Atom Chip with a Permanent Magnetic Film

B. Hall, S. Whitlock, F. Scharnberg, J. Wang, R. McLean,

P. Hannaford and A. Sidorov

ARC Centre of Excellence for Quantum-Atom Optics,

Centre for Atom Optics and Ultrafast Spectroscopy,

Swinburne University of Technology

Melbourne, Australia

SWINBURNE UNIVERSITY OF TECHNOLOGY

ACQAO

BEC on a Chip

- **Scaling down dimensions of atom optical elements**

- **Large values of trap frequencies and tight confinement of matter waves**

- **Highly anisotropic microtraps (1D quantum gases)**

- **Networks of microtraps, waveguides, couplers, gratings (integrated atomic circuits)**

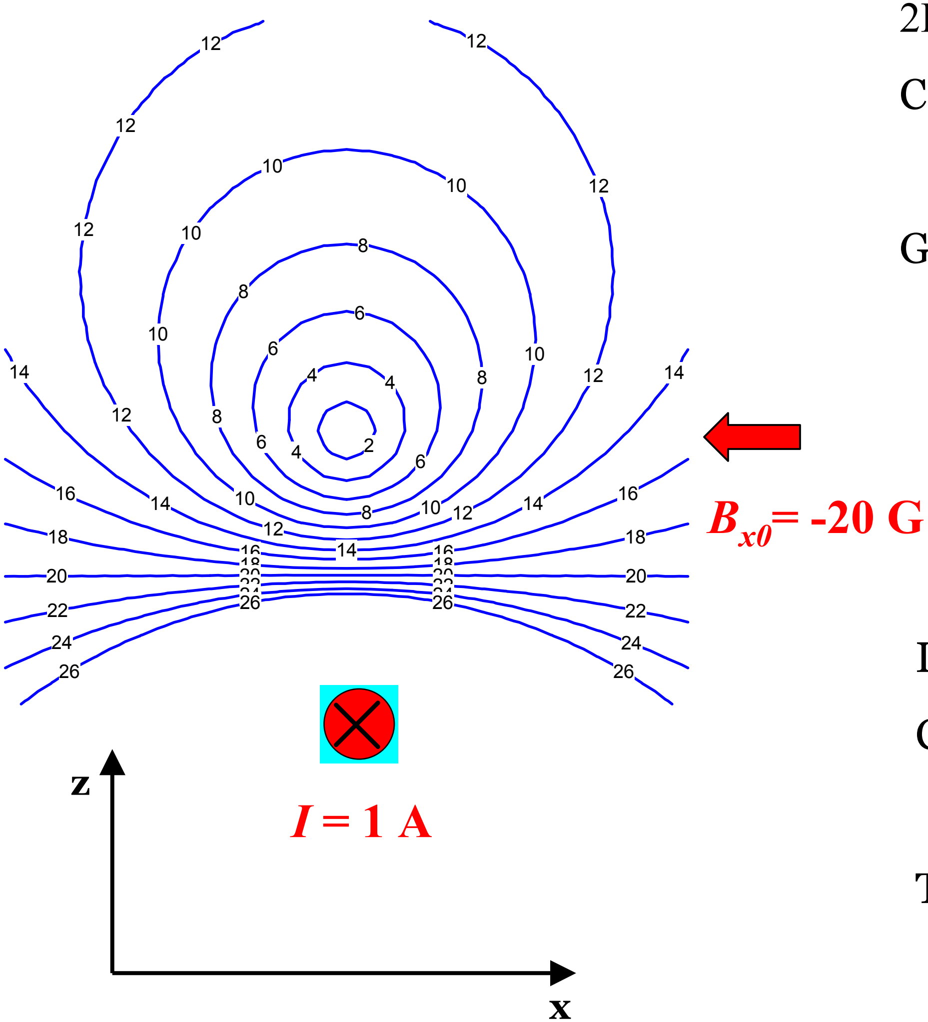
- **Storage of matter waves on a chip**

- **Magnetic lattice**

BEC on a Chip achieved in

Munich, Tubingen, Heidelberg, Sussex/London, Stanford, Boston, Orsay, Boulder, Brisbane.

Atom Chip - Principle



2D quadrupole potential:

Centre at $$z_0 = \frac{2I}{B_{x0}} = 100 \quad \mu m$$

Gradient $$\nabla B = \frac{2I}{z_0^2} = 2 \quad \frac{kG}{cm}$$

If add B_{yo} then 2D harmonic potential

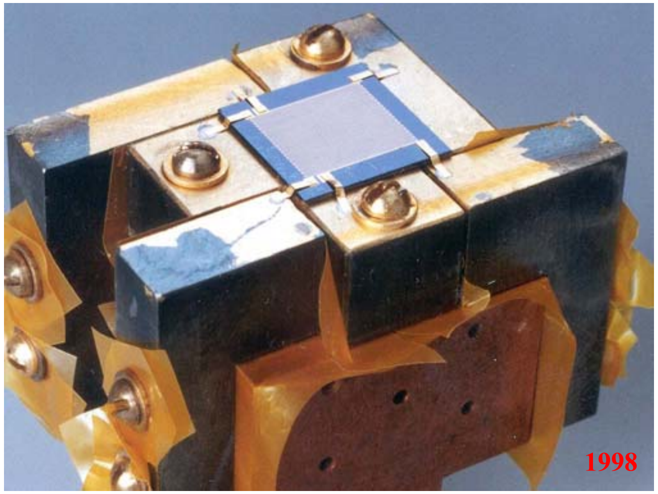
Curvature $$\frac{\partial^2 B}{\partial x^2} = \frac{4I^2}{z_0^4 B_{y0}} = 4\times 10^6 \quad \frac{G}{cm^2}$$

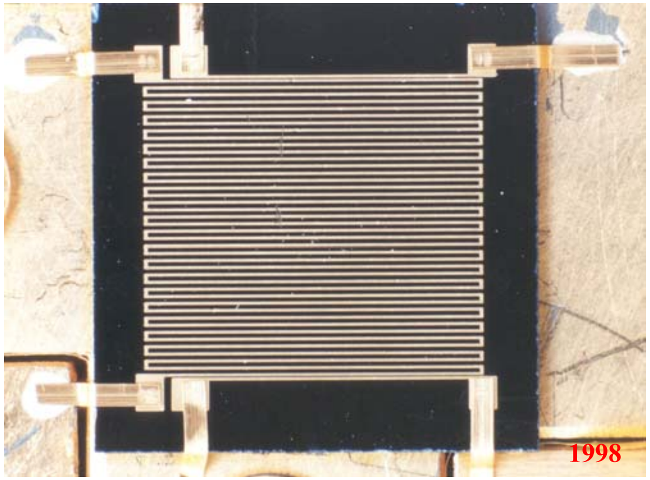
Trap frequency (B_{yo}=1 G)

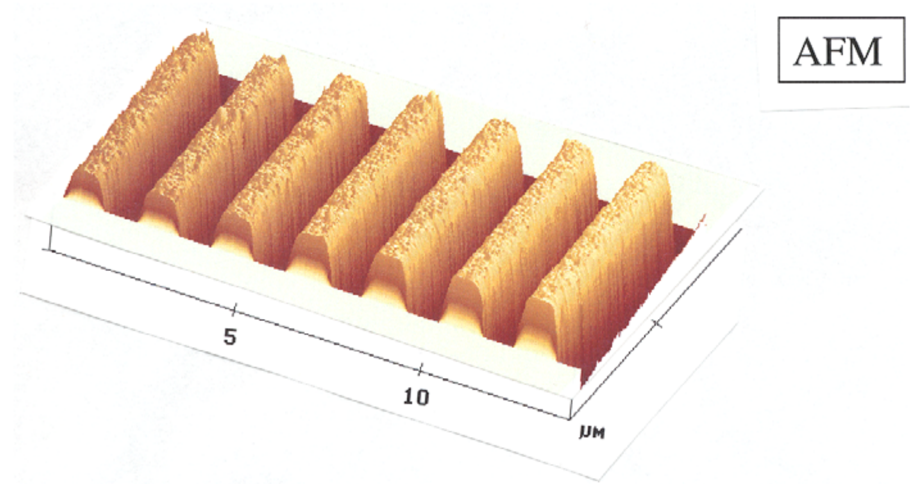
$$\frac{\omega}{2\pi} \approx 1.3\sqrt{\frac{\partial^2 B}{\partial x^2}} \approx 5 \quad kHz$$

