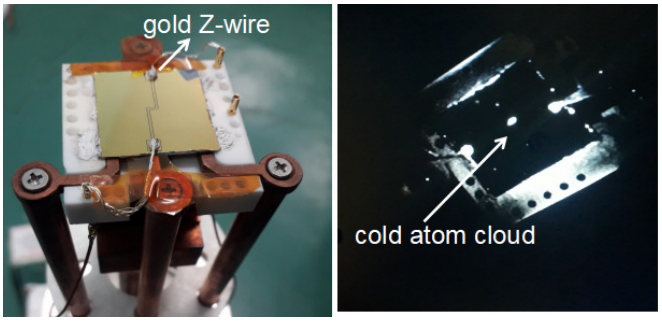
## L.3: Magnetic trapping of Rb atoms on an atom-chip

An atom-chip is a device, which is used for trapping the cold atoms in the miniaturized or tiny magnetic traps (called micro magnetic traps) formed due to magnetic field of micron size current carrying wires on the chip. The atom-chip is anticipated to play an important role in the development of miniaturized atom-optic devices for sensing, metrology and quantum information applications. Due to high magnetic field gradient and high curvature offered by the micron size wires on the atom-chip, the traps on the atom-chip provide a tighter confinement of atoms, which results in a higher number density in the magnetic trap. This finally may yield a faster realization of Bose-Einstein Condensation (BEC) degeneracy due to a higher thermalization rate during the evaporative cooling process.

Here, we report the magnetic trapping of cold $^{87}$Rb atoms on an in-house developed atom-chip. An Ioffe-Pritchard (IP) type magnetic trap was formed by magnetic field due to a current carrying z-shaped micron size (200 µm x 2.5 µm cross-section) wire, inscribed on the atom-chip as shown in Figure L.3.1(a) in the presence of uniform magnetic fields due to bias coils. The atom-chip (size nearly 25 mm x 25 mm) was prepared by gold coating of a silicon substrate after deposition of $SiO_2$ and chromium layers. The wires were inscribed by lithographic techniques. The number of atoms trapped in the magnetic trap was ~ $4x10^6$ with a life-time of ~ 65 ms. This atom-chip trap is first of its kind working in the country. The atom trapping on the chip has been integrated with initial laser cooling of atoms in a magneto-optical trap (MOT) followed by magnetic trapping in mirco-trap of the chip wire.

There are various steps from MOT formation to magnetic trapping on atom-chip. The sequence of these events is controlled by an in-house developed PC-controlled field-programmable gate array (FPGA) based controller system. The atom-chip is kept in an ultra-high vacuum (UHV) chamber ($1x10^{-10}$ Torr) and its face is in the downward direction. First of all, U-MOT is formed near atom-chip surface by using four cooling laser beams (mixed with re-pumper beams), two reflecting on chip and two counter propagating and parallel to the chip plane. An U-shaped external wire (60 A current) along with the bias fields ($B_y$ ~ 10 G and $B_z$ ~ 1.5 G) is used to generate the quadrupole field for MOT. The duration of this stage is nearly 20 s. The U-MOT is formed ~ 6 mm below the chip surface. The number of cold $^{87}$Rb atoms trapped in U-MOT was ~ $5x10^7$ (the atom cloud image is shown in Figure L.3.1(b)). The second step is the compressed MOT (C-MOT), which was achieved by changing the current from 60 A to 80 A in U-wire and increasing the bias field ($B_y$) from 10 G to 27 G in the duration of 90 ms. Due to this, the MOT cloud was shifted to a position of ~ 1.2 mm from the chip surface. In the third step, the gray-MOT (G-MOT) is realized by varying the detuning of the cooling laser beam from -30 MHz to -54 MHz in a span of ~ 10 ms after the C-MOT.

The number and temperature of atoms were ~ $1x10^7$ and ~ 100 µK, respectively at the end of G-MOT stage. After G-MOT, all the magnetic fields and laser lights were switched-off in 1.5 ms, and 2 A current in micron size gold Z-wire on atom-chip was switched-on along with a bias field of 9 G in ~ 500 µs. This led to the formation of a micro-magnetic trap of IP type in which atoms were trapped.




(a) (b)

*Fig. L.3.1: (a) Photograph of mounted atom-chip showing gold Z-wire on it, which is used for micro magnetic trapping of $^{87}$Rb atoms, and (b) CCD image of atom cloud of $^{87}$Rb atoms in U-magneto optical trap (U-MOT) near the chip surface.*

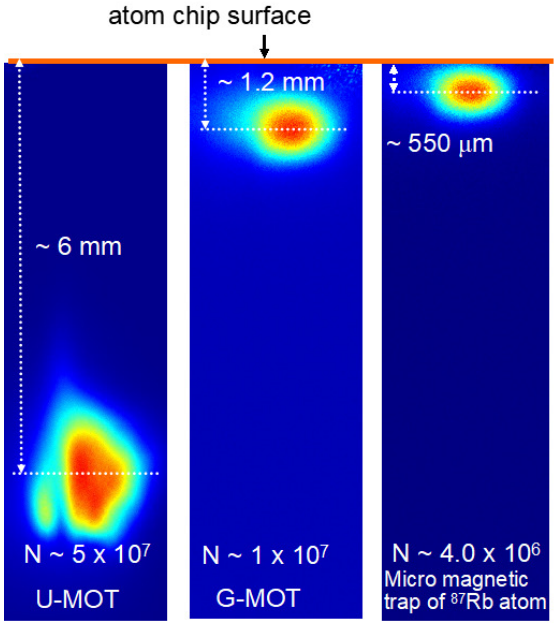



*Fig. L.3.2: Processed CCD images of atom clouds in U-MOT, in G-MOT and in micro magnetic trap on atom-chip.*

Fig. L.3.2 shows the cloud images in MOT stages as well as image of atom cloud in IP micro-magnetic trap near the atom-chip surface (~550 µm below the atom-chip surface). The number of cold $^{87}$Rb atoms in the IP type micro-magnetic trap was ~ 4 x $10^6$. The atom-chip was fabricated in-house in collaboration with Laser Technology Division and Synchrotron Utilization Section.

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