Cooling rubidium atoms with a photonic integrated 3D magneto-optical trap

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Abstract: We demonstrate an integrated photonics infrastructure for atomic laser cooling. We trap 5 x 10^6 ^{87}Rb atoms in a magneto-optical trap using free-space cooling beams emitted from a SiN photonic integrated circuit. © 2022 The Author(s)

1. Introduction

Cold atoms are a central component for many quantum technologies including precision timekeeping, sensing, and quantum computing. Transitioning these technologies beyond the laboratory setting requires portability as well as integration and control [1, 2]. A typical magneto-optical trap (MOT) for laser cooling has a complex arrangement of free-space laser beams aligned with precision bulk optics. Efforts to miniaturize MOT beam delivery have used micro-optic components such as pyramidal mirrors and diffraction gratings [3,4] or metasurfaces for beam expansion and shaping [5]. New photonic integrated circuit (PIC) technologies for beam delivery can enable a large reduction in size and provide an interface between atoms and photonic systems that enable functionality and control.

Photonic integration of a MOT beam interface requires the conversion of guided light to multiple free-space, large-area beams that converge within the atom vapor cell at specific angles. In this work we demonstrate the first 3-dimensional (3D) MOT using a PIC for beam expansion, collimation, and delivery. The PIC was fabricated in a CMOS-compatible process and transforms 780 nm light with mode area 0.45 um^2 from a single waveguide to three collimated free-space beams with dimensions 2.5 mm x 3.5 mm, a factor of ~20 x 10^6 increase [6]. We demonstrate laser cooling and trapping of ^{87}Rb atoms with cooling beams delivered by the PIC, achieving a MOT of 5 x 10^6 atoms. This level of performance eliminates the need for bulky collimation lenses and beam splitters and replaces an array of table-top bulk optical components. The PIC supports the delivery of necessary optical power to the MOT owing to the low absorption and the power handling capability of the Si_3N_4 waveguide platform.

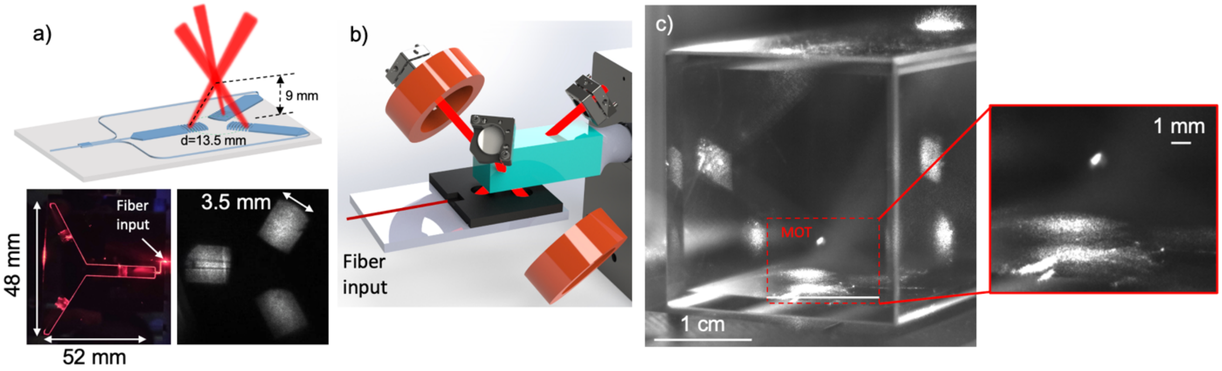

Fig. 1 a) Beam delivery PIC and an image of the fabricated chip coupled with a red laser and the emitted beam profile. b) CAD concept of the PICMOT experiment, including the grating chip, vapor cell, and magnetic field coils. c) Camera view of the glass cell, beams, and MOT cloud.

