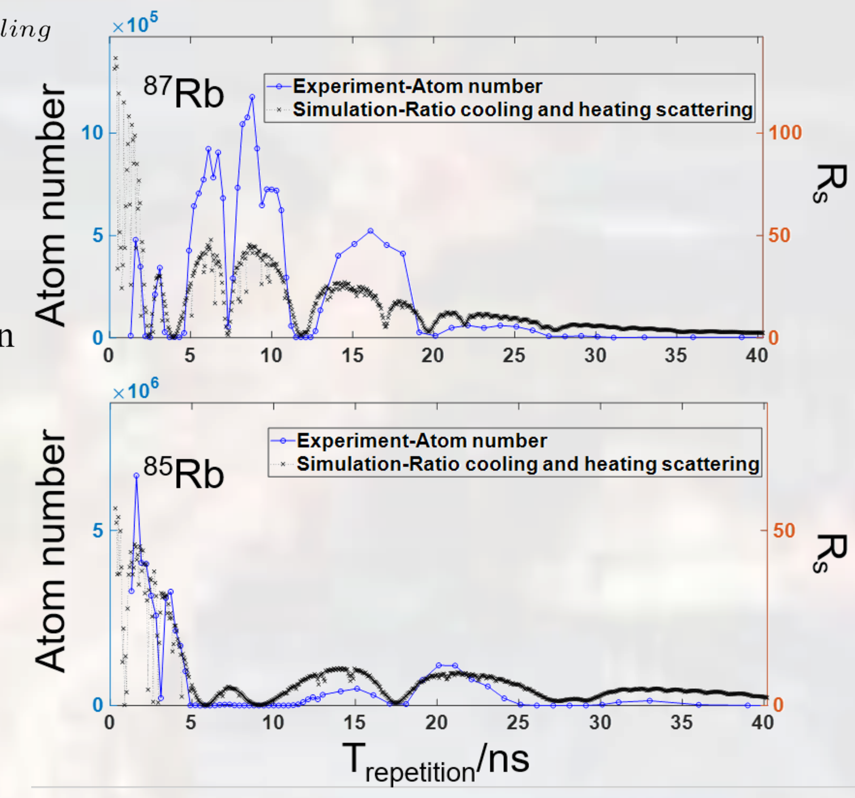

MOT fluorescence image

$$R_s = \frac{\Gamma_{cycling-red}}{\Gamma_{cycling-blue} + \Gamma_{cycling-resonant} + \Gamma_{non-cycling}}$$

In this equation, scattering rates are classified to these types:

- $\Gamma_{cycling-red}$: red detuning to cycling transition
- $\Gamma_{cycling-blue}$: blue detuning to cycling transition
- $\Gamma_{cycling-res}$: resonant to cycling transition
- $\Gamma_{non-cycling}$: non-cycling transition

Features of calculated R_s and measured atom number matches very well.



Atom number and simulated R_s when scanning $T_{repetition}$

Summary and outlook

We develop a wide-band tunable laser system based on side-band modulation of a CW laser using fiber-based Electro-Optical Modulator (fEOM). By filtering out the undesired sidebands with a large area grating, the sideband with desired frequency is amplified up to 1W of laser power, with frequency tuning bandwidth of 11GHz (FWHM), and with power controlled by the sideband modulation with excellent dynamic range. Assisted by controlling microwave electronics, the phase-coherent multi-frequency output can be generated either simultaneously or in interleaved fashion. To demonstrate the unique application of the laser system, we study mixer MOT of ^{87}Rb and ^{85}Rb atoms in a previously unexplored configuration with interleaved nanosecond pulses that cool one isotope at a time. This system, with its versatile tunability and long-term stability, should have useful applications in cold atom technologies.

Funding and references

This project is supported by National Key Research Program of China (2017YFA0304204) and Shanghai Scientific Research Program (15ZR1403200).

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