Miniaturization to chip based optical system for a chip-based cold-atom inertial sensor

S. Hello[1,2], H. Snijders[3] †, B. Wirtshafter[3], C.I. Westbrook[2], A. Brignon[3], M. Dupont-Nivet[3]

[1]Thales AVS France SAS, 40 rue de la Brelandière, 86100 Châtellerault, France
[2]Laboratoire Charles Fabry, Institut d'Optique Graduate School, 2 av. Augustin Fresnel, 91127 Palaiseau, France
[3]Thales Research and Technology France, 1 av. Augustin Fresnel, 91767 Palaiseau, France
† Corresponding author's email: henk.snijders@thalesgroup.com

Cold atoms can be used to build an inertial measurement unit that operates autonomously without the need to relay on external information and are an alternative to global navigation satellite system (GNSS) hybridized inertial systems, which are subject to jamming and spoofing [2]. However cold atom based inertial sensors based on free falling atoms remain too large for many inertial navigation applications. In order to overcome this limitation, we are developing an atom chip inertial sensor with an atom chip that allows the trapping and manipulation of a thermal cloud near its surface throughout the duration of the inertial measurement [3-4].

Here we miniaturized the complex optical system responsible for the cooling, pumping, and imaging of an on-chip based cold-atom inertial sensor [1]. The optical system is miniaturized in two steps: first we build an optical bench that has a volume of 35x25x5 $cm^3 \approx 4.3$ L and in the second step to further reduce the size of the optical system a photonic integrated circuit (PIC) with a volume of 4x2x0.1 $cm^3 \approx 8x10^{-4}$ L is developed. Using the miniaturized bench and PIC, we realized two- and three-dimensional magneto-optical traps for rubidium 87 atoms.

With the optical system, we also developed a laser frequency lock adapted to the optical bench and PIC using saturated absorption in a rubidium cell. The laser beams used to characterize the optical system are frequency locked using saturated absorption spectroscopy in a Pound–Drever–Hall scheme on the pumping laser and using the beat note between the cooling laser and repumping laser. The entire laser source system based on frequency doubling of 1.56 nm fiber lasers including the control system and the saturated absorption module fits in a 5U rack.

The demonstrated volume reduction of the optical system paves the way for a chip-based stand-alone sensor for inertial navigation of moving platforms.

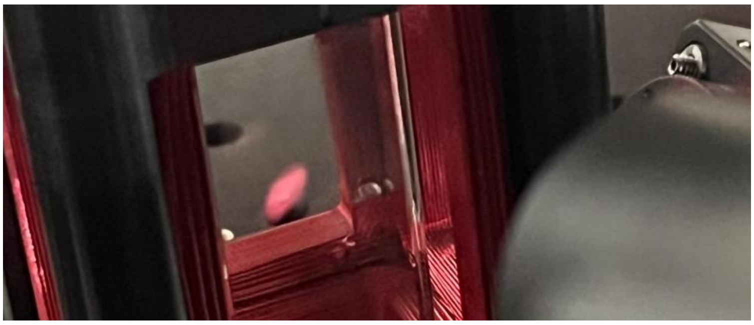

Figure 1: Image of 3DMOT obtained using an optical bench to control the laser beams.

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References

[1] S. Hello, H. Snijders, B. Wirtshafter, et al., "Miniaturized optical system for a chip-based cold-atom inertial sensor", *Applied optics*, 64, 2811, (2025).
[2] 1. R. Geiger, A. Landragin, S. Merlet, et al., "High-accuracy inertial measurements with cold-atom sensors," AVS *Quantum Sci.* 2, 024702 (2020).
[3] 6. P. Böhi, M. Riedel, J. Hoffrogge, et al., "Coherent manipulation of Bose–Einstein condensates with state-dependent microwave potentials on an atom chip," *Nat. Phys*. 5, 592–597 (2009).
[4] 7. T. Schumm, S. Hofferberth, L. M. Andersson, et al., "Matter-wave interferometry in a double well on an atom chip," *Nat. Phys*. 1, 57–62(2005).