2. Experiment and Results

The laser cooling beam interface PIC is shown in Fig. 1 (a). The 780 nm single mode waveguide design is a 400 nm wide, 120 nm thick SiN waveguide core with a 15 um thick thermal oxide lower cladding layer and a 3 um thick oxide upper cladding layer. Light from a 780 nm laser is coupled into the SiN PIC input with a packaged fiber. The guided light is split with a multimode interference structure and routed to three slab waveguide beam expanders each illuminating a large-area surface grating emitter. The gratings are located on a 13.5 mm diameter circle and emit free-space collimated beams at 57 deg from the PIC surface-normal to produce a ~93 deg intersection between all three beams, with a beam intersection height 9 mm above the chip surface inside a glass vapor cell. The measured beam cross-section dimensions are 2.5 mm by 3.5 mm corresponding to a beam overlap volume of 16 mm^3 and have a uniform intensity profile. The loss from the fiber input to each free-space beam output is ~21 dB, which includes the loss from the packaged fiber connector. The output of each beam is linearly polarized and a thin quarter-waveplate directly above each emitter is used to convert to circular polarization of appropriate handedness to generate the MOT trapping force.

The geometry of the PICMOT experiment is illustrated in Fig. 1 (b). The large beam intersection height enables our PIC and waveplates to be placed outside of the vacuum cell. Each PIC beam is retro-reflected with a mirror and quarter-waveplate. Magnetic gradient field coils are aligned along one of the PIC beams and generate a gradient of 20 G/cm. The cooling laser is -12.6 MHz red-detuned from the ^{87}Rb cooling transition. The image of the atoms is captured on a camera near the vapor cell (Fig. 1c) and the MOT cloud fluorescence is focused onto a photodetector. For a power of 150 mW into the PIC fiber, corresponding to an average beam intensity of 14 mW/cm^2, we measure 5 x 10^6 trapped atoms. Fig. 2 shows the MOT loading curve used to obtain the steady state atom number.

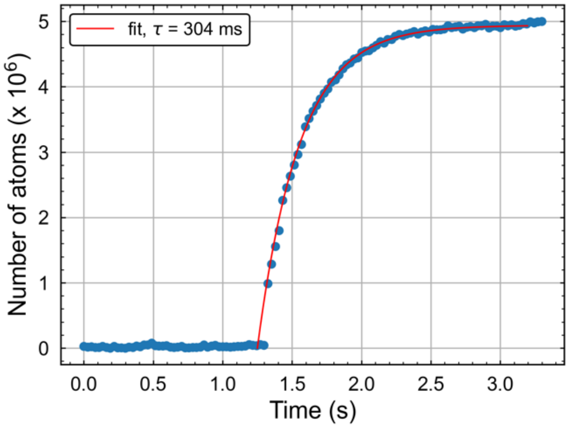

Fig. 2. Loading curve of the PICMOT at 150 mW fiber input.

3. Conclusion

We demonstrate laser cooling with photonic beam delivery for an atomic-photonic interface. The planar geometry is amenable to integration with components such planar magnetic field coils [4]. In future designs we plan to decrease the fiber to PIC beam losses and use a meta-surface retroreflector to eliminate mirrors for a more compact planar stack. Our wafer-scale SiN waveguide platform is compatible with wavelengths for other atomic species such as cesium and strontium. Integrated beam delivery can also be combined with other active and passive photonic components located on one chip. These results open prospects for compact, functional, and low cost cold atom tools and applications.

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References

[1] K. Bongs *et al.*, "Taking atom interferometric quantum sensors from the laboratory to real-world applications," *Nat. Rev. Phys.* **1**, 731-739 (2019).
[2] J. Kitching, "Chip-scale atomic devices," *Applied Physics Reviews*, 5, 031302 (2018).
[3] S. Pollock *et al.*, "Characteristics of integrated magneto-optical traps for atom chips," *New J of Phys.* 13, 043029 (2011).
[4] L. Chen *et al*., "Planar-Integrated Magneto-Optical Trap," *Phys. Rev. Applied* 17, 034031 (2022).
[5] W. G. McGehee *et al*., "Magneto-optical trapping using planar optics," *New J. Phys.* **23** 013021.
[6] N. Chauhan *et al*., "Photonic Integrated Si3N4 Ultra-Large-Area Grating Waveguide MOT Interface for 3D Atomic Clock Laser Cooling," in *Conference on Lasers and Electro-Optics*, OSA Technical Digest (Optical Society of America, 2019), paper STu4O.3.