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Outline of "Cold ytterbium atomic beam with sub-recoil momentum width"

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Atomic interferometers are powerful tools for determining physical quantities such as fine-structure constants. They also provide frequency standards using microwave transitions between two hyperfine ground states. Additionally, atomic interferometers can work as ultra-precise inertial sensors, including accelerometers, gravity gradiometers, and gyroscopes. The sensitivity of the atom interferometer-type inertial sensor increases by using higher-order Bragg diffraction, since the interferometer's effective area increases by a factor of the diffraction order. However, Bragg diffraction requires that the transverse momentum width of the atomic source is less than the photon recoil momentum of the Bragg diffraction beams. This leads to a significant loss of the available number (or flux) of the atomic source and deterioration of the shot noise. This thesis aims to realize a high-flux cold atomic beam with sub-recoil transverse momentum width that can be adapted to Bragg diffraction-type atom interferometers. Alkaline or alkali-earth-like atoms are utilized for implementing the atom interferometer, with the latter having the potential to realize ultra-high sensitivity since it is less sensitive to the environmental magnetic field. The author selected ytterbium, an alkali-earth-like atom with three optical transitions: the dipolar-allowed $^1S_0$-$^1P_1$ transition, the $^1S_0$-$^3P_1$ intercombination transition, and the ultranarrow $^1S_0$-$^3P_2$ transition. The goal is to achieve an atomic beam with sub-recoil transverse momentum width by combining the above three optical transitions.

This thesis is organized into five chapters:

Chapter 1: Introduction – This chapter provides an overview of the historical background of atomic interferometry, with a focus on the precise measurement of inertial forces (acceleration and angular velocity) using atomic interferometry. It also provides a detailed introduction to each of the previous studies. Furthermore, the author proposes a new method for realizing a high-flux and continuously cold atomic beam using the three optical transitions of ytterbium, which is useful for the precise measurement of angular velocity.

Chapter 2: Atom interferometer based on Bragg diffraction – This chapter summarizes theories on Bragg diffraction and atom interferometers. Furthermore, the angular velocity sensitivity of a Bragg diffraction-type atom interferometer with a cold atomic beam is estimated and compared with that of existing gyroscopes.

Chapter 3: High-flux cold ytterbium atomic beam using transverse cooling with intercombination transition – This chapter summarizes the experiment in which the $^1S_0$-$^3P_1$ intercombination transition was used for the cold ^{174}Yb atomic beam generated by the dipolar-allowed $^1S_0$-$^1P_1$ transition to successfully conduct cooling in the transverse direction and cool the transverse momentum width of an atomic beam to several times the recoil momentum. The transverse momentum width is maintained below $5.7\hbar k_{399}$, while the flux is above 6.5×10^8 atoms/s in the longitudinal velocity range of $22 - 30$ m/s.

Chapter 4: Momentum filtering and high-order Bragg diffraction – This chapter describes details of momentum filtering using the $^1S_0$-$^3P_2$ ultra-narrow optical transition and summarizes the experiment where momentum filtering was conducted to the cold ^{171}Yb atomic beam generated by the method described in Chapter 3 to achieve a cold atomic beam with a transverse momentum width smaller than the recoil momentum. The author generated an atomic beam with a transverse momentum width of $0.20(8)\hbar k_{399}$, a longitudinal velocity of 30 m/s, and an atomic flux of 10^7 atoms/s. Further, Bragg diffraction of up to 10th order was observed for the atomic beam.

Chapter 5: Conclusion – This chapter summarizes the entire thesis and describes the future outlooks for precise measurement of angular velocity using alkaline earth-like atoms.

In summary, a high-flux and continuously cold ytterbium atomic beam with a sub-recoil transverse momentum width has been realized. The experimental results show that a gyroscope with the cold atomic beam has the potential to achieve more precise angular velocity measurements than existing gyroscopes. Such a high-performance gyroscope can help improve the performance of non-GPS navigation, observe Earth's polar motion, and test the relativity principle.