Atom Chips: one decade of ultra cold atoms microns from a surface
Or, do atom chips have a future?
10\textsuperscript{th} anniversary of the AtomChip

Ron Folman

An example of an Atom Chip
Science 2008

Israel Science Foundation
FP6 Research Training Network
German Gov. – DIP, GIF

US-Israeli (BSF)
Center for the Science of Complexity
Converging technologies

FP7 Marie Curie Fellowship
French Government
Defense, Industry
10 years ago the question was: Can we make a “solid state”
room temperature device with long coherence times?
(& smooth potentials)

Solid state=
• nano and micro scale potentials
• arbitrary potentials, incl. trapping, guiding, reflection, tunneling
• scalable
• full monolithic integration

Atom, Ion, Molecule, Electron (>30)

Atom Chips: one decade of ultra cold atoms microns from a surface
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10th anniversary of the AtomChip

Ron Folman

Ben-Gurion University of the Negev

Snowbird January 2010

www.bgu.ac.il/atomchip
www.bgu.ac.il/nanofabrication
Atom Chips: one decade of ultra cold atoms microns from a surface
Or, do atom chips have a future?
*10th anniversary of the AtomChip*

Ron Folman

As a measure of success one may ask about specific tasks such as:

- Can we see the Aharonov-Casher effect?
- Can we match the sensitivities of free space atom interferometers?
- Can we do a high fidelity 2-qubit gate (the base for Quantum computing)?

Electrons: Heiblum, Weizmann Inst., 90s
Atoms: Ed Hinds et al. Yale 1993

Kasevich, Ertmer
Outline:

• What is an atom chip

• What is the community working on

• What has been achieved so far (see today’s evening break-out session for realized matter-wave interferometry)

• Concluding remarks
Outline:

• What is an atom chip

• What is the community working on

• What has been achieved so far (see today’s evening session for realized matter-wave interferometry)

• Concluding remarks

I apologize! In a short talk one cannot do justice to the physics and to the physicists
Basics of the Magnetic Potential

Brief History

1921 Stern-Gerlach
1932 Frisch & Segre (bias field and a wire)
1961 Vladimirskii (neutrons)
1992 Schmiedmayer (wires)
1995 Weinstein & Librecht 1999 Prentiss (micro traps)
1996-7 Wonho, Pfau (surface MOT)
1999 Reichel (chip MOT)
2000 The name atom chip PRL 84, 4749
2000 ACQUIRE collaboration
2001 Zimmermann, Reichel (BEC, 30μm from surface)
2003 Reichel (Rabi oscillations), Vuletic (0.5μm atom-surface distance)

Magnetic Interaction

$$U_{mag} = -\vec{\mu} \cdot \vec{B}$$

potential depth: bias field $B_0$
potential height: $h = \frac{\mu_0}{2\pi} \frac{I}{B_0}$
potential gradient: $B_0^2 I \propto 1/h$

PS additional interactions: electric

$$U_{el} = -\frac{1}{2} aE^2$$

$$U_{mirror} \propto e^{-\kappa m z}$$

Also, Optical motor/tweezers, Permanent magnets, and more

Schmiedmayer EPJ D 4, 57 (1998)
Basics II

The U and Z traps

Bending the wire closes the guide and creates ‘end caps’

meta stable state

\[ E = g \mu_B B |B| \]

\[ E = g_F m_F \mu_0 |B| \]

More sophisticated geometries:
Weinstein, Libbrecht PRA 52, 4004 (1995)

MHz traps may be reached!
Trap very weak: atoms at Nano Kelvin temperature!
(device at room temperature – no cryogenics!)
Magneto Optical Trap

quadrupole

camera 1

camera 3

laser beams

camera 2

oven

A)

B)
A Coil Free MOT

Old dog... New tricks...

