Supplementary Material to the article "Atomic chip and diffraction grating for laser cooling of ytterbium atoms"

The temperature and the number of atoms captured in magneto-optical trap estimation method

Experiments to determine the optimal parameters of the ^{171}Yb and ^{174}Yb first stage laser cooling were carried out in a scientific chamber, a simplified diagram of which is shown in Fig. S1. Atomic cloud is captured using a conventional six-beam magneto-optical trap (MOT). CCD camera with converging lens makes it possible to register an image of a cloud at a required time. The probe beam is used to measure the temperature of atoms: it illuminates the cloud after a short period of time from turning off the MOT. There is no slowing beam in the installation. At a certain cooling radiation frequency detuni from the resonance of the $^1S_0 - {}^1P_1$ transition, the maximur number of atoms can be captured.

The number of atoms in the MOT was estimated from image taken by CCD camera, using the following formula:

$$N_{at} = \frac{2\tau\lambda(1+S_0+(4\pi\tau\Delta)^2)k_{grad}\Delta t_{grad}\Sigma_{px}I_{px}}{hcfT_0S_0\Delta t\cdot 2^{(u/128)}} \quad \text{(S1)}$$

where λ – $^1S_0$ - $^1P_1$ transition wavelength in ytterbium, τ – lifetime of the $^1P_1$ state, S_0 – saturation parameter, Δ – MOT radiation detuning from $^1S_0 - {}^1P_1$ resonance, k_{grad} – camera grading coefficient, which connects the brightness of a pixel in image (from 0 to 255) I_{px} with the radiation power per 1 pixel and has been determined experimentally, Δt_{grad} – CCD camera exposition time during graduation, Δt and u – CCD camera exposition time and gain when taking an image of an atomic cloud to estimate number of atoms, T_0 – transmission of the optics between cloud and CCD camera, f – the ratio of the solid angle captured by the imaging system (in our case, it is determined by the lens in front of the CCD camera) to the total solid angle 4π, h – Planck's constant, c – speed of light in vacuum.

Estimation method of the temperature of atoms in the MOT is based on the atomic cloud expansion speed. Measuring the root-mean-square cloud radii r_{rms1} and r_{rms2} from images taken after the passage of time intervals t_1 and t_2 from turning off the MOT, the value of expansion speed v_{rms} can be calculated:

$$v_{rms}^2 = \frac{r_{rms2}^2 - r_{rms1}^2}{t_2^2 - t_1^2} \quad \text{(S2)}$$

Knowing the atomic mass m, the temperature can be estimated from the formula:

$$T = \frac{mv_{rms}^2}{k_B} \quad \text{(S3)}$$

where k_B is Boltzmann's constant.

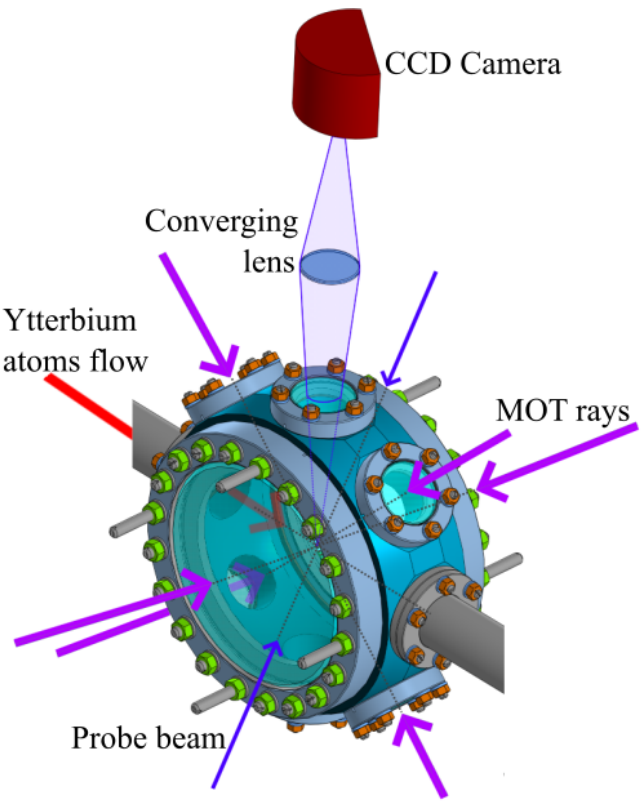

Fig. S1: The scientific chamber simplified diagram.

Atom chip structure

An atom chip for laser cooling of ytterbium atoms should be created from the following layers:

1. Silicon substrate with a thickness of 500 microns. It is necessary for the placement of microwires.

2. A thin layer of silicon oxide for electrical insulation of microwires.

3. A layer of chromium with a thickness of 100 nm to ensure high adhesion of the overlying layers to the substrate.

4. A current-carrying layer of silver with a thickness of 10 microns. Silver has a high electrical conductivity, which makes it possible to reduce ohmic heating.

5. A layer of aluminum with a thickness of about 200 nm. This layer is necessary to reflect laser beams with wavelengths of 399 nm and 556 nm from the chip surface to cool Yb atoms in a mirror-MOT.

6. Silicon oxide layer 50 nm thick to prevent aluminum from interacting with the environment.