Cold Atoms-Solid State Interfaces Meeting

14 March 2013
School of Physics & Astronomy
University of Nottingham, United Kingdom

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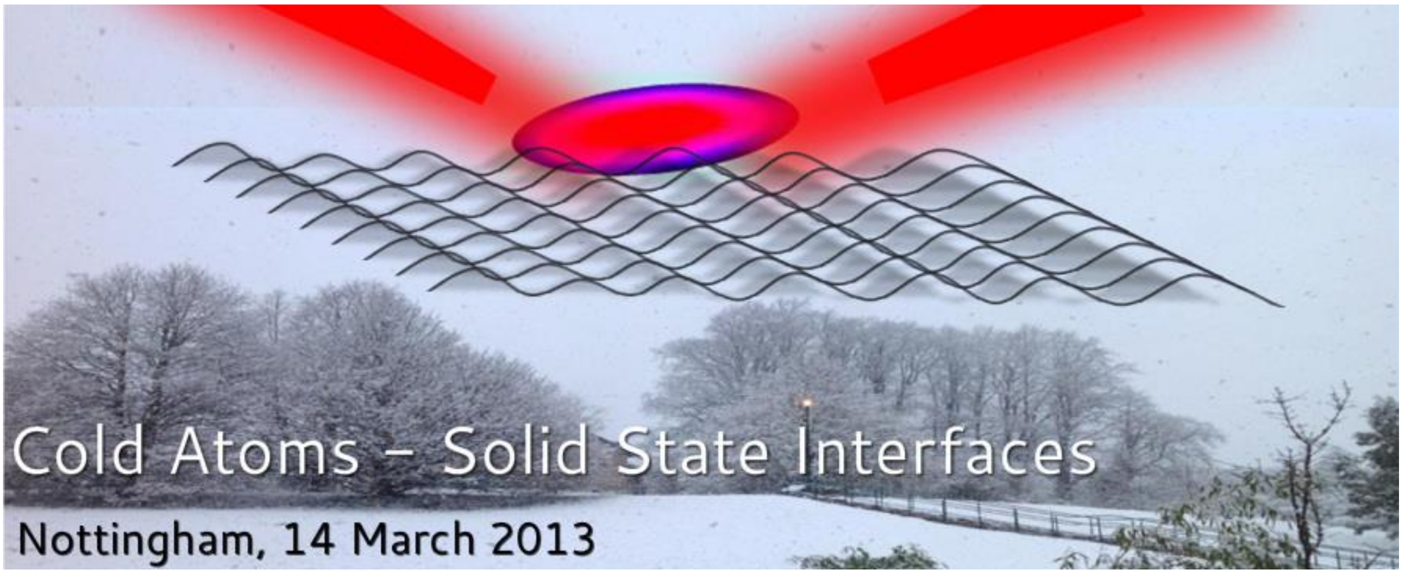

The purpose of the meeting is to gather experts and young researchers working in the field of cold atoms at the interface with solid state physics in order to explore the state of the art and discuss the most fruitful perspectives.

Invited Speakers

- **Joe Cotter**, Centre for Cold Matter, The Blackett Laboratory, Imperial College, London (UK)
- **Daniel Farkas**, ColdQuanta, Boulder, Colorado (USA)
- **Mark Fromhold**, School of Physics and Astronomy, University of Nottingham (UK)
- **Andreas Günther,** Eberhard-Karls-Universität Tubingen (Germany)
- **Christian Koller**, School of Physics and Astronomy, University of Nottingham (UK)
- **Shimon Machluf**, Atomchip Group, Physics Department, Ben-Gurion University (Israel)
- **Kevin Weatherill**, Joint Quantum Centre Durham-Newcastle, Department of Physics, Durham University (UK)

Organiser

Samanta Piano
Midlands Ultracold Atom Research Centre
School of Physics and Astronomy, University of Nottingham (UK)

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Programme

Wednesday 13 March

18.30 Welcome *canapé* reception at *The Hemsley,* University of Nottingham

Thursday 14 March - Room C05 (Physics & Astronomy)

