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An Injection-locked diode laser for cold Rydberg atom experiments

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ABSTRACT

A free-running, temperature stabilized diode laser has been injection-locked to an external cavity diode laser for use in cold Rydberg atom experiments. Cold rubidium atoms in a magneto-optical trap (MOT) are excited to Rydberg states using a 10 ns laser pulse. The Rydberg atoms spontaneously ionize due to dipole forces, and the collisional ionization dynamics are observed as a function of atom density and principal quantum number of the Rydberg state, *n*. The injection-locked diode laser will be used as a repumper in conjunction with a dark spontaneous-force optical trap (SPOT) to increase the Rydberg state density. We report on the design of the injection-locked laser system.

INTRODUCTION

The creation of an almost electrically neutral ultracold, strongly coupled plasma by direct photoionization of 50 μK Xe atoms in a MOT was first reported several years ago by Killian ***et al.*** [1]. Soon after the initial creation of an ultracold plasma from cold atoms in a MOT, a related phenomenon was observed, in which cold atoms in a MOT were excited to Rydberg states with $n^* > 30$ were then found to evolve spontaneously to plasma on a time scale of order 1 μs. This discovery was made concurrently at University of Virginia (UVA), and at Laboratoire Aimé Cotton (LAC), Orsay, France, and reported a paper by Robinson ***et al.*** [2]. Further observations on the evolution of cold Rydberg atoms to plasma were reported by Li ***et al.*** [3]. More recent work has identified the role of dipole forces in the plasma evolution process [4].

We are interested in studying the plasma evolution process at high Rydberg densities ($> 1 \times 10^{10}$ cm^{-3}), and we are also investigating the heating or cooling effects of Rydberg atoms on the electron temperature of a nultracold plasma created by direct photoionization. We describe here the status of our research, and the design of an injection-locked diode laser which will be used to enhance the density of a cold Rydberg sample.

EXPERIMENTAL

We trap 1.2×10^8 ^{85}Rb atoms in our MOT. The MOT chamber is constructed from stainless steel, and is pumped to a base pressure of 3×10^{-10} torr using a 20 l/s ion pump. The trapping and repump external cavity lasers are amplified using injection-locked free-running lasers, and the total laser power into the MOT is in excess of 50 mW for each of the trapping and repump laser beams. The magnetic field gradient is provided by two 280-turn coils of 14-gauge copper wire in the anti-Helmholtz configuration.

Rb atoms in the $5p_{3/2}$ state are excited to ns or nd Rydberg states using a tunable laser pulse, either from a Nd:YAG-pumped Littman dye laser, or from a frequency doubled, dye amplified diode laser. After the laser has excited a Rydberg state, the Rydberg atoms are allowed to evolve for a time of 100 ns to 50 μs. At the end of this interval the atoms are field ionized using an electric field pulse that is applied to one of a pair of parallel, high-transparency meshes that surround the trapped atoms. The pulse ionizes Rydberg atoms, and pushes the resulting ions or electrons (depending on the pulse polarity), plus any electrons or ions from the plasma towards a microchannel plate detector (MCP). A schematic of the interior of the MOT chamber is shown in Fig. 1, and a diagram illustrating the timing of the laser and field ionization pulses is shown in Fig. 2.

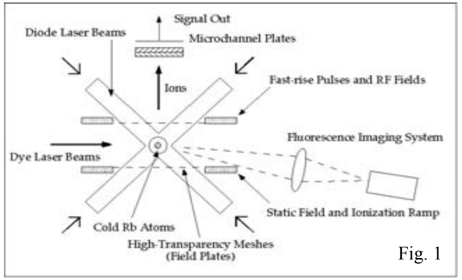

Fig. 1

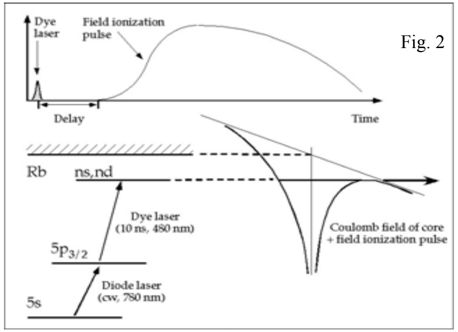

Fig. 2

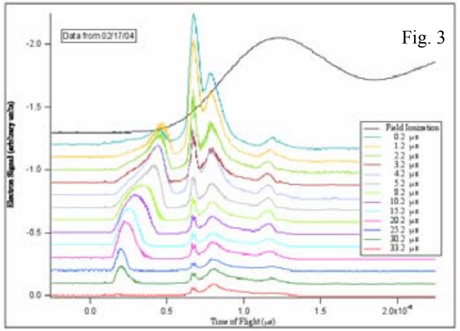

Fig. 3

Fig. 3. Evolution of Rb Rydberg atoms in the 38d state to plasma as a function of delay from the exciting laser pulse.