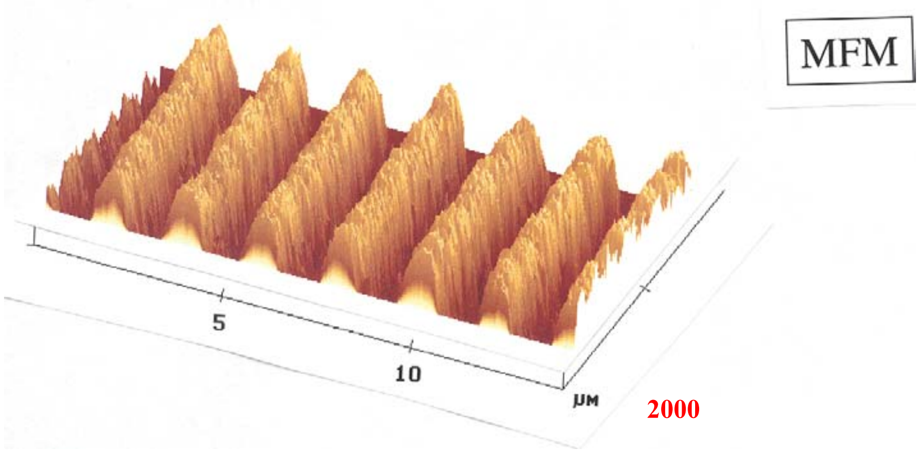
Current-Carrying Wire Mirror

Magnetic Film Mirror









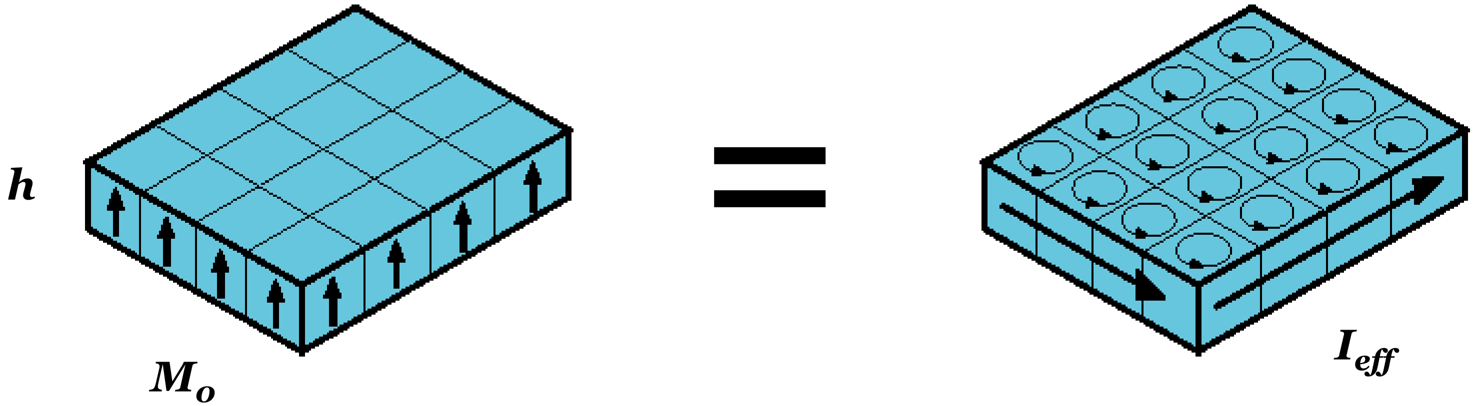
Gold wires on a silicon substrate

D. Lau *et al*, *Europ. Phys. J.* D5, 193 (1999)

Microstructured magnetic film

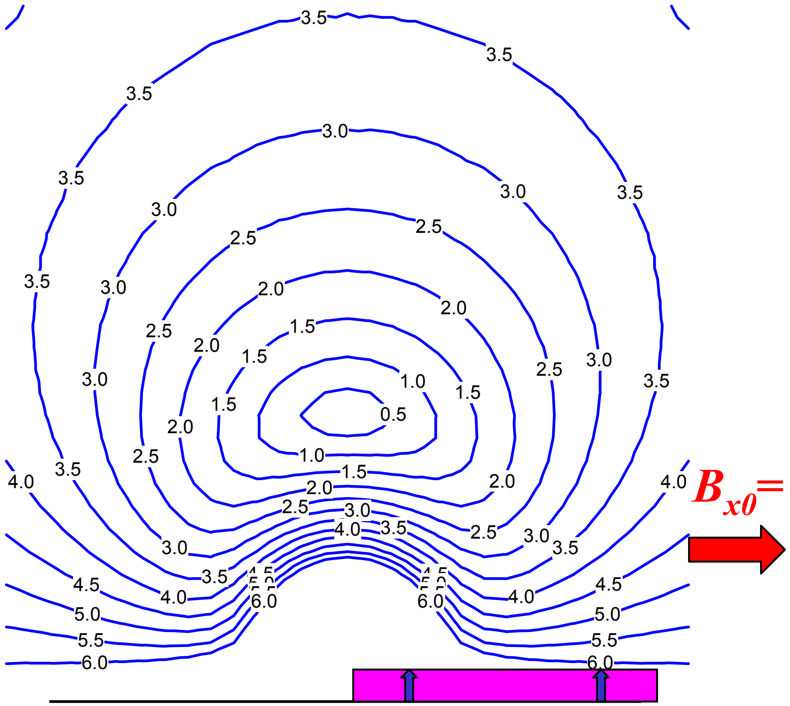
A. Sidorov *et al*, *Comptes Rendus 2*, Series IV, 565 (2001)

Model of a Magnet



$M_o \times h$ is an “effective current” I_{eff}

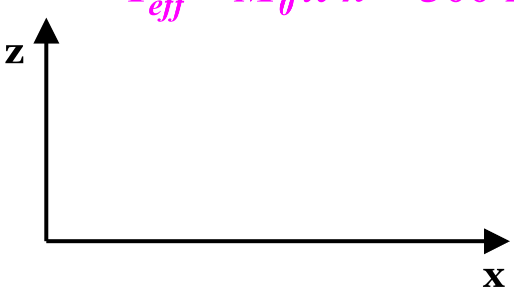
Magnetic Film Waveguide



B_{x0} = 6 G

$4\pi M_0$ = 3.8 kG, 1 μm thick

$I_{eff} = M_0 \, x \, h$ = 300 mA



2D quadrupole potential:

Centre at

$$z_0 = \frac{2hM_0}{B_{x0}} = 100 \quad \mu m$$

Gradient

$$\nabla B(x=0,z) = \frac{2hM_0}{z_0^2} = 600 \quad \frac{G}{cm}$$

If add B_{yo} then 2D harmonic potential

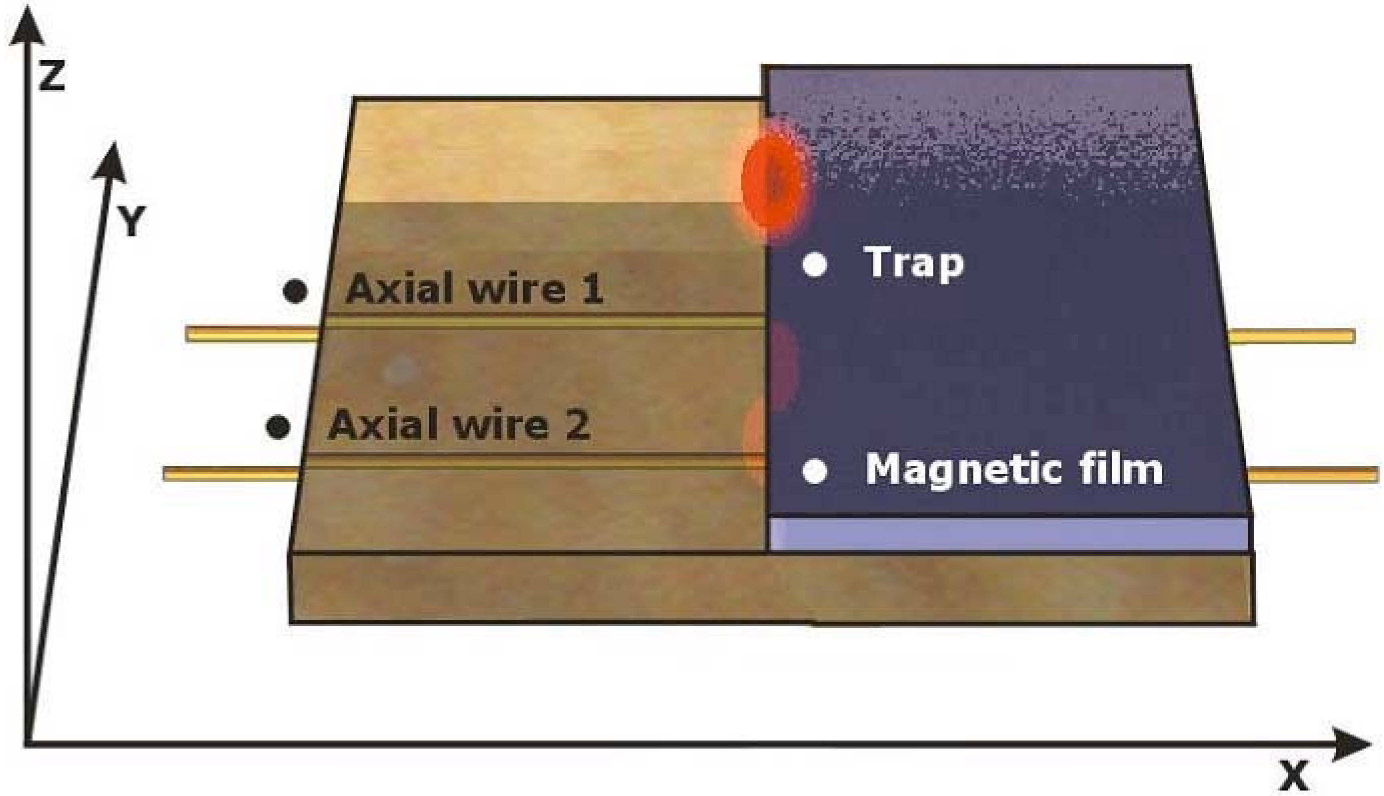
Curvature

$$\frac{\partial^2 B}{\partial x^2}(x=0,z) = \frac{4h^2 M_0^2}{z_0^4 B_{y0}} = 3.6\times 10^5 \, \frac{G}{cm^2}$$

Trap frequency (B_{yo}= 1 G)

$$\frac{\omega}{2\pi} \approx 1.3\sqrt{\frac{\partial^2 B}{\partial x^2}} \approx 780 \quad Hz$$

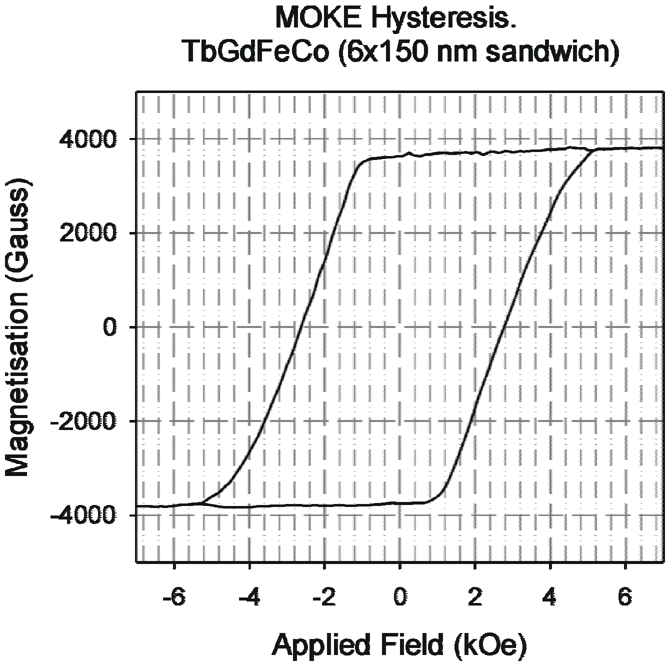
Magnetic Trap: magnetic film + wires

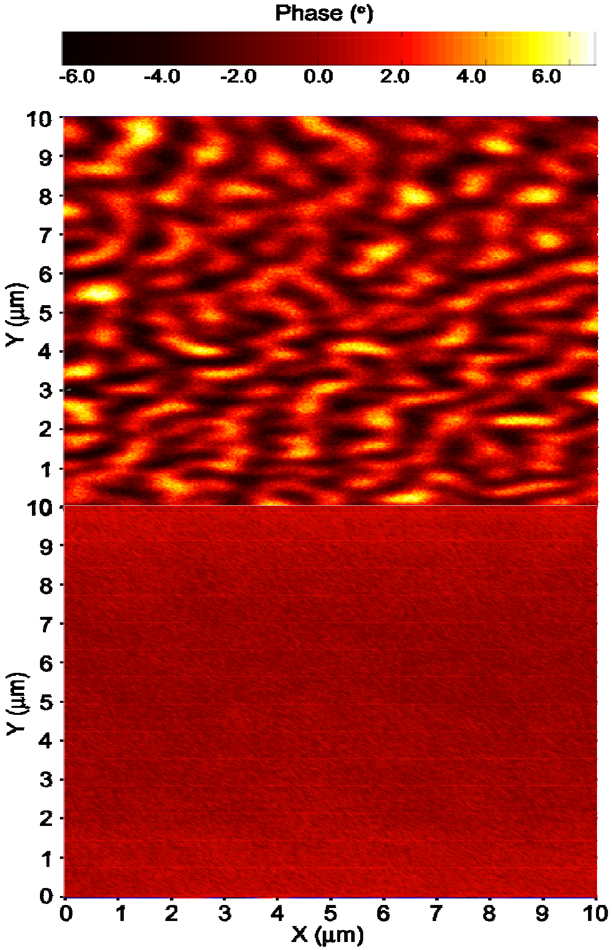


Magnetic film GdTbFeCo

- ***Composition*** $Gd_{9.6}Tb_6Fe_{80}Co_{4.4}$
- ***Thickness 1 μm (sandwich structure of 6 layers)***
- ***Remanent magnetisation*** $4\pi M_o = 3.8$ ***kG***

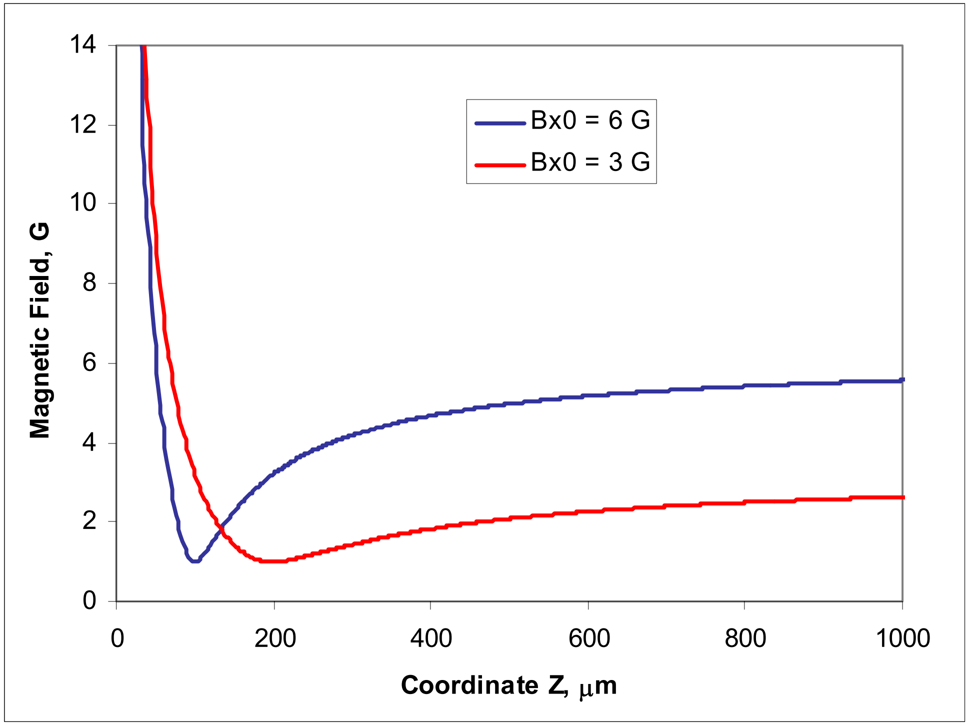
  $(I_{eff} = M_o h = 300$ ***mA)***
- ***Coercivity 2.5 kG***
- ***Curie temperature*** 300^0C



