Specialized fiber collimators

Cooling and trapping atoms using specially developed fiber collimators

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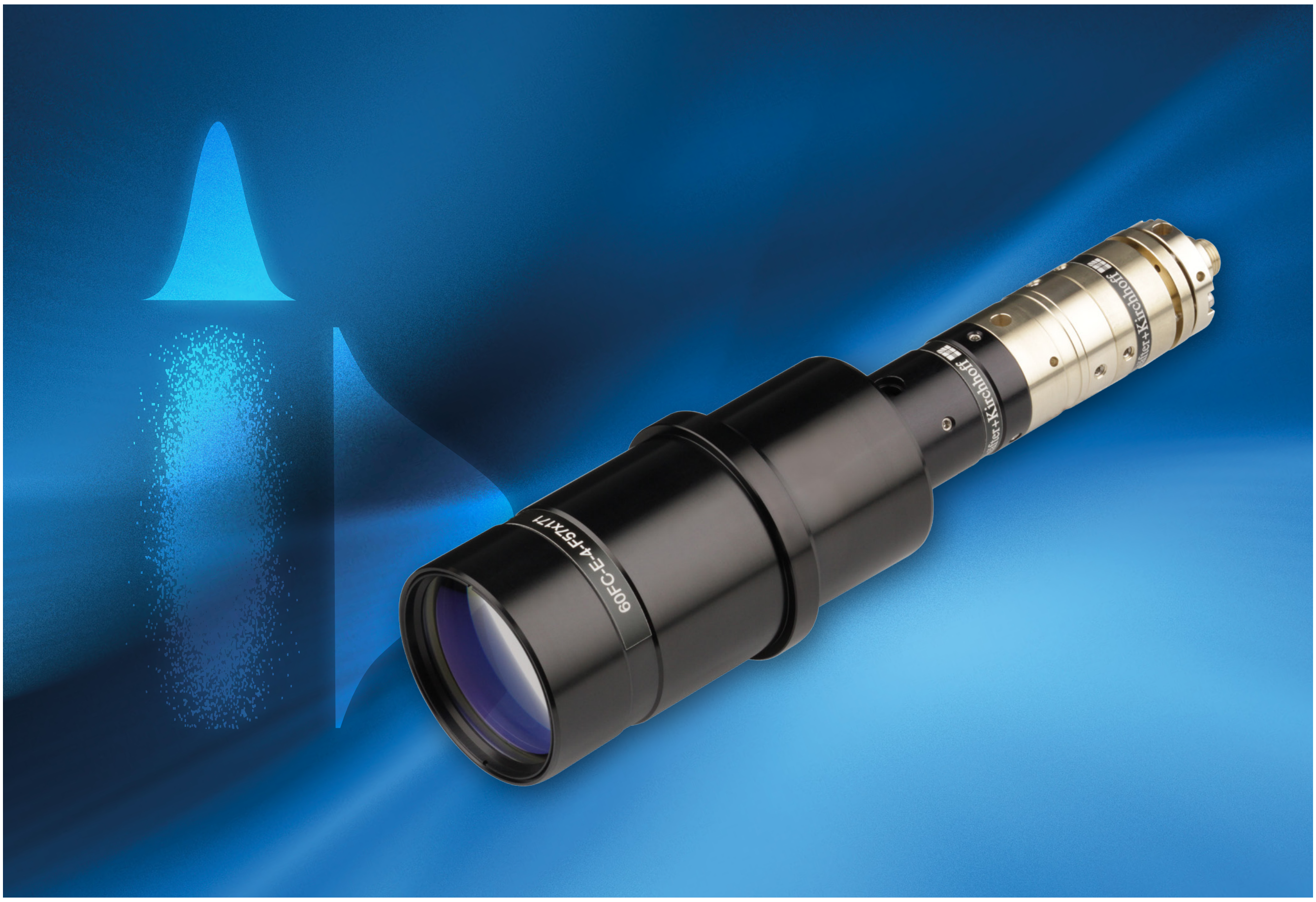

Fig. 1.
Fiber collimator with elliptical beam profile.

