Abstract
We present the fabrication and development of arrays of pyramidal magneto-optical micro-traps in silicon as an elegant and simple way of capturing atoms directly on the surface of atom chips. [1]

We present experimental data and associated theoretical models to predict the capture and loss processes of the MOT in the micropyramids. These experiments have allowed us to study the scaling law which governs the number of atoms trapped in a microtrap as a function of its size. The integration of these devices offers good prospects for reducing the cost and complexity of atom-chip experiments, and it is hoped that an array of these microtraps can provide cold atom sources used for quantum information purposes, or even highly sensitive portable magnetometers or accelerometers.

Silicon Micro-Pyramids
Arrays of hollow micro-pyramidal mirrors etched into a silicon wafer have successfully been fabricated, and their optical properties have been extensively studied.[3]

Principle of the Pyramid MOT

Figure 1: In a Pyramid MOT, six circularly polarised light beams are formed from one input beam. They form a MOT when a quadrupole magnetic field is present. [2]

Figure 2: 21µm (left) and 4mm (right) pyramids
We can create pyramids in on scales of microns up to millimetres, allowing for trapping of just one atom, or several thousand in a MOT. The pyramids are produced by anisotropic etching in KOH, which preferentially etches the {100} planes to reveal the {111} planes, which form hollow pyramids with apex angle 70.5°.

Scaling laws in the MOT
We have demonstrated that these pyramidal mirrors are suitable for laser cooling clouds of atoms by creating a macroscopic model of the 70° pyramid from 4 glass blocks. This forms an exact scale replica of the ‘micro-pyramidal’, and allows us to make preliminary investigation into the behaviour of the MOT in small trapping volumes.

Figure 3: By using an aperture to reduce the effective opening of the pyramid, and translating the magnetic centre using external bias fields it was possible to simulate a range of pyramid sizes.

Figure 4: It is clear to see that at scales below 10mm the behaviour deviates from the expected $L^{4/3}$ scaling law (grey line) as predicted in [4] and instead scales at a rate consistent with a scaling law of $L^{4/4}$ (dashed line). This behaviour appears to be independent of factors such as the coating we place on the mirrors and whether or not the corners of the pyramid are masked to prevent unwanted reflections.

Imaging small numbers of atoms in a MOT
We have developed some experimental techniques to reliably overcome the technical challenges of imaging very small numbers of atoms inside the pyramid against the background of scattered light from the chip surface.

Figure 6: Fluorescence images of $3 \times 10^4$ and 3,000 atoms (and reflections) trapped in the macroscopic pyramid MOT. We have improved our imaging from initially being able to detect only several $10^3$ atoms, to reliably imaging as few as 100 atoms in a MOT 100µm in size.

Using a high speed, high bit depth camera we can rapidly obtain large numbers of images in order to reduce the poissonson noise inherent to the imaging process. We subtract the background by either displacing the MOT a small distance with a corresponding small bias field, or imaging at high speed at the very start of the MOT loading process when sufficiently few atoms will be trapped in the MOT to be detected.

Integration of the micropyramid MOT
We have developed some experimental techniques to reliably overcome the technical challenges of imaging very small numbers of atoms inside the pyramid against the background of scattered light from the chip surface.

Figure 7: A complete atom chip compromising arrays of micropyramids. This chip has microfabricated wires encircling each pyramid which, in conjunction with a uniform bias field creates the magnetic quadrupole required for a MOT or magnetic traps of depths exceeding 100µK.

Figure 8: Fluorescence images of 3

We demonstrate that fabrication of silicon micropyramids is possible over a range of sizes allowing for arrays of either small magneto-optical traps or single atom sources. Experimental and computational investigations of the scaling laws affecting MOTs in small trapping volumes have shown that the number of atoms trapped in a pyramidal magneto-optical trap scales as $L^{4/3}$ due to a reduction in capture efficiency. We anticipate seeing several thousands of atoms in the largest of our silicon pyramids. It is our hope that as well as simplifying the process of loading cold atoms onto atom chips, these micropyramids will lead to novel experiments in atomic physics and towards quantum information processing applications.

Conclusion

References

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