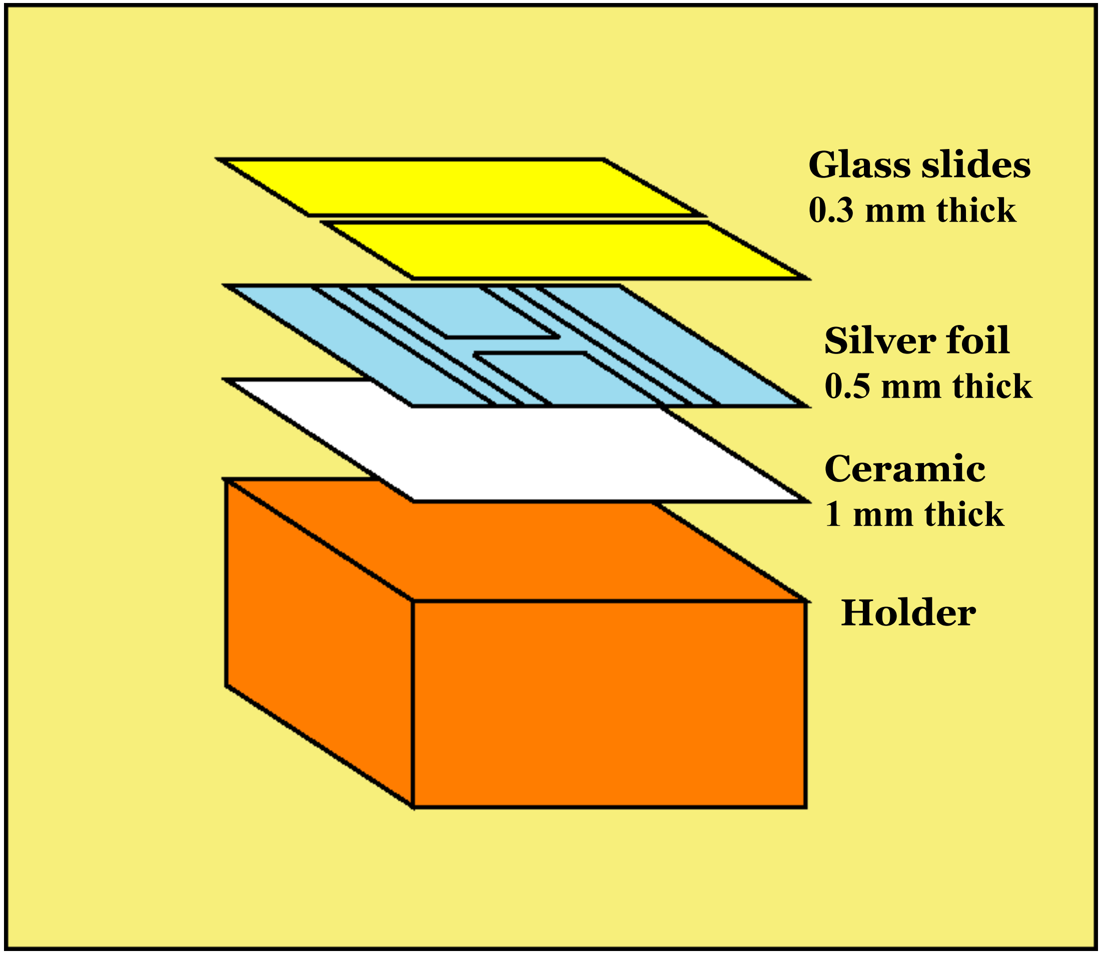


MFM images of unmagnetised (Top) and magnetised (Bottom) TbGdFeCo films

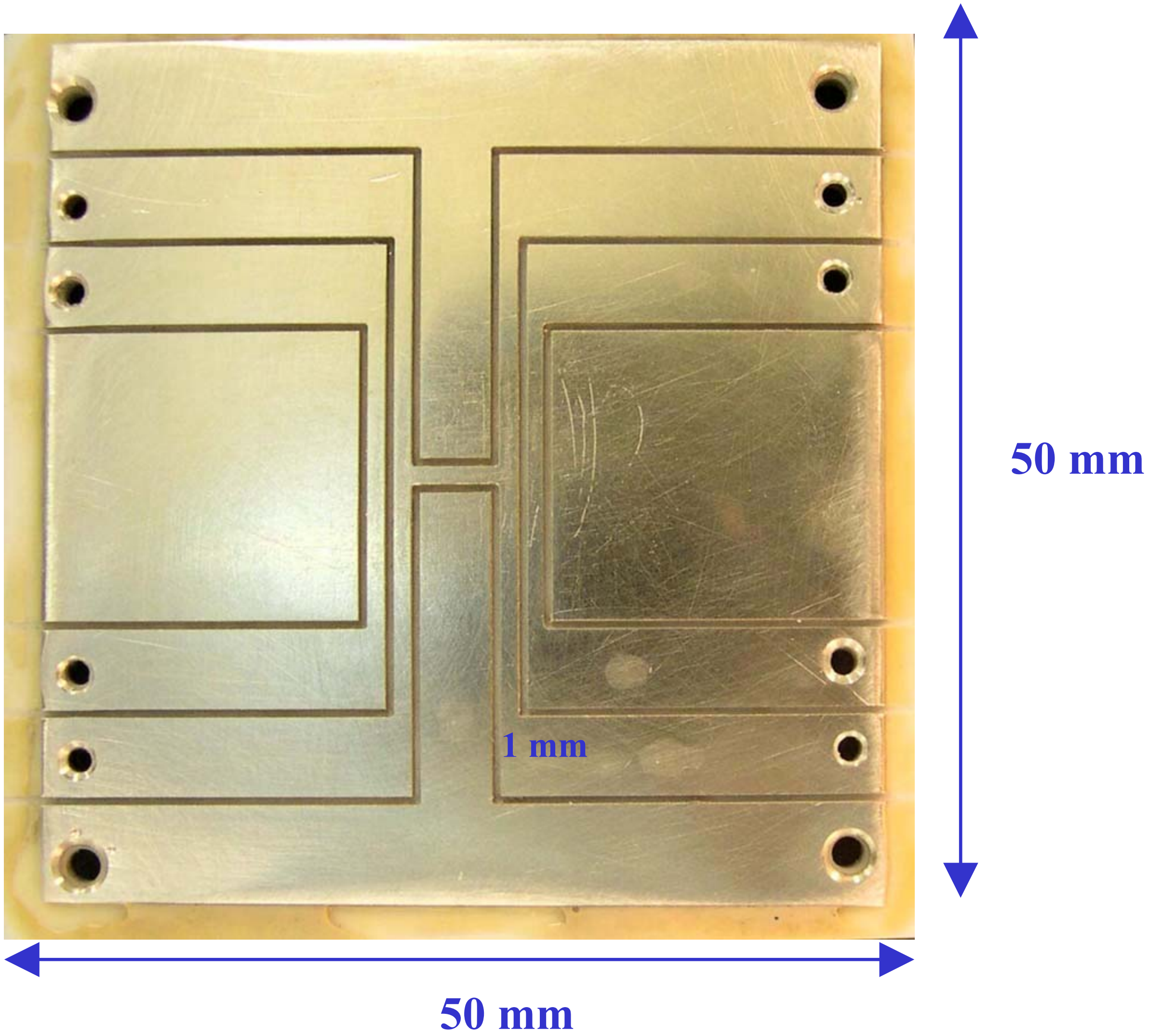
Magnetic film: trap limits



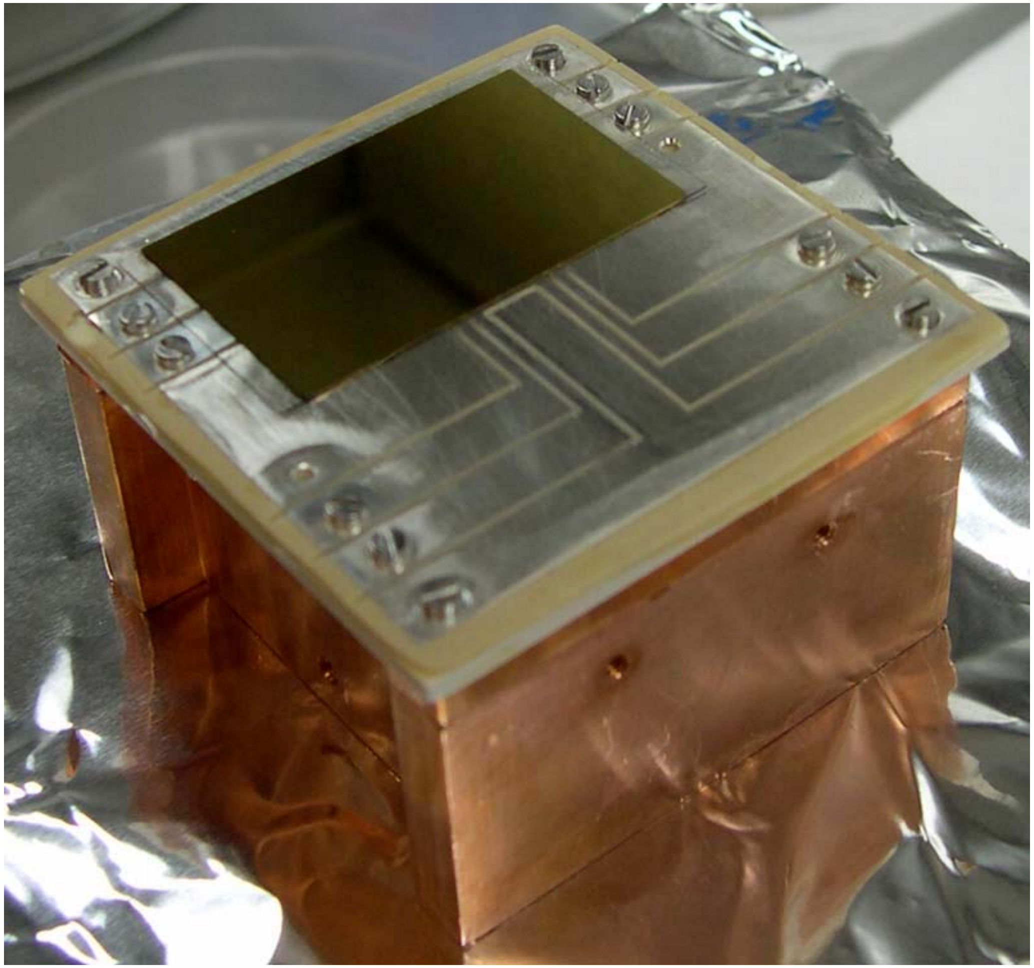
Atom Chip - Design



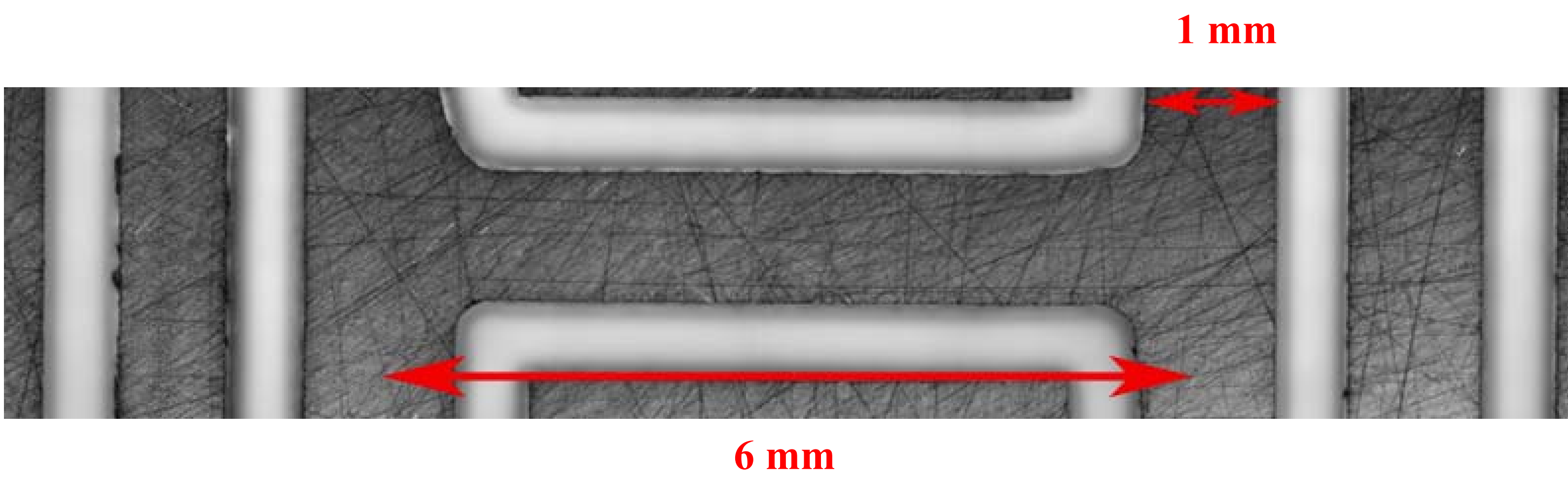
Current-Carrying Wires

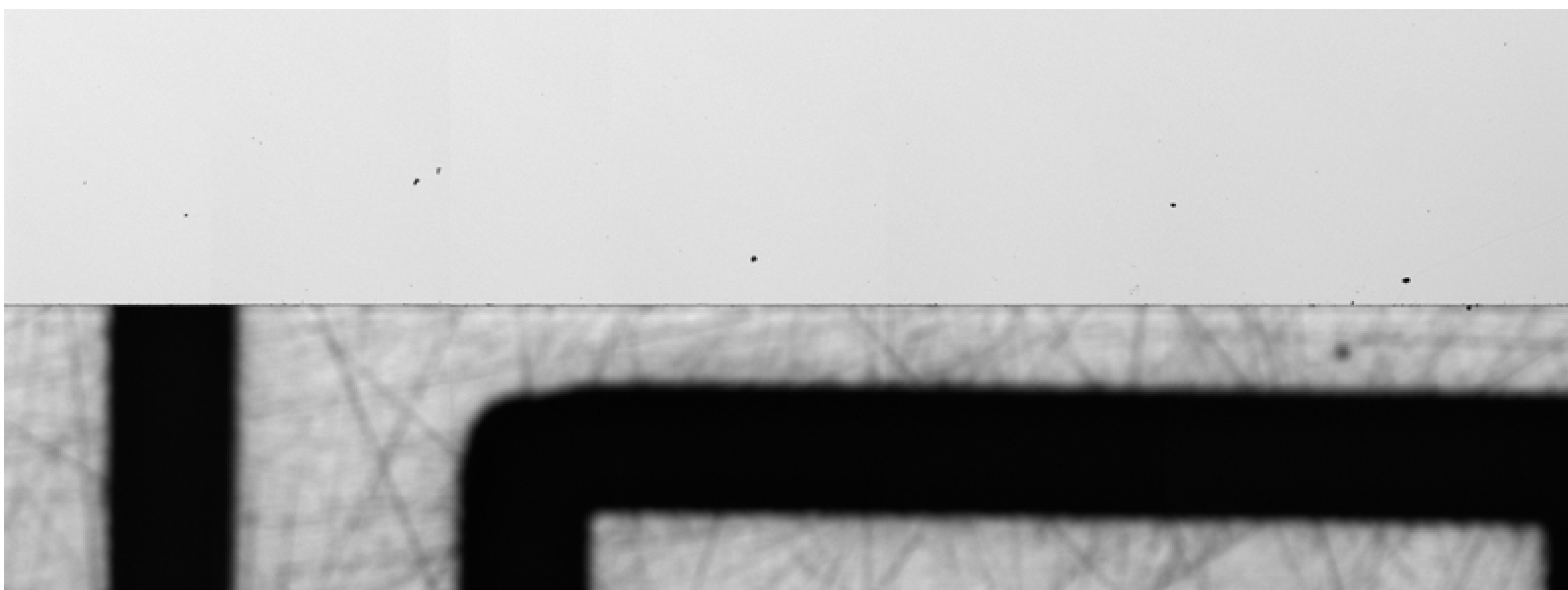


Magnetic Film & Wires

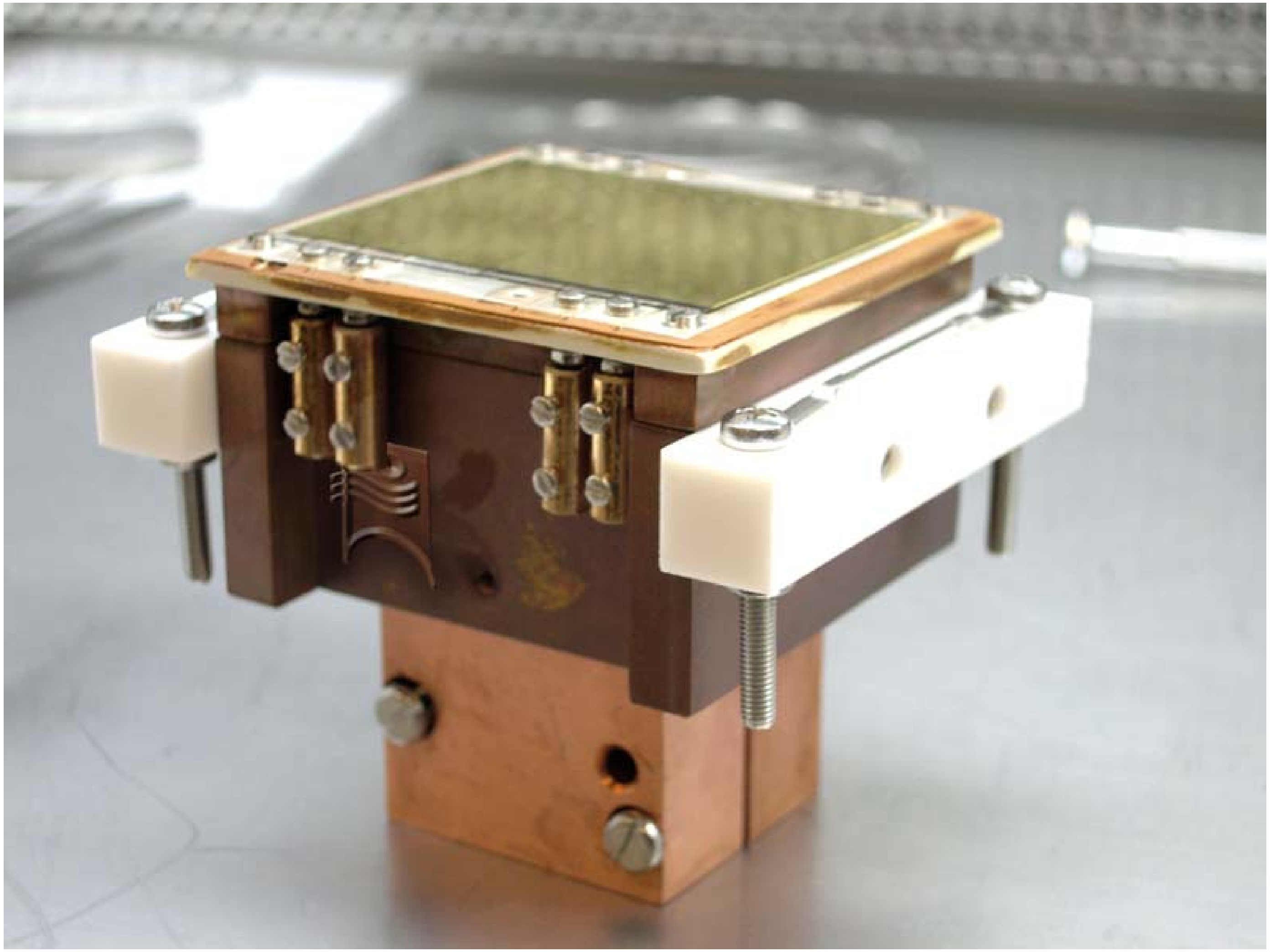


Under Microscope