The general interest in the investigation of ultra-cold atoms and their distinct features has been constantly growing over the last decades [1]. Whereas in the beginning the process of cooling down presented the major challenge, now the extraordinary features of these ultra-cold systems - for example Bose-Einstein-Condensation - motivate researchers world-wide to look closer than ever. Using fiber-optic equipment has been proven to be a powerful tool for these experiments that profit from the increased stability and convenience. The large variety of requirements e.g. on the collimation for the different quantum optics experiments is resembled in the number of specially designed fiber collimators (Fig.1).
These include fiber collimators with integrated quarter-wave plate for the direct generation of circularly polarized light or anamorphic optics to produce elliptical beams.

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Both the cooling processes and the experimental investigations themselves highly rely on the successful manipulation of atoms by light. This imposes strict requirements on the quality and stability of the equipment used. A widely used effective cooling and trapping method is the magneto-optical trap (MOT). A MOT requires highly frequency-stabilized, narrow width laser radiation to be launched into a vacuum chamber from up to six different directions. There are different type of MOTs, e.g. Rubidium MOTs (working wavelength 780 nm), potassium (767 nm) or strontium- only to name a few.

The beam delivery can be achieved by using a fiber port cluster [2, 3], a compact opto-mechanical unit that splits the radiation from one or more polarization-maintaining (PM) fibers (Polarization Extinction Ratio, PER >26 dB at 780 nm) into one or multiple output polarization-maintaining fiber cables with high efficiency and variable splitting ratio [4]. Fiber port clusters often utilize a cascade of rotary half-wave plates in combination with polarization beam splitters as radiation splitting mechanism.

The polarization-maintaining fiber optics serves as a defined interface between the laser and the very sensitive environment of the experiment. The physical separation enables a mechanical and thermal decoupling, avoiding any negative mutual impacts - both on the laser source and the experiment.

Upon exiting the polarization-maintaining singlemode fiber the diverging Gaussian beam is collimated and launched into the vacuum chamber. The optimal collimation focal length is determined by the beam diameters required by the experiment and can be calculated from the nominal NA (commonly defined by the manufacurer on the 1 - 5%-level of the Gaussian beam) or with better accuracy by using the effective fiber NA_{e^2} [5] of the fiber and the target beam diameter (both defined on the 13.5% or 1/e^2-level). Focal lengths from 2.7 mm up to 200 mm for example when using a fiber with NA_{e^2} 0.09 (or nom. NA 0.11) can produce beam diameters ranging from 0.5 mm to 36 mm. An integrated tilt mechanism allows the alignment of the beam axis to the optical axis, avoiding diffraction arising from a clipped beam and vignetting of the collimated beam. If desired the collimators can be made from amagnetic titanium.

Fiber Collimators with integrated quarter-wave plate

The circularly polarized radiation required for the cooling and trapping mechanism in the MOTs can be provided by using fiber collimators with directly integrated quarter-wave plates (Fig. 2).

The retardation plate is integrated into the divergent beam and can be rotated with respect to the linear input polarization producing right-handed as well as left-handed circular polarization.

Analyzation of the polarization states that are produced during the rotation can for example be made using a Polarization Analyzer [6] that continuously maps the current state of polarization on

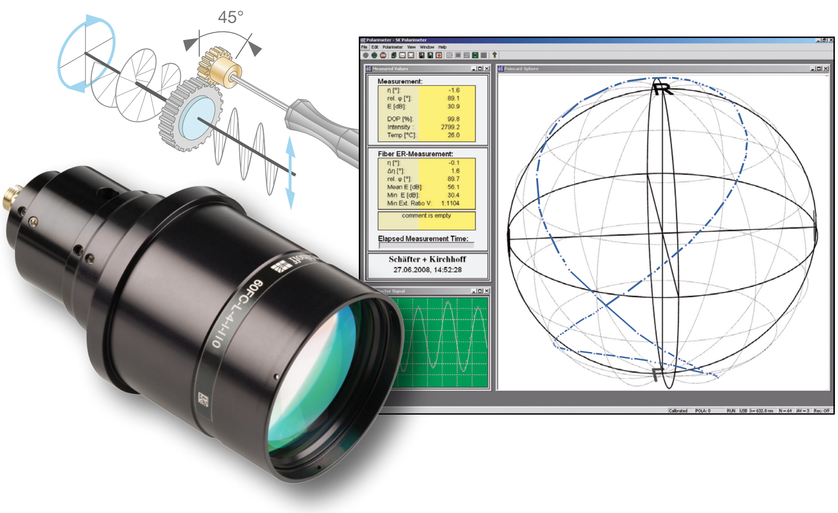

Fig. 2.