Experimental advantages:

- can be switched on/off immediately
- no quadrupol coils required any more
- \(1\text{kW} \rightarrow 1\text{W}\)

Current distribution
Some atom chip picts:

<table>
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Drawing from paper by Jakob Reichel; conveyer belt – invention by Ted Haensch
Some atom chip pict's:

One of the humble beginnings:
R. Folman et al.

Atom chip review article:
R. Folman et al.
Some atom chip picts:

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Applications: clocks, acceleration sensors, gravitational sensors, magnetic sensors, quantum memory and communications, quantum computing

Fundamental science: Decoherence, interferometry, many body, atomic physics, low dimensional systems, atom-surface physics, surface physics, symmetries and fundamental constants

Drawing from paper by Jakob Reichel; conveyer belt – invention by Ted Haensch
Some atom chip pics:

One of the humble beginnings:
R. Folman et al.

Applications: clocks, acceleration sensors, magnetic sensors, quantum memory and communications, quantum computing

Industry “adopted” the name

Fundamental science: Decoherence, interferometry, many body, atomic physics, low dimensional systems, atom-surface physics, surface physics, symmetries and fundamental constants

Atom chip review article:
R. Folman et al.
AtomChips: miniaturization, integration, monolithic

Electronics  ➔  Optics  ➔  Matter waves

➔ accuracy, complexity  ➔  novel functionality
The monolithic integration dream

Schematic diagram of an integrated atom chip with pumps, guides, MOT, integrated lasers and fibre connections.

Courtesy of Tim Freegarde
Some of the many things
The community is working on
Technology

Clocks

Cold cloud or BEC  Pi/2 pulse  Ramsey time  Pi/2 pulse  Detection

QIP

Reichel
Navigation systems: Sagnac (2 out of many proposals)

Paul Baker
and US AirForce

Using Time-Reversal Symmetry for Sensitive Incoherent Matter-Wave Sagnac Interferometry

Y. Japha, O. Arzouan, Y. Avishai, and R. Fisman
Department of Physics, Ben-Gurion University, Be’er-Sheva 84105, Israel
(Received 6 December 2006; published 8 August 2007)

Phase rigidity

White light fringe allows the use of a high flux thermal source

Rotation sensitivity grows as the square root of the finesse

Fig. 4. Current through the closed interferometer of Fig. 3(a) as a function of the magnetic field. The various traces show the current at various settings of the plunger gate potential $V_p$ across a resonance of the QD. The phase as a function of $V_p$ does not change gradually, but jumps by $\pi$. 

PRL 99, 060402 (2007)
Cold Atom Inertial Navigation Systems (INS)

- Cold atoms: a gas of atoms slowed by lasers
- Cold atoms are incredibly sensitive to inertial forces
- Cold atom sensors enable ultra-accurate navigation w/o external reference (e.g., GPS-denied environments, space)
- Adaptable to multiple platforms
- Current accuracies equivalent to most accurate mechanical gyros at significantly reduced cost
- Performance headroom for future improvements

AFRL Focus: Reduced Size & Cost, Increased Sensitivity
Atom - Light

For trapping, manipulation, measurement and state transfer e.g. for quantum communication

Dan Stamper-Kurn

Westbrook, Aspect

Rosenblit, Horak, Folman

Schmiedmayer
My favorite proposal:

Figure 1: (a) Schematic diagram of the cavity. The light field drops to 1/e of its central value at radii $r_0^2 \approx 2.85 \mu m$ in the plane $y = \pm 3/4(23 R)^2$, at the waist of the cavity mode and $y = 3/4(23 R^2)$ on the concave mirror. Here $R$ is the cavity length and $R$ is the radius of curvature of the concave mirror. (b) Scanning electron microscope image of an uncoated mirror template cleaved almost across the diameter.


