Optical lattices with low decoherence for ultracold ^{6}Li

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We describe the design of a stable high power 1064 nm laser for use in optical lattice experiments. The system is based on a high quality mephisto NPRO seeding an array of four heavily modified fiber amplifiers. The intensity of every beam is stabilized with a low noise, nonlinear feedback system, and the waist can be smoothly controlled.

I. INTRODUCTION

Trapping atoms in an array of optical lattices is a mature and powerful technique for manipulation and control of quantum many-body systems. The use of neutral atoms trapped in an optical lattice has facilitated precision measurements, creation of interesting many body states, and implementation of quantum gates in neutral atoms.

Optical lattices rely on the optical dipole force of light on neutral atoms and the interference of light. Depending on the laser wavelength and the atomic species used, atoms can be drawn toward or repelled by regions of high intensity.

$$V(\boldsymbol{x}) = \alpha(\omega)|\boldsymbol{E}(\boldsymbol{r})|^2 \tag{1}$$

When two or more laser beams are interfered, the interference pattern has a spacing $l > \lambda/2$. Different interference geometries provide a wide variety of lattice geometries that have been demonstrated.

By FIGURE - high level block diagram of system

- why cold atoms are great, and why you need lattice: clocks, hubbard etc
- what are the requirements of lattice
- what have we built

II. MEASURING INTENSITY NOISE

A. Photodiodes

FIGURE: Transimpedance amplifier, with our parameters

- Transimpedance amplifier - typical parameters
- design criteria, part numbers, typical voltage levels
- cutting off windows
- thermal stuff (inGas)
- lens or no
- using photodiodes for looking at these things

FIG. 1. (a) Layout of the seed source of the high power laser system, (b) Noise spectra of the Mephisto laser in various configurations

B. Measuring Power Spectral Density

FIGURE - maybe WINDOW FUNCTION

- FFT machine, spectrum analyzer window functions revisited, -resolution, video bandwidth

C. Residual Intensity Noise

RIN:

- what is it and how do you measure it
- easy to measure, enters into parametric heating effects

D. Heating Effects

- Trap shaking, parametric heating

III. FIBER AMPLIFIER SYSTEM

IV. SEED LASER

Mephisto:

- Mephisto basics - what is it and how does it work
- noise coming out of laser (w,w/0 noiseeater)
- noise coming out of a fiber (into nufern)
- Schematic of beam splitting

The high power laser system is seeded by a single Innolight Mephisto 1064 nm, ultra-narrow, low noise, nonplanar-ring-oscillator (NPRO) laser. Figure **??**<++>

V. FIBER AMPLIFIER MODIFICATIONS

We chose to use *Nufern* 50 W fiber amplifier systems (part number FIXME), due to their inexpensive price and relatively high performance in terms of power and intensity noise. In their default configuration, however, the fiber amplifiers suffer from several severe problems:

1. A large number of noise spurs at low frequencies.

2. A 30 FIXMEdB noise spur at the switching power supply frequency.

3. A built in power supply containing a cooling fan that vibrationally couples to the gain fiber.

4. An inconvenient USB digital interface.

In order to address these problems, the fiber amplifier had to be heavily modified. First, the two power supplies required by the fiber amplifier were moved outside its immediate enclosure an connected with 15 foot long AWG FIXMEcables. The pump diode driver, part number FIXMEwas unmodified, but the general purpose power supply was replaced with a low noise switching supply from Acopian Corporation, part number FIXME. A high power line filter, part number FIXME, was added to reduce the switching supply spike on the fiber amplifier by FIXMEdB.

Further, the control of the fiber amplifiers is done by a pair of printed circuit boards, where one primarily handles the USB communications, and the other communicates the power supplies and interlocks. The USB board was replaced by a custom board compatible with out experimental control system.

VI. FEEDBACK

VII. MEPHISTO LASER SYSTEM

FIGURE - MEPHISTO LAYOUT

A. Acousto-optic Modulation

FIGURE - RIN OF MEPHISTO, driven by difft oscillators Mephisto+oscillators

- how does the RIN spectrum change as a function of oscillators

VIII. FIBER AMPLIFIER SYSTEM

FIGURE - BLOCK DIAGRAM OF FIB AMP SYSTEM

A. Fiber Amplifier Modifications

FIGURE - SBS DATA

- Mephisto+Fiber amplifiers
- fiber amplifiers work like so so
- schematic what it looks like and does
- Modifications
  - electronics control board,
  - PSU's
  - filters
  - switching spikes removed
  - fan noise stopped
- Two stage amplifier
  - second stage has this special fiber
  - large mode area fibers
  - leakage into cladding modes
  - sbs (cut off)
- SBS data

IX. FIBER AMPLIFIER OPTICS

A. Fiber Amplifier Cleanup

- How to collimate and reject cladding modes - no dust in hp areas,
- FC compensate for cleave
- mechanical stable
- evidence of fiber tip shaking if there were fans inside changing collimator dist wrt fiber - focus about 80 cm - focus through aom - no movable optics between AOM and chuck
- mode quality - quote m^2
- mode shape changes dramatically with pump current (output power)
- thermal settling - run at full power continuously
- dump cladding modes
- optics have to handle full power - BK7 bad, fused silica good
- high quality IBS sputtered optics if you care
- brewster polarizers - glued cubes are terrible (contacted cubes expensive, supression ratio not as good) - 10k:1
- brewster plates walk the beam

B. Isolation

- backreflections are bad,
- retroreflection -> 2 stages
- as seen in ligo Yttg isolation decreases with optical intensity - coupling between optical effects and faraday
- not as bad as ligo, since not in vacuum.
- thorlabs -> high power 5mm aperture -> BK7 bad
- waveplate ibs coating
- Can of mumetal for physics reasons
- attenuation of field is XXXXX
- watercooling
- stack 2x

DUMPING -watercooled beamdumps far removed from the optics for thermal reasons

C. Intensity Control

2 Step intensity control

1. Berek Compensator

- high dyn range actuator
- berek compensator

custom coating quartz plate that is z-cut mounted on camtech galvo can act as translates rotation into polarization rotation with brewster polarizers can act as variable attenuation bias with waveplates BW = XXX attenuation = XXX induces walkoff

BEAM with well defined polarization on optical table M^2 = this, waist focused 80cm to a 650um, which is consistent with ABCD tracing

2. AcoustoOptic Modulation

- AOM is this 80MHZ, TeO2
- large active area AOM to reduce intenisty going through
- thermal problems
- watercooled
- custom flexure mount to minimize motional degrees of freedom.
- obtain a diffraction efficiency of M^2
- 20cm in front of AOM - diffraction process changes this - characterize this
- AOM's thermal effects pointing noise mostly. BW is traveling wave such and such speed of sound.
- shut off time is 500ns
- polarization is negligible
- POINTING is stable.

X. FEEDBACK

- galvo
- aom
- AR pickoff
- PD - lenses and imaging
- Loop filter sqrt
- Exponential
- Pump current

XI. TELESCOPE

-beam parameters such and such

XII. ALIGNMENT TRICKS

XIII. WAIST CONTROL

XIV. APPENDIX: FOURIER TRANSFORMS AND POWER SPECTRAL DENSITIES

- FT
- PSD
- FFT?
- Window functions, discretization effects

XV. APPENDIX: FEEDBACK THEORY

mini feedback tutorial