Interaction of Ultracold Atoms with Nanomagnetic Domain Walls

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INTERACTION OF COLD ATOMS WITH MAGNETIC NANOWIRES

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Atoms

• Sensitive to magnetic fields
• Use as qubits requires confinement
• Desire control over many atoms at once

Nanowires

• Tunable sources of magnetic fields
• Domain walls are highly localised
• Inherently scalable
• Soft magnetic material $\rightarrow$ reconfigurable
• Small characteristic size $\rightarrow$ massive field gradients

This talk

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Magnetic domains are regions of aligned magnetisation.

Domain walls form between opposing domains.

At a wall there is an out of plane magnetic field.
Simplest approximation to the field from a domain wall:

We consider two regimes:

\[
\vec{B}(\vec{r}) = \frac{\pm q_m}{4\pi |\vec{r}|^2} \hat{r}
\]

Single Domain Wall

Many Domain Walls


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The wires are written in a serpentine pattern.

The magnetisation has 2 states.

The ground state has a single domain.

Applying a field we form a metastable state.

This has many domain walls.

We can also switch back to the ground state.

Hence we can toggle the fringing fields.

Ideal magnetic mirror has sinusoidally varying magnetisation.

- Exponentially decaying potential.
- Domain wall array mimics this structure.
- Discrete nature produces corrugation of the field.

High field gradients $\rightarrow$ point-like interaction.

Corrugation $\rightarrow$ Diffuse reflection.
Realization of the manipulation of ultracold atoms with a reconfigurable nanomagnetic system of domain walls
A D West et al., Nano Letters 12, 4065-9 (2012)
Quantitative analysis is provided by a light sheet:
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ATOM MIRROR

Time (ms)

Light Sheet Absorption (%)

Data

Theory

77 μK
70 μK
60 μK
48 μK
39 μK
32 μK
27 μK
20 μK
15 μK
13 μK

Drop
Reflection

versity
held.
Recall we can reconfigure our mirror

By applying external fields we can populate/annihilate domain walls.

We can tune the atom-chip interaction.
We can use the atoms to probe the collective micromagnetic behaviour. Domain wall sites have a distribution of switching fields.

Single shot measurements give a bounce signal.

Single magnetic field pulses reconfigure the chip.

We can switch with 100% reliability.
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**ATOM TRAPS**

- Single Domain Wall
  - Atom Trap
- Many Domain Walls
  - Atom Mirror
Take the field from a single domain wall.

\[
\vec{B}(\vec{r}) = \frac{\pm q_m}{4\pi |\vec{r}|^2} \vec{r} - B_{\text{bias}} \hat{z}
\]

Add in a bias field.

Described by a 3D quadrupole

\[
\vec{B} = B'(x\hat{x} + y\hat{y} - 2z\hat{z})
\]

Small characteristic size \(\rightarrow\) Large \(B'\) \(\rightarrow\) High trap frequency

Has the intrinsic problem of \textbf{spin-flip losses}.


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Huge field gradients $\rightarrow$ need large TOP fields, at high frequencies

Producing a deep, adiabatic trap is difficult.

Let’s oscillate the chip instead!

\[ y(t) = y_0 \cos(\omega_{\text{TOP}} t) \]

\[ x(t) = x_0 \sin(\omega_{\text{TOP}} t) \]

Now we use the massive gradients to our advantage.

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Many conventional methods are inappropriate for nanoscale traps.

We aim to create a time averaged potential.

We propose piezoelectric actuation as an alternative time-averaging technique.
**SUMMARY – ATOM MIRROR**

- We produce a 2D array of walls
- This gives a decaying field
- Atoms reflect from an isosurface

*Images showing the progression of atom reflection over time.*
SUMMARY – ATOM MIRROR

A light sheet shows atom dynamics

Data agree well with theory

We can probe micromagnetic behaviour

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