Also Rosenblit, Horak, Folan.
Probing surface physics

Magnetic probing

- e.g. electron transport

Noise probing

On the feasibility of studying vortex noise in 2D superconductors with cold atoms

Stefan Scheel,* Rachele Fermani, and E.A. Hinds

Quantum Optics and Laser Science, Blackett Laboratory,
Imperial College London, Prince Consort Road, London SW7 2BW
(Dated: April 6, 2007)

We investigate the feasibility of using ultracold neutral atoms trapped near a thin superconductor to study vortex noise close to the Kosterlitz-Thouless-Berezinskii transition temperature. Alkali atoms such as rubidium probe the magnetic field produced by the vortices. We show that the relaxation time $T_1$ of the Zeeman sublevel populations can be conveniently adjusted to provide long observation times. We also show that the transverse relaxation times $T_2$ for Zeeman coherences are ideal for studying the vortex noise. We briefly consider the motion of atom clouds held close to the surface as a method for monitoring the vortex motion.
Loss due to Johnson noise magnetic fields

\[ \gamma \approx 75 \text{s}^{-1} \left( \frac{\mu}{\mu_B} \right)^2 \left( \frac{T_s}{300 \text{K}} \right) \left( \frac{\rho}{\rho_{\text{Cu}}} \right) (\text{Tr} Y_{ij} \times 1 \mu\text{m}) \]

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Tr $Y_{ij}$</th>
</tr>
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<tbody>
<tr>
<td>Half-space</td>
<td>$\pi/\hbar$</td>
</tr>
<tr>
<td>Layer</td>
<td>$\pi d/\hbar^2$</td>
</tr>
<tr>
<td>Wire</td>
<td>$\pi^2 a^2/(2\hbar^3)$</td>
</tr>
</tbody>
</table>

Similarly for heating and decoherence!
The noise at the SC phase transition point

Another example, do cooler metals produce less magnetic noise?

\[ S_B^{ij}(x, \omega) = \frac{\mu_0^2 k_B T}{4\pi^2 \rho} Y_{ij}(x) \]

The answer is NO, unless we contaminate the sample!

SC and Alloys: V. Dikovsky et al., EPJD (2005, 2009)
The noise at the phase transition point

Another example, do cooler metals produce less magnetic noise?

It would also be interesting to measure the noise and electron transport in molecules

The answer is NO, unless we contaminate the sample!

SC and Alloys: V. Dikovsky et al., EPJD (2005, 2009)
Can we suppress decoherence at room temperature?

**NO!** Because it has exactly the same $T$ dependence as in the spin flip rate.

\[
\gamma_{\text{spin decoherence}} = \frac{\Delta \mu^2}{2\hbar^2} S_{||} (\vec{r}; 0) \quad \Delta \mu_{||} = \langle 2 | \mu_{||} | 2 \rangle - \langle 1 | \mu_{||} | 1 \rangle
\]

**Not true!** The little parallel sign makes the difference!

Take anisotropic material:

\[
S^{(||)}_{xx} \propto T \left( \sigma_{zz} X_{yy} + \sigma_{yy} X_{zz} \right) \\
S^{(\perp)}_{yy} \propto T \left( \sigma_{zz} X_{xx} + \sigma_{xx} X_{zz} \right) \\
S^{(\perp)}_{zz} \propto T \left( \sigma_{yy} X_{xx} + \sigma_{xx} X_{yy} \right)
\]

$S$ – noise power spectrum $T$ – temperature $\sigma$ – conductivity $X$ – geometrical factor

Angle between magnetic moment and the good conductivity axis
Life time prediction may be readily verified if one can fabricate the surface:

\[ |1> = |2,1> \text{ and } |2> = |2,2> : \text{ first order Zeeman} \]

But to measure decoherence suppression, may not be easy

\[ \rho_{\text{HOPG}}/\rho_{\text{Au}} = 18 \quad \rho_a/\rho_b = 3750 \]

highly oriented pyro-graphite (HOPG)

But strong masking by broadening due to inhomogeneous trap (mag. field)