Fiber collimators with integrated quarter-wave plate. Right-handed as well as left-handed circular polarization can be produced by rotating the quarter-wave plate using a special tool. The rotation corresponds to a figure-of-eight on the Poincaré sphere.

a Poincaré sphere. In this representation linear states of polarization are located on the equator whereas circularly polarized light is located on the poles.

As can be seen in Fig. 2 a full rotation of the quarter-wave plate corresponds to a figure-of-eight on the Poincaré sphere. At the poles, circularly polarized light is produced with right-handed circular polarization located at the north pole, and left-handed polarization located at the south pole. If the actual retardation of the optics deviates from the desired value then the extreme values do not reach the poles.

The properties of the retardation optics used within the fiber collimators play an important role for the quality of the outcome polarization. Possible error sources include temperature variations, different angles of incidence, as well as wavelength variations. Zero-order, low order, multiple order or compound zero-order wave plates are available that all exhibit a different susceptibility to these error sources.

The change in retardance as a function of wavelength as well the change in retardance as a function of temperature both is directly proportional to the total retardance of the wave plate itself. Thus true zero order, compound zero order or low order wave plates typically are less sensitive to temperature or wavelength variations compared with multiple order wave plates (retardance >1).

True zero order wave plates additionally are often least sensitive to variations in incidence angle. For a quarter-wave plate placed into a diverging beam that exits a fiber with nom. NA 0.11, the incidence angle (5%-level) ranges from ± 6.2°. For such small angles the change in retardance as a function of incidence angle is minimal and can often be neglected or corrected for.

Dichroic fiber collimators

Some MOTs e.g. strontium MOTs are operated with multiple input wavelengths. If the wavelength difference needed is so large that the radiation cannot be transmitted by one single PM fiber, dichroic fiber collimators are used for collimation.

The optical scheme (Fig. 3) shows the two input laser beam couplers that collimate the input beams, the dichroic beam combination and the expansion of the single collimated beam. Even for these collimators it is possible to generate circularly polarized beams by the use of appropriate dichroic quarter-wave plates that generate circularly polarized beams for both wavelengths simultaneously.

Elliptical fiber collimators

In the special case of a dipole trap, laser beams with an elliptical cross-section are required. This is achieved by fiber collimators with integrated anamorphic beam expanders, producing beams with an elliptical aspect ratio of up to 3:1, see Fig. 4.

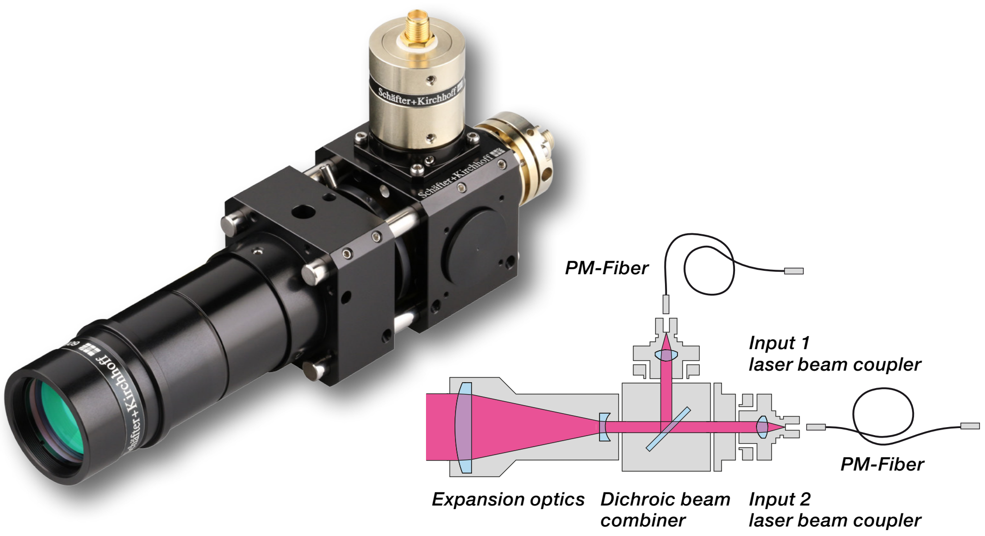

Fig. 3.

