Metasurface Gratings as Flat Optics for Magneto-Optical Trap Beam Delivery

Wenqi Zhu, Zi Wang, Amit Agrawal
National Institute of Standards and Technology, Gaithersburg, MD 20899
wenqi.zhu@nist.gov

The ability to trap and manipulate neutral atoms forms the backbone of many quantum computing and sensing systems. Among various atom trapping technologies, magneto-optical trapping (MOT) is a routine approach to trap an ensemble of neutral atoms. The optical implementation of a MOT typically involves 3 pairs of counter-propagating, circularly polarized laser beams, all at a wavelength blue-shifted from the atom resonance. Preparing these trapping beams requires usage of several bulk optical components and iterative efforts for optical beam alignment. To address the scalable demand of MOTs in large quantum systems, various nanophotonic approaches to form such trapping beam geometry have been adapted. Recently, the use of dielectric metasurface optics has been explored to simplify MOT geometries[1]. The ability to arbitrarily control phase, amplitude, and polarization of light in a single metasurface device hint at the possibility of replacing bulk optics needed for creating a MOT, thereby allowing simplification and miniaturization of MOT-based systems.

In this work, we explore metasurface gratings as flat optics to prepare and deliver optical beams required for MOT configurations. We present a number of designed metasurface optics that work as beam deflectors, retroreflectors, polarizations optics, multi-functional grating couplers, eliminating the need for bulk optics for MOT. All components are designed via inverse optimization to deliver circularly polarized light for ^{87}Rb at the trapping wavelength of 780 nm. The metasurface gratings are made of titanium dioxide (TiO_2) and fabricated using a Damascene process based on atomic layer deposition[2]. We experimentally demonstrate retroreflector with 71% efficiency and 0.86 ellipticity, meeting performance requirements for MOT operation. The grating coupler is characterized through full-wave electromagnetic simulations, showing 20% out-coupling efficiency and 0.85 polarization ellipticity. These metasurface grating optics should pave the way for manufacturable miniaturized MOT systems that can be integrated within future quantum systems.

---

[1] J. Sindhu, et al., Three-dimensional, multi-wavelength beam formation with integrated metasurface optics for Sr laser cooling, Opt. Lett. 49, 6013 (2024).

[2] R. C. Devlin, et al., Broadband high-efficiency dielectric metasurfaces for the visible spectrum, Proc. Natl. Acad. Sci. 113, 10473 (2016).

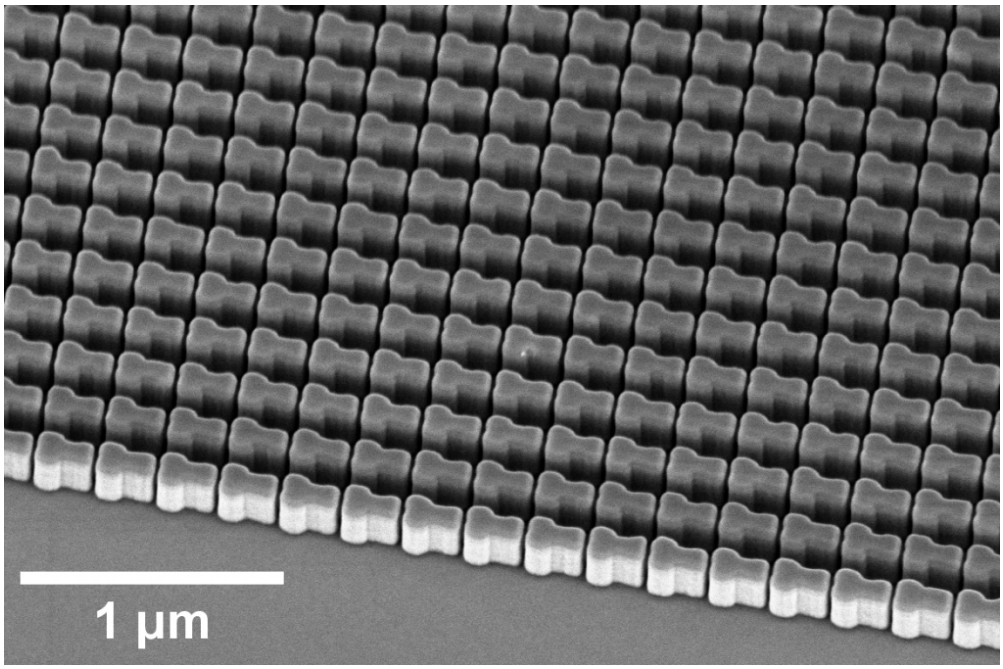

Figure 1: Metasurface grating based flat optics. The micrograph shows the metasurface grating to function as a retroreflector for circularly polarized light. It consists of 330nm tall, T-shaped TiO_2 nanopillars on top of a SiO_2/Ag coating on a silicon substrate.