The Miniaturized Integrating Sphere Cold Atom Clock based on Fiber Mirrors

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***Summary*—Diffuse laser cooling provides a compact cold atom system for quantum precision measurement processes, especially for the integrating sphere cold atom clock. However, the laser cooling system of current integrating sphere cold atom clock is bulky and complex, which is not conductive to the miniaturization of cold atom clock. In order to make a less complex diffuse laser cooling system, we adopt the scheme to combine the fiber mirrors and the diffuse laser cooling technique. The incident laser beams are reflected by the fiber mirrors and teflon, and the atoms can be successfully cooled and detected in the miniaturized zone. The preparation of fiber mirrors and the realization of diffuse laser cooling system with a simple optical system can lay a solid foundation for further miniaturization of the overall system of integrating sphere cold atom clock in the future.**

Keywords—diffuse laser cooling, miniaturization, fiber mirrors, ISCAC

I. INTRODUCTION

Diffuse laser cooling is an effective technique without magnetic field to cool the neutral atom in the order of μK, which provides the cold atom cloud for quantum precision measurements[1]. It has been successfully used in integrating sphere cold atom clock (ISCAC)[2], and will be extended to many other fields, such as atomic gravimeter, magnetometer and microwave measurement. The ISCAC is the next generation satellite borne atomic clock, whose prototype has exhibited excellent results: a short-term frequency stability of $3\times10^{-13}\tau^{-1/2}$ and a preliminary long-term frequency stability of 8.6×10^{-16}. With the development of engineering, the less complex diffuse laser cooling system appears to be one of the main challenges in the development of ISCAC. Many efforts have been done both in laboratories and industry to find the elegant schemes for the compactness: the integration of integrating sphere and microwave cavity[3], the controlling of the shape of a cold atom cloud in the cylindrical cavity, the compact physical package with one vacuum chamber, etc. In those schemes, all the laser beams are reflected by the inner surface of the metal cylindrical cavity. Although the structure of the traditional diffuse laser cooling is relatively simple and compact, the volume of diffuse laser cooling system with cylindrical cavity is close to 1L, which is not easy to further miniaturized. Up to now, there is no feasible idea for the miniaturization of diffuse laser cooling, so it is necessary to find other elegant solutions for miniaturization. Taking the reflection process into consideration, the fiber mirrors[4] are the promising candidate for the miniaturization of diffuse laser cooling due to the function of laser injection and reflection. The fiber mirrors play a central role in producing the unique diffuse laser cooling system, which should be combined with other diffuse materials to directly determines the inner surface and the isotropic laser field. Owing to the fiber mirrors, the ISCAC has the potential to be miniaturized.

Here, we show a new scheme of the miniaturized ISCAC based on fiber mirrors, whose diffuse laser cooling system is mainly composed by optical fiber, fiber mirrors and teflon. The fiber mirrors and the inner surface of teflon can offer the required inner surface for diffuse reflection, and the atoms can be successfully cooled and detected in the miniaturized zone. In addition, the optical system in the new scheme can be simple, and the efficiency of laser power can be improved. So the new scheme not only offers an original miniaturization of diffuse laser cooling system, but also lay a solid foundation for further miniaturization of the overall system of ISCAC in the future.

II. METHODS

As shown in Fig. , the new scheme of the miniaturized ISCAC based on fiber mirrors is composed of the diffuse laser cooling system and optical system. The diffuse laser cooling system is mainly composed by optical fibers, fiber mirrors and teflon, in which the laser cooling, state preparation, microwave interrogation and absorption detection occur at the same place. The surface of fiber can be processed into the a fiber mirror for laser reflection and another identical fiber is placed on its opposite direction. The two fiber mirrors fabricated by laser ablation has advantages in terms of smaller radius of curvature and low-roughness surface, resulting in a smaller waist and high reflectivity after coating. The two inherent fibers in diffuse laser cooling system reduces the

number of laser beams and eases the laser injection angle. To avoiding the escape of light between two fiber mirrors, a teflon cylindrical cavity is placed to enclose the two fibers, which can offer the required inner surface for diffuse reflection. So the combination of the two fiber mirrors and the teflon cylindrical cavity can provides the reflection inner surface for diffuse laser cooling. The incident laser beams are reflected by the fiber mirrors and teflon, and the atoms can be successfully cooled on the miniaturized zone. Besides, the cold atoms can be interacted with the microwave for Ramsey fringes by the microwave horn. Furthermore, this system can also offer a new absorption detection method, in which the cold atoms will be interacted with the near-resonance probe light reflected from the inner surface and the transmitted probe light will be detected by a PD. The advantage of the new absorption detection method is that the overall cold atoms can be detected, that means the efficiency of cooling light can be improved.