09.45-10.05 Registration and introduction

10.05-10.50 **Kevin Weatherill** - ***Manipulation of cold atoms using domain walls in magnetic nanowires***

10.50-11.15 *Coffee Break* Room B16

11.15-12.00 **Christian Koller** - ***Cold Atoms-Solid State Interfaces in Cryogenic environments***

12.00-12.45 **Shimon Machluf** - ***Coherent Stern-Gerlach momentum splitting on an atom chip***

12.45-14.00 *Lunch* Room B16

14.00-14.45 **Andreas Günther** - ***Cold-Atom Scanning Probe Microscopy***

14.45-15.30 **Daniel Farkas** - ***An Atom-Chip-Based System for High-Resolution Imaging and Control of Ultracold Atoms***

15.30-16.00 *Coffee Break* Room B16

16.00-16.45 **Joe Cotter** - ***Diffractive optics for laser cooling and trapping on an atom chip***

16.45-17.30 **Mark Fromhold** - ***The interplay between ultracold atoms and quantum electronic systems***

17.30-18.30 Discussion and lab visit

19.00 *Dinner* (for invited speakers): Debsh Restaurant, 153 Wollaton St, Nottingham NG1 5GE

Abstracts

Kevin Weatherill
Affiliation: Joint Quantum Centre Durham-Newcastle, Department of Physics, Durham University, Durham (UK)
Title: ***Manipulation of cold atoms using domain walls in magnetic nanowires***

Abstract: Planar magnetic nanowires have been vital to the development of spintronic technology. They provide an unparalleled combination of magnetic reconfigurability, controllability, and scalability, which has helped to realize such applications as racetrack memory and novel logic gates [1]. We experimentally demonstrate the amalgamation of spintronic technology with ultracold atoms [2]. A magnetic interaction is exhibited through the reflection of laser-cooled Rb atoms from a 2 mm × 2 mm periodic array of domain walls [3]. In turn, the incident atoms approach the array at heights of the order of 100 nm and are thus used to probe magnetic fields at this distance. We also consider the prospects for using domain walls to trap and manipulate atoms [4-6]

[1] Allwood et al, Science, 309, 1688(2005)
[2] West et al. Nano Letters, 8, 4065 (2012)
[3] Hayward et al. J. Appl. Phys. 108, 043906 (2010)
[4] Allwood et al, Appl. Phys. Lett. 89, 014102 (2006)
[5] Hayward et al. J. Appl Phys. 110, 123918 (2011)
[6] West et al. Appl. Phys. Lett. 101, 023115 (2012)

Christian Koller
Affiliation: Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Nottingham, Nottingham (UK)
Title: ***Cold Atoms-Solid State Interfaces in Cryogenic Environments: Towards Hybrid Quantum Systems and high throughput BEC microscopy***

Abstract: Concerning the development of technical applications for ultra cold atoms, cryogenic atomchips offer distinct advantages over their room temperature counterparts. For the development of Quantum Information processing cryogenic environments offer the possibility to implement superconducting structures and qubits directly on the atomchip. These qubits (e.g. Transmons [1]) could be combined with the cold atomic clouds to form hybrid quantum systems. In this approach one system could benefit of the advantages provided by the other, e.g coherence times or coupling strength. One of the most common approaches here is the one of circuit quantum electrodynamics (CircQED), using superconducting planar cavities as a quantum bus to mediate between the processor (formed by a Transmon qubit) and the memory (formed by an atomic ensemble, see e.g. [2, 3]).
Another interesting application of ultra cold atomic ensembles is their use in Bose Einstein Condensate (BEC) Microscopes [4]. Measuring the density distribution of the condensate gives a probe for magnetic fields with an unmatched balance of high spatial resolution and magnetic field sensitivity. Up to date one of the drawbacks of this technology is the huge effort necessary to exchange the sample due to the ultra high vacuum necessary to achieve a BEC. Due to cryogenic pumping however, low temperature environments for atomchips would greatly increase the throughput rate of a BEC microscope in addition to provide the necessary platform to study interesting structures such as superconductors, 2D electron gases or superconductor-magnetic hybrids.
In this talk the advances of the Vienna setup towards a hybrid quantum architecture will be presented as well as details about the next generation BEC microscope setup that is under current development in Nottingham. In addition we will introduce trechniquesthat will greatly enhance both concepts, such as reducing the trapping distance from the surface by using thin membrane chips. This will help to both increase the field sensitivity of BEC microscopes and the coupling strength to planar cavities in a Hybrid Quantum System.

