Frequency Doubled Diode Laser Decelerating Calcium Atoms to Load a Magneto Optical Trap

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Abstract

We present a frequency doubled extended cavity diode laser used to decelerate Calcium atoms from an atomic beam in order to load a Magneto Optical Trap (MOT). We doubled the frequency of an 80mW diode laser using a KNbO$_3$ crystal placed inside an external power enhancement cavity. This laser provides up to 16mW of useful power at 423nm that can be continuously tuned in a range of 1GHz. Using a fast photodetector we have determined the linewidth of the diode laser by a beat-note measurement with a stabilized Ti:Sapphire laser. The optimum detuning for the deceleration and the trapping beam, to maximize the number of atoms, were determined using the beat-note. We have then observed an increase by a factor of two in the number of trapped atoms, in comparison with the case where the decelerating and trapping beams are derived from the same laser.

Introduction

High resolution atomic and molecular spectroscopy requires single-mode and tunable lasers. Diode lasers, particularly attractive because of their low cost and long lifetime, generally do not fit this requirement, but can be forced to oscillate single-mode when used in extended cavity configurations [1, 2]. Although their tuning range is acceptable for most applications, they are available only in certain wavelength regions. In particular, laser cooling and trapping of alkaline-earth atoms, as Calcium, is one example that requires tens of miliwatts of single-mode laser power in blue-violet region. In spite of the recent progress on development of diode lasers emitting in the blue region of the spectrum [3], the commercially available devices have still relative low power and the spectral range covered by them is rather limited. Thus, nonlinear frequency generation is still the solution to cover a broader range with high power.

Hot atoms leave an oven in an atomic beam. A laser beam decelerates them and the coldest atoms can be trapped in a MOT. The MOT is performed by three sets of two counter-propagating laser beams crossing each other at the center of the magnetic field generated by anti-Helmholtz coils. Generally the cooling and the trapping beams come from the same source, where the cooling beam has often its frequency shifted by an acoustic optical modulator (AOM). The detuning of the beams, their intensities, and the gradient of the magnetic field determine the number of atoms trapped in the MOT. With the laser beams coming from different sources their frequencies are independent, allowing optimizing the number of trapped atoms.

In the present work we first describe an alternative configuration for the extended cavity, consisting of a dispersing prism and a thin glass plate, used with a quantum well AlGaAs diode laser. The laser frequency is doubled using a KNbO$_3$ crystal placed inside an enhancement cavity, generating up to 16mW of light at 423nm. This light is then used to cool the Calcium atoms from an atomic beam to load a MOT running with a frequency doubled Ti:Sapphire laser. We show that twice more atoms are trapped in the MOT when the cooling beam comes from an independent laser. We determine the optimum detuning measuring the beat-note of the diode laser with the frequency stabilized Ti:Sapphire laser [6] using a fast photodetector (BW 6GHz)

Experimental Setup

We have used a commercial diode laser (SDL 5422-H1), which can deliver up to 180mW at an operating current of 200mA. The laser package includes an internal thermoelectric cooler (peltier) and a thermistor for temperature control. The extended cavity, shown in figure 1, is made by a thin plate that reflects back to the laser about 9% of the total power. Between the laser and the plate an isosceles prism disperses spatially the different wavelengths of the light. By tilting the plate, we select a wavelength reflecting
it back to the laser forcing the oscillation in that specific wavelength. The prism is positioned near to Brewster angle so the losses due to reflection and scattering (10%) are very low in comparison to the losses in a diffraction grating (30%-40%), used in the conventional extended cavities. Therefore more output power is available. The frequency is doubled in a 1cm long KNbO$_3$ crystal placed inside a power enhancement cavity.

The cavity is kept resonant electronically to the laser by the Hänsch-Coulliaud method [4]. The non-critical phase-matching is achieved with the crystal temperature around -14°C. Two optical isolators (60dB) are required to avoid any feedback from the resonant doubling cavity to the laser. Unfortunately, these isolators generate losses of 40% since one of them is designed for a different wavelength. Then, 80mW of the fundamental power enter the cavity and generate up to 16mW of blue light at 423nm [5].