INJECTION LOCKED DIODE LASER

Our aim is to make a really dense plasma, or a dense sample of cold Rydberg atoms which will evolve to a strongly coupled plasma, with a Coulomb coupling parameter, Γ, much greater than 1 [5]. A recent suggestion that we want to investigate as a possible path to this regime is whether Rydberg atoms can be used to control and cool the plasma electron temperature [6]. For these experiments, a cold plasma will be formed directly by the photoionization of cold atoms using a pulsed dye laser, and a second pulsed laser will be used to create the Rydberg sample embedded within the plasma. Such experiments are expected to be critically dependent on the Rydberg atom density, and our goal is to increase the cold atom density by making a dark SPOT. We will then use a second diode laser repumper beam to transfer population from the dark state to the $5p_{3/2}$ state.

Previous experimental research has shown that the density limit in the (MOT) is as a result of 2 main processes. The first being as a result of collisions between ground and excited-state atoms in which part of the excitation energy can be transformed into kinetic energy, resulting in a trap loss rate. The second limit is due to the repulsive forces between the atoms caused by the reabsorption of scattered photons [7]. These limits may be overcome by using a dark spontaneous-force optical trap ("dark SPOT"). This reduces the aforementioned limitations by confining the ^{85}Rb atoms to the $5s_{1/2}$ F = 2 state (commonly referred to as the dark state). A dark SPOT is made by shielding atoms at the center of the trap from the repumper laser ("Repumper 1"). The repump laser beam is split into two beams which intersect in the center of the MOT. Both beams have a "hole" (zero intensity) in their centers. Their intersection in the MOT creates a dark spot with an approximate volume of 1 mm^3. Atoms in this region of the trap do not see Repumper 1, and are thus pumped into the dark state by the trapping laser beams. A schematic of the dark region is shown in Fig. 4.

While the dark SPOT enormously enhances the cold atom population in the $5s_{1/2}$ F = 2 state, we need to pump this population to the $5p_{3/2}$ F = 3 state in order for the pulsed laser to enhance the Rydberg atom density. We have built a second repump laser ("Repumper 2") for this purpose. The laser we built is shown in Fig. 5. For the repump laser to work effectively, its on and off timing must be synchronized to the pulsed laser. Our plan is to turn on the second repump laser for approximately 10μs and then turn it off. Immediately after this, the blue-pulsed laser is turned on for 10ns. This cycle is repeated at a frequency of 20Hz. A schematic of the transitions pumped by the various diode laser beams is shown in Fig. 6.

Repumper 2 is an injection locked diode laser. A small amount of light from a frequency-locked external cavity diode laser that is used as the oscillator for Repumper 1 is passed twice through an acousto-optic modulator (AOM) for optical isolation, and to provide the necessary frequency offset. This beam is then injected into the Repumper 2 laser, which then produces an amplified output at the same frequency. The output beam from Repumper 2 is pulsed by switching on and off the rf drive to the AOM. A schematic of the optical arrangement is shown in Fig. 7.

ACKNOWLEDGEMENTS

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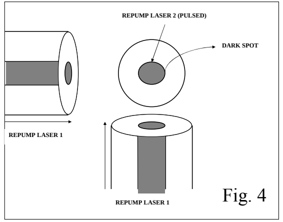

Fig. 4

Fig. 5**:** Repump Laser 2 (Pulsed)

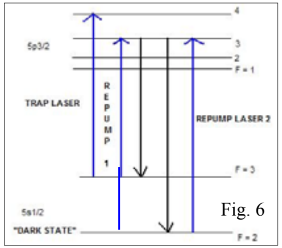

Fig. 6

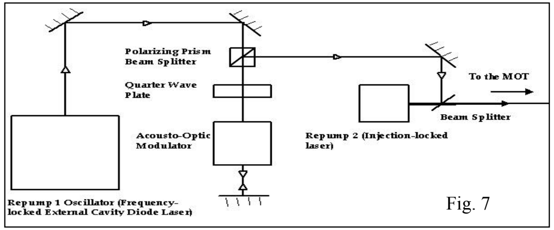

Fig. 7

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