Conventional light-force atom traps, in particular the Bragg and the magnetic-force traps, are limited in density by optical depth effects. We show that FORIs can achieve these densities in a tight optical lattice with 10^4 atoms per lattice site. A simple optical lattice is described which results from a tight lattice depth. Rapid free expansion leads to phase-space densities of 10^4 atoms per lattice site. This is also attractive for a number of experiments, including ultracold Rydberg atom physics.
beam \( I_0 \). Along the \( z \) propagation direction of the light the interference arises from the Talbot effect \cite{9}. The resulting lattice sites (microtraps) are \( 10 \ \mu m \times 10 \ \mu m \times 100 \ \mu m \) in size. With the individual beams focussed to \( 80 \ \mu m \) and a total power of \( 8 \) W the depth of the central microtrap is \( 500 \ \mu K \) and the oscillation frequencies are \( 17 \) kHz, \( 17 \) kHz, and \( 0.7 \) kHz. These calculated frequencies were experimentally confirmed by parametric heating of the HAT atoms \cite{7}. Since the lasers are nearly copropagating, the potential is quite stable against vibrations and the YAG laser can have a large bandwidth. Our multi-longitudinal mode laser has a bandwidth of approximately \( 25 \) GHz. Heating due to intensity noise \cite{13} was easily eliminated with an acousto-optic intensity stabilizer. The relatively large lattice sites allow many atoms (\( \sim 10^5 \)) to be trapped in each site.

Fig. 2 shows a calculated density distribution for atoms trapped in the HAT at \( 50 \) \( \mu K \) temperature. We use a probe laser propagating along the \( y \) direction to take spatial heterodyne \cite{14} phase images that show the atoms’ isolation within the Talbot fringes and the microtraps (Fig. 3). We observe Bragg diffraction of the probe beam from the atoms in the microtraps by interference with the probe beam, also shown in Fig. 3. An interesting observation from Fig. 2 is that there should be a relative misalignment of the microtraps in successive Talbot fringes. This is confirmed by the spatial profiles shown in Fig. 4. Analysis of such images gives about \( 4 \times 10^5 \) atoms per Talbot fringe. Time-of-flight temperature measurements of \( 50 \) \( \mu K \) coupled with knowledge of the trapping potential imply peak densities exceeding \( 2 \times 10^{14} \) cm\(^{-3} \) and phase space densities of \( 1/150 \). Typically 25 microtraps are occupied within each Talbot fringe, with \( 10\% \) of the atoms in the central microtrap.

Key to the HAT’s success is an efficient loading protocol. We begin with a vapor cell forced dark spot MOT \cite{15} with \( 50\% \) of the \( 10^7 \) atoms in each of the hyperfine ground states (\( F=1/2 \) \( F'=1 \), \( 1 \) \( F'=2 \)) of \( ^8 \) Rb. The dark spot is achieved by imaging an opaque object in the hyperfine repumping beam (\( F=1 \rightarrow 3 \) \( F'=2 \)). The trapping light (\( F=2 \rightarrow F'=3 \)) is tuned 3 linewidths \( \Gamma \) below resonance and has an intensity of \( 72 \) mW/cm\(^2 \). We add a depumping laser, tuned to the high frequency side of the \( F=2 \rightarrow F'=2 \) resonance, to optically pump more atoms down to the \( F=1 \) ground state. To load the HAT from the MOT, we compress the cloud by decreasing the trapping light intensity by a factor of 3, then increasing the MOT magnetic field. After 20 msec we turn on the HAT laser. AC Stark shifts tune the repumping and trapping beams away from resonance and the depumping beam towards resonance, causing the atoms in the HAT to be extremely dark (estimated \( \sim 0.001 \) in \( F=2 \) inside the FORT) \cite{16}. During the HAT loading phase we shift the trapping laser detuning to \(-\Omega T \). The number of trapped atoms increases until it reaches steady state in about 50 msec, after which all the MOT lasers are extinguished. The MOT to HAT transfer efficiency is as high as \( 15\% \).

We show in Fig. 5 the temperature and number of atoms vs time after the loading ceases. The temperature rapidly decreases to a value of about \( 50 \) \( \mu K \), approximately \( 1/10 \) of the trap depth, as expected for free evaporation of atoms from the HAT \cite{17}. The evapora-
Evaporative cooling of the atoms occurs after the cooling lasers are switched off. The number of atoms in a single Talbot fringe (circles) and the temperature (triangles) rapidly decrease until the temperature reaches roughly 1/10 the trap depth.

Evaporation is rapid due to the very high densities; we estimate the elastic collision rate to exceed 3000/s. Such high collision rates make evaporative cooling very promising for the HAT and such experiments are underway in our laboratory. Trap lifetime studies show that after the evaporation ceases the temperature stays fixed but the atoms are slowly ejected from the trap and/or heated [18] by background gas collisions with a time constant of about 500 msec. For comparison, the MOT lifetime is typically 2-3 seconds for our vapor-loaded trap.

These high density samples are of potential interest for a variety of experiments. In addition to obvious examples such as evaporative cooling and cold collisions, many groups are interested in ultracold Rydberg atoms. Excitation of Rydberg states of principal quantum number $\sim 100$ in our HAT will give rise to strong, long-range dipole-dipole interactions. Because atoms in our microtraps are localized within a 15 $\mu$m region, these interaction energies are in excess of 1 MHz for atoms on opposite sides of a microtrap. Consequently, excitation by a narrow-band laser of more than one Rydberg atom at a time per microtrap should be greatly suppressed. This ‘dipole blockade’ is of great interest for applications in quantum information processing [19] and single atom and photon sources [20]. Similarly, the densities are high enough to expect efficient excitation of novel long-range Rydberg molecules such as those recently reported [21, 22]. In addition, it will be interesting to see how the very much higher densities achieved in the HAT as compared to MOTs affect the production of cold plasmas [23].

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