Atom Chips and Bose-Einstein Condensates

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Outline

• BEC on a foil based atom chip
• Fragmentation
• High temperatures...
• Accurate atom number detection
• Conclusions
UQ Atom Chip / BEC
Atom Chips

- Atom optics - Control and manipulation of atomic deBroglie waves
- **Atom Chips**: Allow us to place atom optical elements very close to a BEC.
- Two main advantages:
  - “Easy” to produce BECs (lower currents)
  - Tight and complex trapping potentials
Atom Chips

- Z-wire + bias field = mini Ioffe-Pritchard trap

- Produces a magnetic trap with 3D confinement
UQ Atom Chip

• A silver foil (125 µm) glued to a ceramic substrate.

• Silver polished to mirror finish (thickness ≈ 90 µm).

• All materials UHV compatible.
UQ Atom Chip

- Wires patterned with a micro-cutter (150 μm diameter).
- Electrical connections made with copper tabs screwed onto chip.
- Mirror surface for MOT.
- Wires for magnetic trap.

Magneto-Optical Trap

- Fluorescence image
- $\sim 10^8 \ ^{87}\text{Rb atoms}$
- $T = 100 \ \mu\text{K}$
Magnetic Trap

- Atoms trapped in magnetic fields produce by currents through wires on chip.

- Absorption image
- Compressed trap
- ~ $2 \times 10^7$ atoms
- $T = 300 \ \mu K$
Evaporative Cooling

**Final RF = 3MHz**
- $3 \times 10^6$ atoms
- $T = 50 \, \mu K$

**Final RF = 1MHz**
- $5 \times 10^5$ atoms
- $T = 6 \, \mu K$
BEC!!

- $\sim 4 \times 10^4$ atoms
- $T = 200 \text{ nanoK}$
- View after expansion

$N = 2 \times 10^5$
$T = 700 \text{nK}$
Thermal Cloud

$N = 8 \times 10^4$
$T = 450 \text{nK}$
Partial BEC

$N_0 = 4 \times 10^4$
$T = 200 \text{nK}$
Almost Pure BEC

Fragmentation
Fragmentation

• When very cold atom clouds are brought very close to a conducting wire the cloud fragments into lumps.

\[ T = 4 \, \mu \text{K}, \]
\[ y = 45 \, \mu \text{m}. \]
Fragmentation

- Small axial fields, $B_{ax}$, are produced by the guide current which can add to/subtract from the total axial field creating potential barriers/wells.

$$|B_{ax}| \sim 10^{-3} - 10^{-4} |B_{wire}|$$

- A meandering current produces these small $B_{ax}$ components...

Fragmentation

• If the conductor is not perfectly straight...

\[ \text{RMS amplitude of edge roughness} \approx 0.5 \, \mu m \]

• Our fragmentation appears to be due to edge roughness.
Fragmentation

- The amplitude of the fragmenting potential scales as:

\[ K_1(ky) \approx \frac{e^{-ky}}{\sqrt{k}y} \]

- When \( y > L_{\text{BEC}} \) fragmentation becomes negligible

From nanoK to kiloK...
Fire in an a/c duct...

- Experiment not burnt, but covered in soot
Following the fire...

• Packed up experiment

• New lab space was prepared
Call in the strong men...
Shifted to a new building...
A new home for the BEC

• The experiment is now ready to be reconnected and brought back to life in the new lab.
Accurate Atom Number Detection
What sort of detector??

• To study quantum statistics of atom numbers in condensates we would like a detector with accuracy better than $1/\sqrt{N}$, typically:

\[
\frac{\Delta N}{N} < \frac{1}{\sqrt{N}} \approx 10^{-3}
\]

• Absorption imaging doesn’t really offer this kind of accuracy (usually a few %).

• Possible solution: Photoionisation
Our proposed scheme is shown below.

Ions are accelerated towards the channeltron and detected there.

PI lasers

Atoms/BEC

≈ -3 kV

Channeltron
Efficient Photoionisation

- Use **STI**mulated **Raman** **Adiabatic** **Passage** (STIRAP) to transfer from 5S to 5D state.
- Ionise with pulsed Nd:YAG laser.

Duncan et al., PRA 63 043411, (2001).
STIRAP (Theory)

- Coherently transfer population from $|1\rangle$ to $|3\rangle$
- Use counter-intuitive pulse order

\[
\begin{bmatrix}
0 & \Omega_{12}(t) & 0 \\
\Omega_{12}(t) & 2\Delta & \Omega_{23}(t) \\
0 & \Omega_{23}(t) & 0
\end{bmatrix}
\]

One eigenstate of $\hat{H}$ is:

\[
|\psi_0(t)\rangle = \cos(\theta(t))|1\rangle - \sin(\theta(t))|3\rangle
\]

where, $\tan(\theta(t)) = \frac{\Omega_{12}(t)}{\Omega_{23}(t)}$
STIRAP (Theory)

- Population transfer vs. pulse timing

Effect of Pulse Order on Transfer Efficiency

- $5D_{5/2}$ population
- $5P_{3/2}$ population
- $5S_{1/2}$ population

Rabi frequency

- $\Omega_{23}$ Rabi freq
- $\Omega_{12}$ Rabi freq
STIRAP (Experiment)

- A signature of the 5D state population is 420nm fluorescence

- Measure blue fluorescence to obtain STIRAP efficiencies
Experimental set up
STIRAP Experiment

- The lasers are pulsed on and the blue fluorescence is monitored on a scope
STIRAP Results

- Counter-intuitive ordering works better!!

\[ \Omega_{12} \approx 30 \Gamma_{21} \]
\[ \Omega_{23} \approx 15 \Gamma_{21} \]
Summary and Outlook

• Produced BECs on an atom chip
• Saw fragmentation similar to electroplated wires
• Started STIRAP experiments
• New laser locking (see poster by A. Ratnapala)

• Get BEC working in new lab
• Photoionise with a pulsed Nd:YAG laser
• Try to photoionise a condensate
  - Investigate Pauli blockade