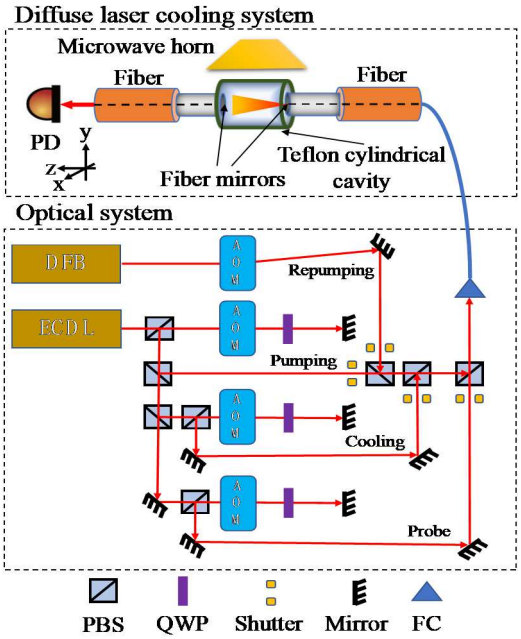

Fig. 1 The scheme of the miniaturized ISCAC based on fiber mirrors. PBS, polarization beam splitter; QWP, half wavelength plate; AOM, acoustic optical modulator; FC, fiber coupler; PD, photodetector

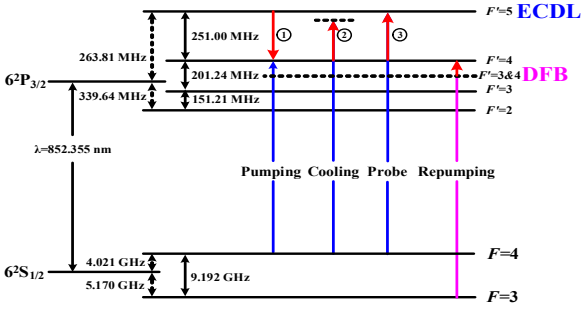

Fig. 2 The scheme of laser frequency stabilization and shifts

In the optical system, both an ECDL and a DFB laser allow us to realize the desired laser beams, which are cooling light, repumping light, pumping light and probe light. For Cesium, the corresponding scheme of laser frequency stabilization and shift is shown in Fig.2 and the scheme of optical path with four laser frequency shift processes realized by acoustic-optical modulators (AOMs), which meets all the requirements. After laser frequency shifts, the four laser beams are injected into the diffuse laser cooling system by a single-mode polarization-maintaining fiber.

III. DISCUSSION

In the new diffuse laser cooling system, the diameter of the fiber mirror is 100~150 μm, which is beneficial to realize the miniaturization. So the volume of this system is mainly determined by the size of teflon cavity. Considering the required cold atom cloud in order of mm^3 and the wall thickness of teflon in order of mm, the volume of this system can predicted in order of mm^3. Compared with the traditional diffuse laser cooling system, the volume of the new diffuse laser cooling system is reduced at least 5 orders of magnitude. That means a huge reduction of the physics package of ISCAC is realized. Significantly, the assembly of this system can show the good stability in the ultra-high vacuum environment and their high reflectivity can be maintained for a long time, meeting the experimental conditions required for the operation of ISCAC. In addition, the optical system to provide the required laser beams can be developed with the miniaturized optical elements, which also has the potential to be miniaturized. As a whole, the miniaturized ISCAC based on fiber mirrors with a simple optical system will be a promising candidate for the miniaturized cold atom clock in the future.

IV. CONCLUSION

In conclusion, we present a new scheme of the miniaturized ISCAC based on fiber mirrors, whose diffuse laser cooling system is mainly composed by optical fiber, fiber mirrors and teflon. The fiber mirrors and the inner surface of teflon can offer the required surface for diffuse reflection, and the atoms can be successfully cooled and detected in the miniaturized zone. Together with the simple optical system, the new scheme can not only offers an original miniaturization of diffuse laser cooling system, but also lay a solid foundation for further miniaturization of the overall system of ISCAC. In the future, it will be validate and developed.

REFERENCES

[1] W. Ketterle, A. Martin, M. A. Joffe, D. E. Pritchard, "Slowing and cooling atoms in isotropic laser-light," Physical Review Letters, vol. 69, issue. 17, 1992. pp. 2483.

[2] P. Liu, Y. L. Meng, J. Y. Wan, X. M. Wang, Y. N Wang, L. Xiao, H. D. Cheng, and L. Liu, "A new scheme of compact cold atom clock based on diffuse laser cooling in a cylindrical cavity," Phys. Rev. A, vol. 92, issue. 6, 2015. pp. 0621.

[3] Y. L. Meng, Y. C. Gao, B. C. Zheng, P. Liu, J. Y. Wan, L. Xiao, X. M. Wang, H. D. Cheng, and L. Liu, "Design for the integration of integrating sphere and microwave cavity," Chinese Journal of Lasers, vol. 41, issue. 9, 2014. pp. 0918001.

[4] Y. H. Pan, L. Li, X. L. Zhou, D. Y. Huang, Z. Shen, J. Wang, C. F. Li, and G. C. Guo, "Fabrication, testing, and assembly of high-finesse optical fiber microcavity for molecule cavity QED experiment," Chinese Optics Letters, vol. 20, issue. 12, 2022. pp. 122702.