URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024

Diffraction gratings for laser cooling of atoms

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Cold atom-based sensors are revolutionizing the existing market of quantum technology by offering sensitivity levels several orders of magnitude better than the existing technologies. These sensors are increasingly utilized in metrology, timing, navigation, and various sensing applications such as magnetometry and gravimetry [1]. Currently, research efforts are focused on developing portable, compact cold atom-based sensors that can be deployed in harsh environments. Central to these systems is the Magneto-optical trap (MOT), which confines atoms in a specific region for experimentation by using laser cooling. Generally, the process of laser cooling involves large vacuum chambers with many laser beams which take up a large laboratory space The use of diffraction gratings is crucial for creating a compact tetrahedral MOT system, as the traditional six-beam MOT setup is bulky thus adding more size and weight to the setup. Other methods include a pyramidal MOT(PMOT) which utilizes inclined mirrors to generate required tetrahedral configuration however the number of atoms trapped in a PMOT are significantly lower and since the atom cloud is formed inside the pyramidal configuration of mirrors it creates inconvenience to access and detect the atoms [2].

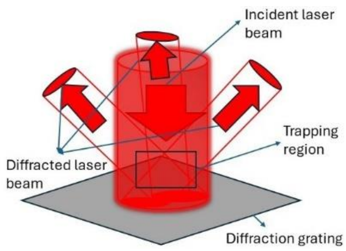

Figure 1. A schematic of laser cooling of atoms using a diffraction grating.

By employing diffraction grating, we can generate a tetrahedral configuration of laser beams, which is needed for the MOT using just a single laser beam. This can be achieved by using first order diffractions from a diffraction grating with triangular grooves which forms a tetrahedral configuration by combining with the incident beam falling directly on the grating center as shown in figure 1. Current research aims to maximize the first-order diffraction efficiency by varying the groove depth and grating period. Three grating structures namely binary gratings, blazed grating, hemispherical groove grating are compared to analyze the required parameters for maximal efficiency of the grating. Gratings with symmetric grooves can diffract maximal light into first order of diffraction but the light is equally distributed in m = +1 and m= -1 diffraction orders. Non-symmetric groove shape like blazed grating can diffract light maximally in m = -1 diffraction order. Higher order diffraction orders are minimized if $d_g < 2\lambda$, where d_g is the grating period and λ is wavelength of laser incident on the grating. Zeroth order diffraction is a major source of intensity loss that can be minimized by varying the groove depth. Additionally, we assess the force profile and relative cooling efficiency across different grating structures, providing insights into the optimal designs for enhancing the grating performance of compact cold atom-based sensors.

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2. Shimizu F, Shimizu K, Takuma H. Laser cooling and trapping of Ne metastable atoms. Physical Review A. 1989 Mar 1;39(5), doi: 10.1103/PhysRevA.39.2758.