Figure 1: Left: experimental setup of the extended cavity frequency doubled diode laser. Right: the atomic beam and MOT chamber.

The blue light goes to the MOT chamber after been enlarged by a telescope and amplitude modulated by a fast shutter (closing time 200 µs), as shows figure 1. The alignment to the atomic beam is made with the help of a removable mirror. Without this mirror the Ti:Sapphire beam decelerates the Calcium atoms and by adding the removable mirror, the Ti:Sapphire is blocked and the diode laser follows the same path. Thus, we can easily compare both situations. The optimization of the number of atoms has been made keeping the net power of the deceleration beam in 6mW and the trapping power in 10mW. The diameter of the trapping beams is 4mm what gives a saturation parameter S=1.33. The number of trapped atoms is estimated by analyzing the fluorescence of a fraction of the emitted photons using a calibrated photodetector. As the photons are emitted in all directions with equal probability, the power hitting the detector is a fraction of the total power emitted given for the solid angle covered by the detector lens. This detector, with a response of 1.05mV/nW, has been previously calibrated using a power meter (Coherent Field Master). As we are saturating the transition, the power emitted by a single excited atom depends only on the photon energy and the lifetime of the atomic level. The total power, emitted for all the trapped atoms will be just the number of atoms times the single atom emitted power.

To determine the optimum detuning for deceleration, the first step was to decelerate and trap the atoms using just the doubled Ti:Sapphire laser and find out the detuning which maximized the fluorescence in this case. Then, the same measurements have been made using the doubled diode laser decelerating the atoms. Those measurements have been done for different values of the current in the anti-Helmholtz coils (from 0.5A to 1.75A), i.e., for different magnetic gradients. We analyze the optimum number of trapped atoms for different power of the trapping beams.

The center of the Calcium resonant “cooling” transition has been determined by a spatial analysis of the atomic fluorescence induced by the vertical beam of the MOT. We observe the spatial Zeeman splitting of the trapped atoms as the frequency of the Ti:Sapphire laser is varied. To determine the linewidth and the detuning of the diode laser relative to the Ti:Sapphire laser we deviate a small fraction of the fundamental power from both lasers and measure the beat-note with a fast photodetector (BW 6GHz) and then analyze the signal with a Spectrum Analyzer.
Results and Discussions

The beat-note reveals a linewidth for the diode laser of 6MHz, in 20s. This measurement has been performed using a Ti:Sapphire laser locked to a quartz cavity, which has a fast linewidth of 20 KHz and a drift of 10MHz/hour (figure 2).

Figure 2: Beat-note of the diode laser and the frequency stabilized Ti:Sapphire laser. A linewidth of 6 MHz is found for the diode laser in 20s.

The optimum detuning for the deceleration and trapping beams have been determined by measuring the beat-note frequency in a RF spectrum analyzer. It is observed that the optimum detuning frequency increases with the increase of the magnet current. In the case of the trapping beams, however, this dependency is not significant, figure 3.

Figure 3: Left: Optimum detuning of the trap beams as a function of current in the MOT coils. Right: Optimum detuning as a function of current in the MOT coils. In this case, the detuning has been measured relative to the trapping beams operation frequency.

The optimum number of trapped atoms increases when the deceleration is made with the diode laser, figure 4. This number increases more for the higher values of the magnetic field gradient.
In none of these cases a significant dependency of the number of trapped atoms with the power of the trapping beams has been found.

Conclusion

We have presented an alternative extended cavity diode laser being used to cool the atoms of an atomic beam to load a MOT of Calcium atoms and optimizing the number of the trapped atoms. We have briefly described the experimental setup and the detection details. We have determined, using beat-note measurements, the optimum detuning of the trap and the slower beams for different values of the magnetic field gradient. We also measure the linewidth of the diode laser, 6MHz in 20s, using the beat-note.

It has been shown that the number of trapped atoms is up to 2.7 times larger when the diode laser performs the cooling. The direct dependency of the number of atoms with the magnet current indicates that an even higher number can be achieved for higher values of this current.

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References