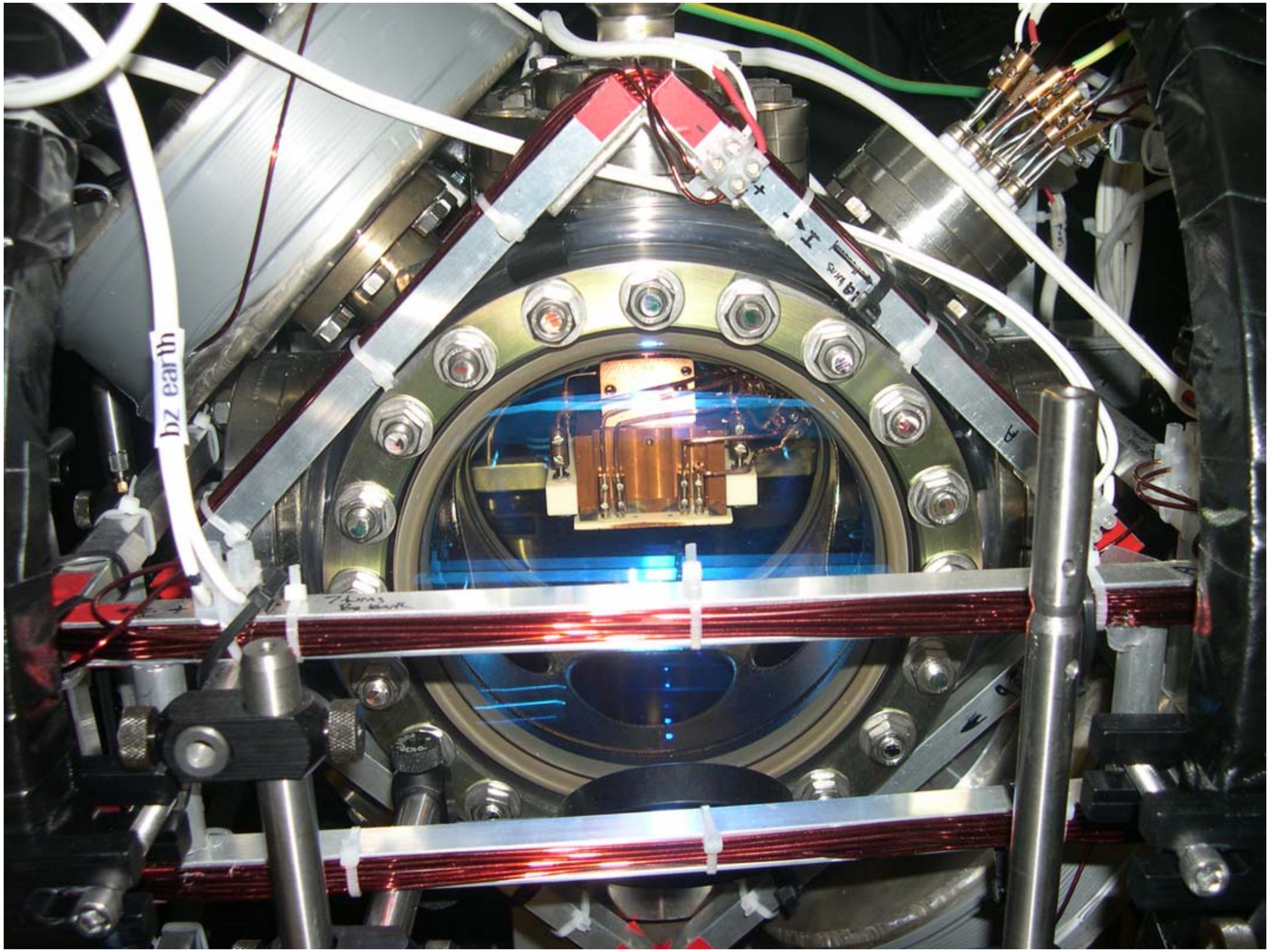




Atom Chip

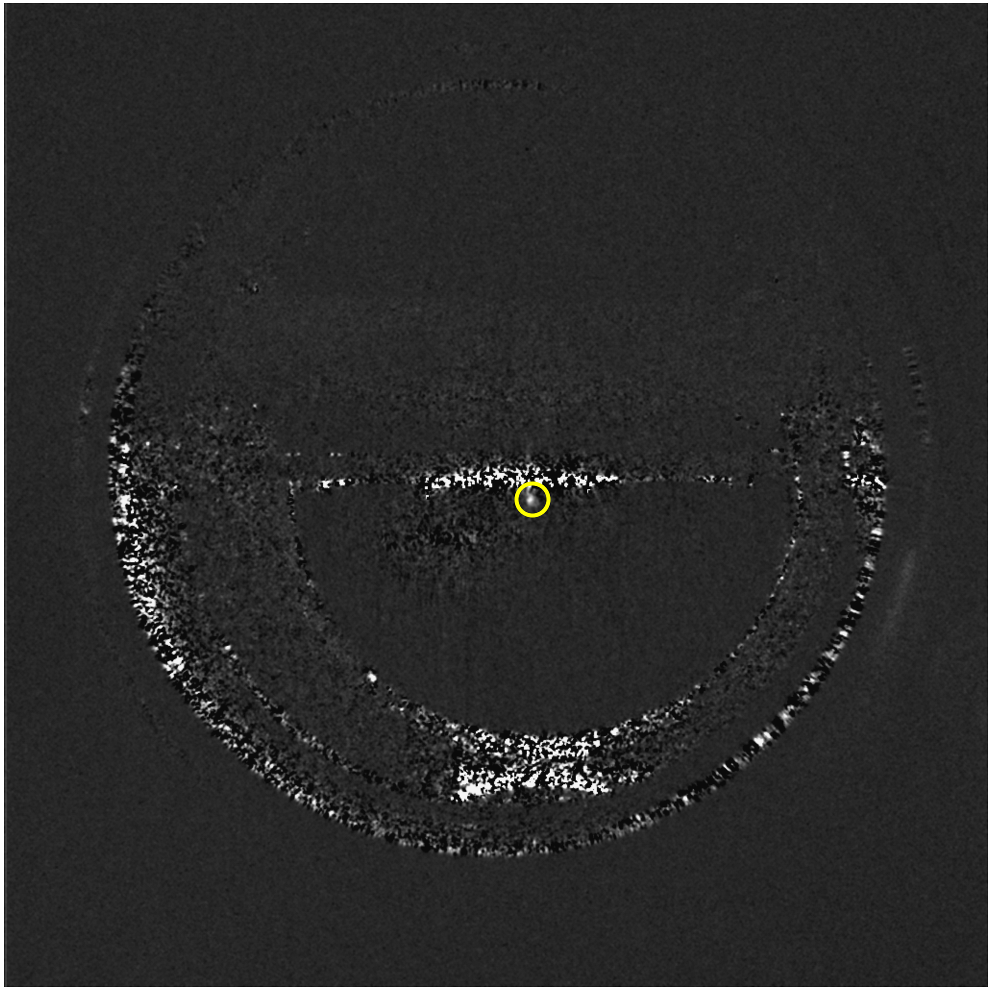


Atom Chip



$p < 1 \times 10^{-11}$ Torr

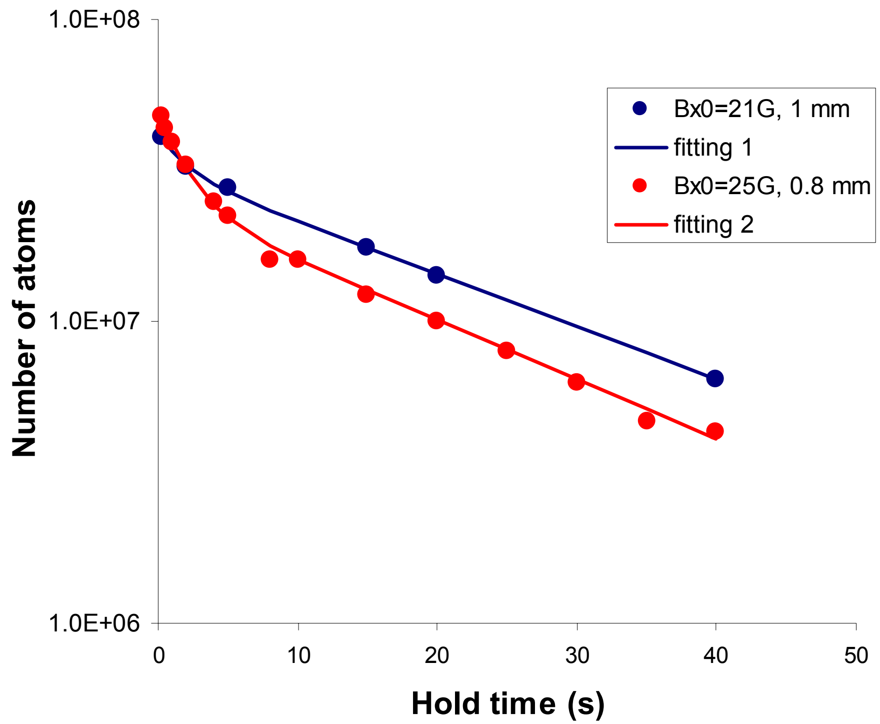
Magneto-Optical Trap:
Film + Two Axial Currents

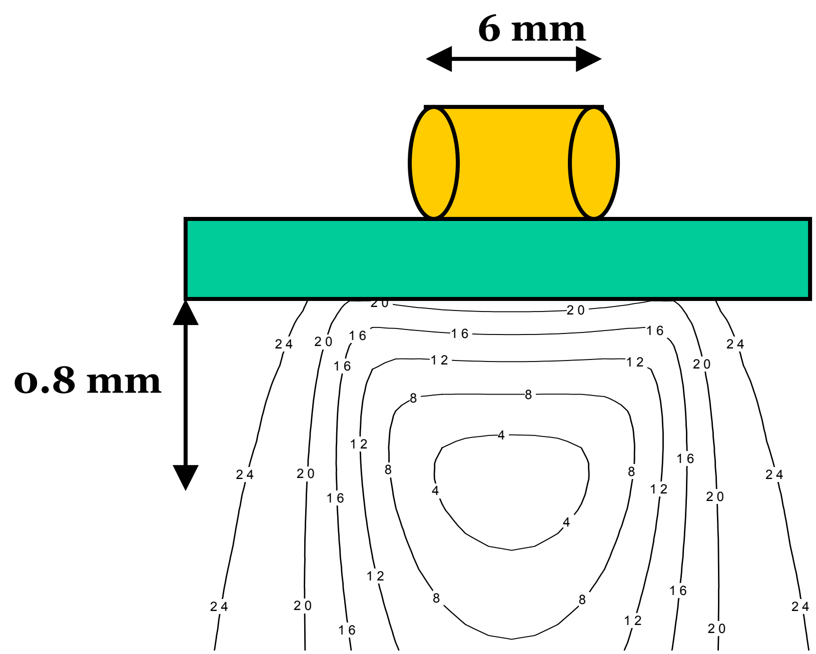


Loading Sequence

Step	pressure	number of atoms	T	distance from surface
Current 6.5 A through dispenser for 12 s	**1×10^{-10} Torr**			