[1] J. Koch et al., Phys. Rev. A 76, 04319 (2007).
[2] A. André et al., Nature Phys. 2, 636 (2006).
[3] J. Verdu et al., Physical Review Letters, 103, 043603-1 (2009)
[4] S. Wildermuth et al., Nature 435, 440 (2005), Appl. Phys. Lett. 88, 264103 (2006)

Shimon Machluf
Affiliation: Atomchip Group, Physics Department, Ben-Gurion University (Israel)
Title: ***Coherent Stern-Gerlach momentum splitting on an atom chip***

Abstract: Coherent splitting of matter waves into superpositions of precise momentum states by laser light is widely used in large-scale atom interferometry, whereas splitting with local potentials serves for studying effects of many-particle entanglement on the micrometer scale. We propose a novel method [1] which utilizes local field gradients for fast splitting into momentum states, offering wide range in momentum transfer and a versatile geometry. As a proof of principle, we demonstrate matter-wave splitting on an atom chip. We use magnetic field gradients and radio-frequency Rabi transitions between Zeeman sub-levels. We observe spatial interference fringes with measurable phase repeatability, whose analysis lays the grounds for a variety of future realizations with high phase and momentum stability. Our method can be applied for both Bose-Einstein condensates and thermal atoms, and can give rise to either spatial fringes or internal state population signals.
Our beam-splitter may serve as a basic tool for probing micron-scale solid state and surface physics or for inertial sensing. It is expected to enhance considerably the power of non-interferometric measurements with ultracold atoms on a chip, which have already contributed, for example, to the study of long-range order of current fluctuations in thin films [2], the Casimir-Polder force [3-6] and Johnson noise from a surface [7].

[1] Machluf, S., Japha, Y. & Folman, R. High momentum splitting of matter-waves by an atom chip field gradient beam-splitter. arXiv:1208.2526 [physics.quant-ph].
[2] Aigner, S. et al. Long-range order in electronic transport through disordered metal films. Science 319, 1226–1229 (2008).
[3] Lin, Y., Teper, I., Chin, C. & Vuletí c, V. Impact of the Casimir-Polder potential and Johnson noise on Bose-Einstein condensate stability near surfaces. Phys. Rev. Lett. 92, 50404 (2004).
[4] Pasquini, T. A. et al. Quantum reflection from a solid surface at normal incidence. Phys. Rev. Lett. 93, 223201 (2004).
[5] Pasquini, T. A. et al. Low velocity quantum reflection of Bose-Einstein condensates. Phys. Rev. Lett. 97, 093201 (2006).
[6] Obrecht, J. M. et al. Measurement of the temperature dependence of the Casimir-Polder force. Phys. Rev. Lett. 98, 063201 (2007).
[7] Jones, M. P. A., Vale, C. J., Sahagun, D., Hall, B. V. & Hinds, E. A. Spin coupling between cold atoms and the thermal fluctuations of a metal surface. Phys. Rev. Lett. 91, 080401 (2003).