Dichroic fiber collimator. The two input beams are collimated, then combined using a dichroic beam combiner and finally expanded to the desired beam diameter.

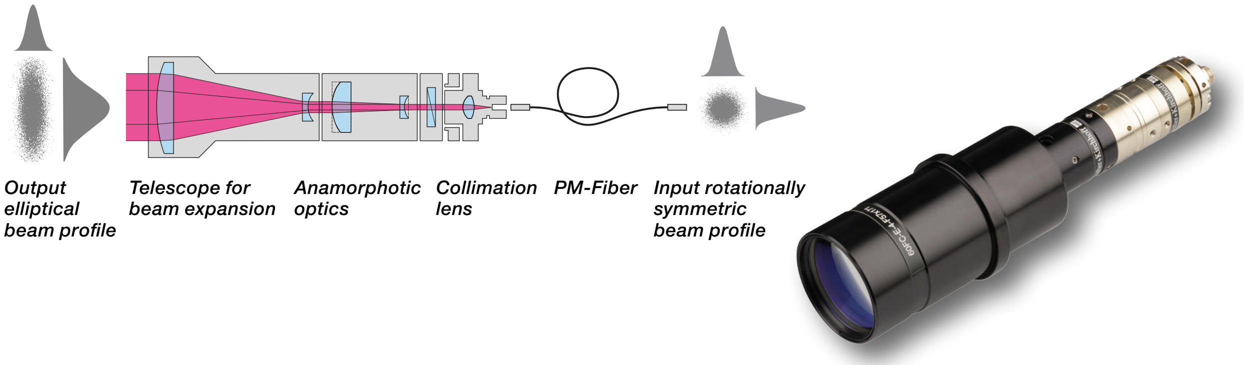

Fig. 4.

Fiber collimators with integrated anamorphic beam shaping optics to produce a collimated Gaussian beam with elliptical cross-section. These fiber collimators are used in dipole traps.

Here the beam is first collimated and then one beam axis is expanded and recollimated using both a positive and negative cylinder lens. Finally the beam is expanded to the desired value using a telescope. If needed, a quarter-wave plate can be integrated into these fiber collimators as well.

Conclusion

Using fiber optics can significantly enhance stability and convenience of measurement setups. For MOTs the different beams needed can be delivered using a fiber port cluster - a compact and stable modular unit that splits the radiation into multiple polarization-maintaining fibers.

In order to meet the various different requirements and high demands of the different experiments a large variety of fiber collimators was specially designed including collimators with integrated quarter- wave plate, dichroic collimators or collimators that produce an elliptical beam profile.

References

[1] W. Ketterle - Nobel Lecture: When Atoms Behave as Waves: Bose-Einstein Condensation and the Atom Laser“. Nobelprize.org. Nobel Media AB 2013. Web. 9 Mar 2014. <http://www.nobelprize.org/nobel_prizes/physics/laureates/2001/ketterle-lecture.html>

[2] G. Varoquaux et al. I.C.E., An ultra-cold atom source for long-baseline interferometric inertial sensors in reduced gravity, arXiv: 0705.2922 (2007)

[3] T. Könemann et al., A freely falling magneto-optical trap drop tower experiment, Applied Physics B: Lasers and Optics 89 (4), 431 (2007)

[4] Schäfter+Kirchhoff GmbH, Optomechanics for demanding fiber optic applications, https://www.sukhamburg.com/support/technotes/fiberoptics/multicube/art_cluster.html

[5] Schäfter+Kirchhoff GmbH, Fiber Coupling to Polarization-Maintaining Fibers and Collimation, https://www.sukhamburg.com/support/technotes/fiberoptics/coupling/couplingsm/art_fibercouplingnae2.html

[6] Schäfter+Kirchhoff GmbH, Polarization Analyzer for fiber optics and free beam applications, https://www.sukhamburg.com/support/technotes/fiberoptics/SK010PA/art_poarizationanalyzer.html