Quadrupole reflection MOT (∇B = 10 G/cm, 25 s holding)	**7×10^{-11} Torr**	**2.5×10^{8}**	**90 μK**	**6.5 mm**
U-wire reflection MOT (∇ B = 10 G/cm):		**2.5×10^{8}**	**90 μK**	**5 mm**
Compressed and red detuned MOT (∇ B = 40 G/cm)				**2 mm**
Optical pumping into the F = 2 m_F = +2 state		**2.3×10^{8}**	**65 μK**	**2 mm**
Z-wire magnetic trap (I = 13 A, B_x = 10 G, ∇ B = 40 G/cm):		**4×10^{7}**		**2 mm**
Compressed Z-wire magnetic trap (I = 19 A, B_{xo} = 21 G, B_{yo} = 4.2 G, B_{offset} = 0.7 G, ∇ B = 150 G/cm, ν_{rad} = 230 Hz, ν_{ax} = 20 Hz):		**4×10^{7}**	**150 μK**	**1 mm** **1.6 mm from wire centre**

Lifetime in compressed MT



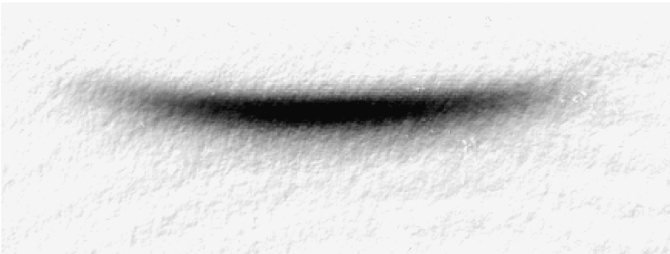


Fitting 1: $N(t) = 3.2\times10^{7} e^{-t/25s} + 10^{7} e^{-t/1.8s}$

Fitting 2: $N(t) = 2.5\times10^{7} e^{-t/22s} + 2.5\times10^{7} e^{-t/2s}$

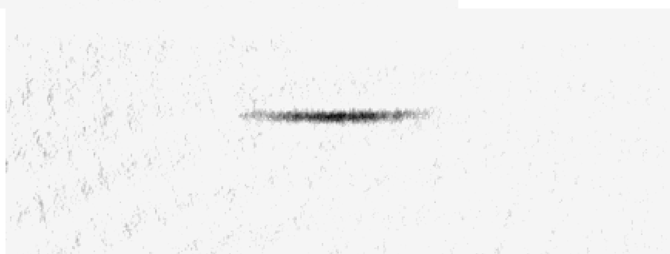
Long lifetime τ_{loss} **= 25 s** – background pressure 7 × 10^{-11} Torr

