Exploration of a high-performance grating magneto-optical trap for atomic clocks

Muming Li[1,2], Shiming Wei[1], Zhilong Yu[1], Yadong Zhou[2], Junyi Duan[3] and Xiaochi Liu[1]

[1]Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan, China

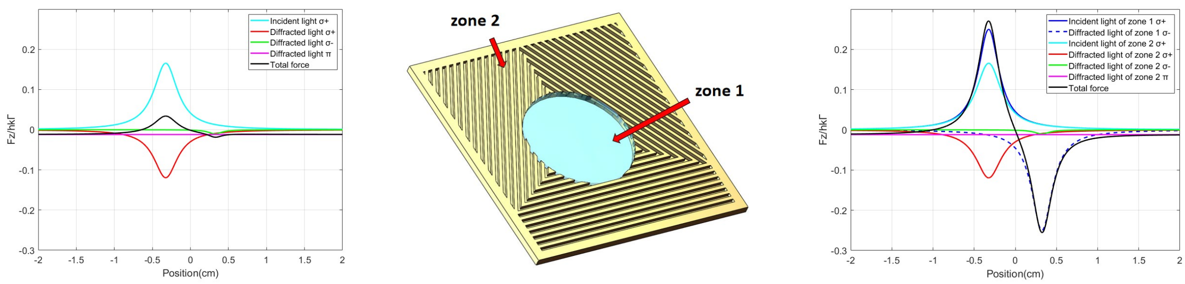
[2]College of Optical and Electronic Technology, China Jiliang University, Hangzhou, China

[3]Center for Advanced Measurement Science, National Institute of Metrology, Beijing, China

Email: liuxc@apm.ac.cn

The GMOT system significantly reduces the volume and complexity of the conventional cold atoms technique. Various cold atoms-based quantum standards and sensors have been proved the feasibility of this compact/miniaturized technique, such as CPT clock, POP clock, atomic interferometer, Zeeman slower[1-4]. Although the GMOT system have demonstrated its cooling capability with a simple architecture, there are still several challenges to convert this technique/system to the practical applications.

The key component of the GMOT system is a deep-etched sub-wavelength optical grating[5]. A single incident beam and the corresponding diffracted beams form a balance scattering force zone. Unlike the conventional MOT using counterpropagating $\sigma^{\pm}$ transitions, the $\sigma^{\pm}$ and π transitions are all involved in the diffracted beams from the grating (Fig. 1a). Among these transitions, only the σ^{-} transition offers the opposite force to the incident beam. However, the σ^{-} transition component is relatively weak compared to the other transitions due to the grating structure. Thus, the scattering forces are not balanced, which will limit the cooling capability of the GMOT system[6]. Here we proposed a simple new design of the grating chip to rise the σ^{-} transition as Fig. 1b shown. The partial counterpropagating beams in the center of the grating chip could significantly increase the σ^{-} transition (Fig. 1c). The maximal trappable velocity of the atoms also increases compared to the conventional grating structure. More details and results of this design will be presented in the conference.



(a) (b) (c)

Fig. 1. (a) Scattering forces of the conventional grating design (a); (b) the σ^{-} improved design and (c) the scattering forces.

The scattering forces of the GMOT also depend on the strength gradient of quadrupole magnetic field. To miniaturize the GMOT system, a planar coils chip is proposed to replace the conventional anti-Helmholtz coil pairs[7]. Recently, we have proposed a nested architecture planar coils chip to reduce the power consumption further[8]. The planar architecture could significantly reduce the volume of the whole system, nevertheless, it exhibits a highly nonlinear field. The GMOT combined with the conventional grating chip and the planar coils chip may not be capable to trap the atoms due to this nonlinearity. The improved σ^- transition architecture grating could overcome this defect of the planar coils chip (Fig. 2).

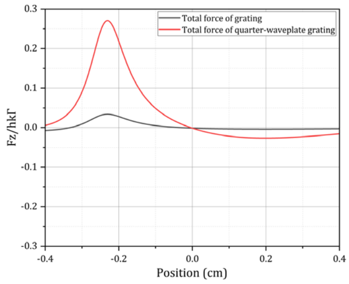
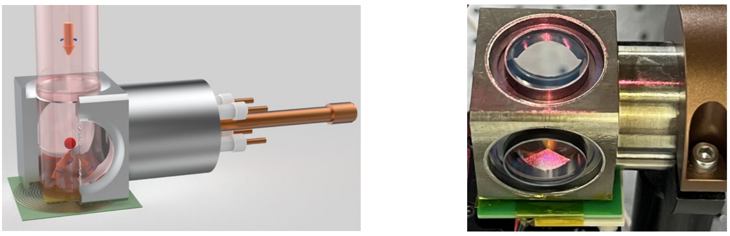


Fig. 2. Scattering forces of the GMOT system consists of the conventional grating (black) and the new design grating (red) with the planar coils chip.

Furthermore, we have also demonstrated a whole compact GMOT system (Fig. 3) consists of the grating chip, the planar coils chip and a robust passively-pumped vacuum chamber[8-9], up to 10^6 atoms are trapped in the system.



(a) (b)

Fig. 3. (a) Basic architecture of the fabricated vacuum chamber with the grating chip and the coils chip; (b) Photo of the fabricated vacuum chamber with the grating chip and coils chip.

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