Andreas Günther
Affiliation: Eberhard-Karls-Universität Tubingen (Germany)
Title: ***Cold-Atom Scanning Probe Microscopy***

Abstract: Using our recently developed cold-atom scanning probe microscope (CA-SPM), we investigate the interaction between ultracold quantum gases and chip-based nanostructures. A magnetic nano-positioning system is used to scan the cold-atom probe tip across the surface of interest and interaction data are acquired in either contact or dynamic operation mode. Using the CA-SPM we investigate the contact interaction between ultracold atoms and a single free standing carbon nanotube. From the measurements, we are able to extract the strength of the Casimir-Polder (van der Waals) interaction between the nanotube and the ultracold probe tip atoms. In future experiments we will use the CA-SPM for dynamic force spectroscopy of nanostructures and focus on the remote interaction between nanostructures and ultracold atoms via electric and magnetic fields. This includes local correlation measurements via field ionization at charged nanotips, as well as the development of a quantum galvanometer for measuring quantum current noise in nanowires. In addition I will show our progress towards high resolution imaging of quantum gases, based on ionization and subsequent ion detection with ultrahigh spatial and temporal resolution.

Daniel Farkas
Affiliation: ColdQuanta, Boulder, Colorado (USA)
Title: ***An Atom-Chip-Based System for High-Resolution Imaging and Control of Ultracold Atoms***

Abstract: High resolution optical access (< 1 µm) to ultracold atoms offers new capabilities and insights into applications where single-site resolution and control of optical lattices is warranted [1-3], as well as the development of atromtronics components [4]. Using atom chips with composite glass+silicon substrates, we have demonstrated high-resolution imaging and optical control in a vacuum system small enough to be held in one's hand [5]. High-NA optics are placed outside of the vacuum system, greatly simplifying the system. Using the optics in reverse, optical potentials can be projected onto the atoms with the same high resolutions. We show how the latter was used to demonstrate the first atomtronic transistor [4].

[1] W. S. Bakr, J. I. Gillen, A. Peng, S. Fölling, and M. Greiner, Nature 462, 74 (2009)
[2] J. F. Sherson, C. Weitenberg, M. Endres, M. Cheneau, I. Bloch, and S. Kuhr, Nature 467, 68 (2010).
[3] J. Simon, W. S. Bakr, R. Ma, M. E. Tai, P. M. Preiss, and M. Greiner, Nature 472, 307 (2011).
[4] S. C. Caliga, C. J. E. Straatsma, A. A. Zozulya, and D. Z. Anderson, arXiv:1208.3109 (2012).
[5] E. A. Salim, S. C. Caliga, J. B. Pfeiffer, and D. Z. Anderson, Appl. Phys. Lett. 102, 084104 (2013).

Joe Cotter
Affiliation: Centre for Cold Matter, The Blackett Laboratory, Imperial College, London (UK)
Title: ***Diffractive optics for laser cooling and trapping on an atom chip***

Abstract: Atom chips are becoming increasingly important as a technology for quantum optics, quantum measurement and quantum information processing. I will present a new atom chip which uses planar, diffractive optics to simplify the integration of laser cooling and trapping in a compact apparatus. This source can deliver ~1e8 rubidium atoms at temperatures as low as 50 microK from a single laser beam. This is ten thousand times more atoms than previous microfabricated magneto-optical traps and at sub-Doppler temperatures. The devices are easy to fabricate and can be integrated into many existing chip designs, therefore offering significant benefits for portable cold-atom technologies.

Mark Fromhold
Affiliation: Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Nottingham, Nottingham (UK)
Title: ***The interplay between ultracold atoms and quantum electronic systems***

Abstract: I will consider the prospects for interfacing ultracold atoms with quantum electronic systems fabricated within two-dimensional electron gases (2DEGs) in semiconductor heterostructure membranes and graphene layers. The low Casimir-Polder attraction of ultracold atoms to these membranes, combined with the low spatiotemporal noise of 2DEGs, suggests that atom chips incorporating quantum electronic conductors could trap atoms < 1 micron away. This may enable the creation of hybrid systems, which integrate ultracold atoms with quantum electronic devices to give high sensitivity and control: for example, activating a single quantised conductance channel in the 2DEG can split a Bose-Einstein condensate for atom interferometry. In turn, the condensate itself offers structural and functional imaging of quantum devices and transport processes.

Participants

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