Imaging of atoms during RF evaporative cooling



1 s, 14.5 MHz

8 s, 2.8 MHz



11 s, 1.5 MHz

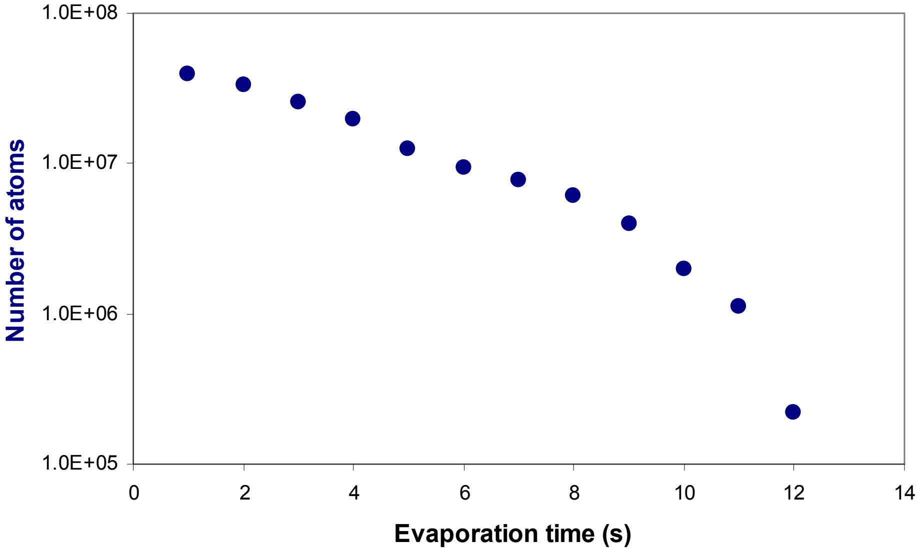
12 s, 1.2 MHz

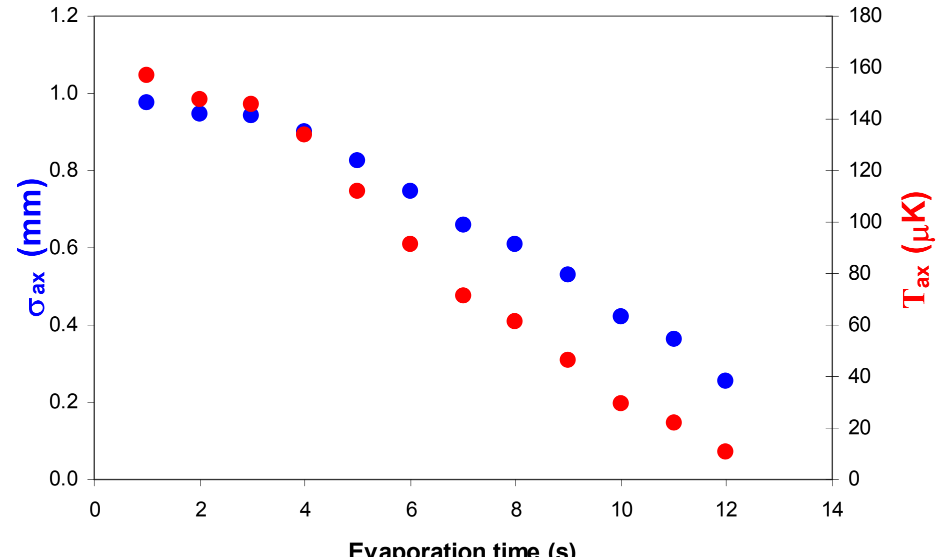
Logarithmic RF frequency sweep

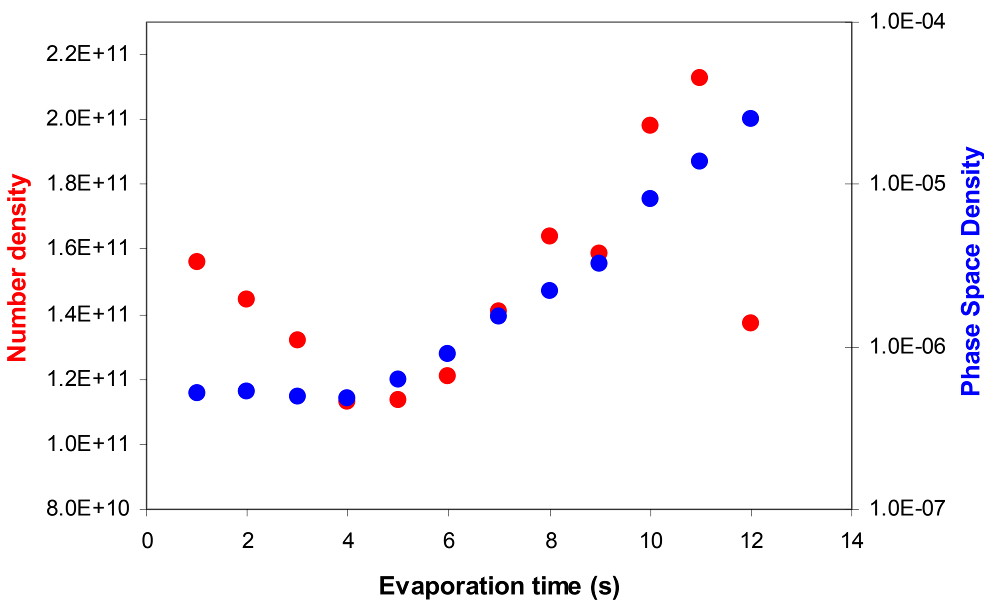
18 MHz – 0.5 MHz in 16 s

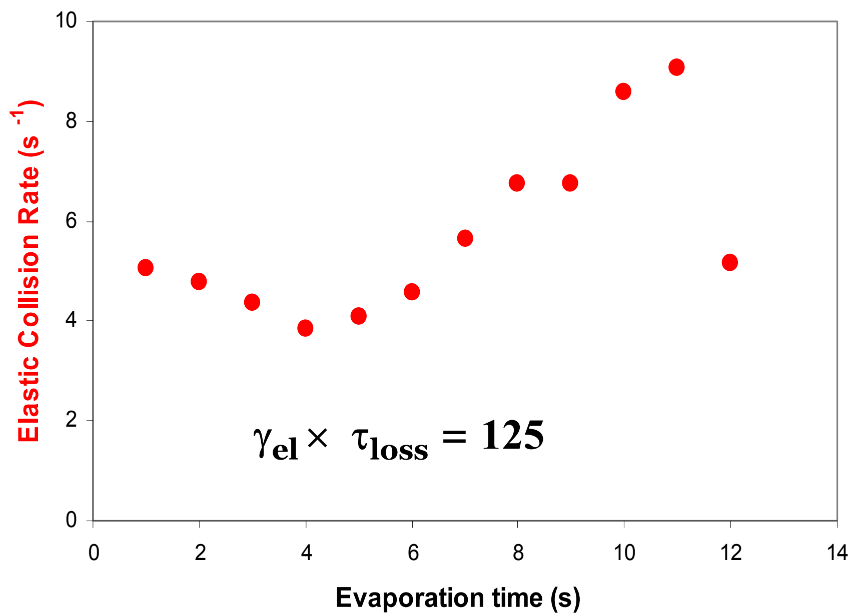
13 s, 0.92 MHz

RF cooling – logarithmic sweep 18 – 0.5 MHz in 16 s









Conclusion:

- **Increase the elastic collision rate:**
  - **- better mode matching (currently 20% transfer)**
  - **- to compress the magnetic trap (currently limited by 20 A)**

- **Increase the lifetime τ_{loss}:**
  - **- cool the chip with liquid nitrogen**

- **RF cooling + continuous compression of magnetic trap**

- **Fragmentation**

- **Outcoupling**

Characterisation of Z-Wire Trap