T. David et al., EPJD (2008) – chosen as highlight paper
Life time prediction may be readily verified if one can fabricate the surface:

\[ |1> = |2,1> \quad \text{and} \quad |2> = |2,2> \] : first order Zeeman

Angle between magnetic moment and the good conductivity axis

90 \quad 45 \quad 0

But to measure decoherence suppression, may not be easy

But strong masking by broadening due to inhomogeneous trap (mag. field)

T. David et al., EPJD (2008) – chosen as highlight paper
Can we make curved light mirrors?
With what corrugation?
Dispersion of mirrors?
Is there importance to deBroglie length vs. cavity length?
How would atom-atom collisions enter?
How do we load?
What beam will come out?
Reversible state transfer between superconducting qubits and atomic ensembles

David Petrosyan,1,2 Guy Bensky,1 Gershon Kurizki,1 Igor Mazets,3,4 Johannes Majer,3 and Jörg Schmiedmayer3

1 Department of Chemical Physics, Weizmann Institute of Science, Rehovot 76100, Israel
2 Institute of Electronic Structure & Laser, FORTH, 71110 Heraklion, Crete, Greece
3 Atominstitut der Österreichischen Universitäten, TU-Wien, A-1020 Vienna, Austria
4 A.F. Ioffe Physico-Technical Institute, 194021 St.Petersburg, Russia
(Dated: December 20, 2009)

Or perhaps to QD or mesoscopic states?
Bose-Einstein condensate coupled to a nanomechanical resonator on an atom chip: a proposal

Philipp Treutlein, David Hunger, Stephan Camerer, Theodor W. Hänsch, and Jakob Reichel

Max-Planck-Institut für Quantenoptik and Fakultät für Physik der Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 München, Germany

Laboratoire Kastler Brossel de l'E.N.S., 24 Rue Lhomond, 75231 Paris Cedex 05, France

(Dated: July 10, 2007)

We theoretically study the coupling of Bose-Einstein condensed atoms to the mechanical oscillations of a nanoscale cantilever with a magnetic tip. This is an experimentally viable hybrid quantum system which allows one to explore the interface of quantum optics and condensed matter physics. We propose an experiment where easily detectable atomic spin-flips are induced by the cantilever motion. This can be used to probe thermal oscillations of the cantilever with the atoms. At low cantilever temperatures, as realized in recent experiments, back-action of the atoms onto the cantilever is significant and the system represents a mechanical analog of cavity quantum electrodynamics. With high but realistic cantilever quality factors, the strong coupling regime can be reached, either with single atoms or collectively with BECs. We discuss an implementation on an atom chip.

PACS numbers: 85.85.+j, 03.75.Nt, 39.90.+d, 42.50.Pq

Keywords: atom chip, NEMS, Bose-Einstein condensate, cavity quantum electrodynamics

Can we cool the resonator?
Can we go quantum?
Atomic trapping and Cavity QED with plasmons

Trapping and manipulation of isolated atoms using nanoscale plasmonic structures


First experiments with a QD emitter

 Photon correlations

\[ g^2(\tau) \]

\[ \begin{align*}
  &0.4 \\
  &0
\end{align*} \]

dot-dot

dot-wire end

\[ \tau \]

\[ \text{20 ns} \]
Interference Swapping in Scattering from a Nonlocal Quantum Target

Daniel Rohrlich, Yakov Neiman, Yonathan Japha, and Ron Folman

Department of Physics, Ben-Gurion University, Beer-Sheva 84105, Israel
(Received 23 January 2006; published 5 May 2006)

We describe a new and distinctive interferometry in which a probe particle scatters off a superposition of locations of a single free target particle. Probe particles scattering off a single free “mirror” (in one dimension) or a single free “slit” (in two dimensions) can “swap” interference with the superposed target states. The condition for interference is loss of orthogonality of the target states and reduces, in simple examples, to transfer of orthogonality from target to probe states. We analyze experimental parameters and conditions necessary for interference to be observed.
Matter Wave Pulse Shaping

Dynamic Matter-Wave Pulse Shaping

M. Nest¹, Y. Japha², R. Folman², R. Kosloff³

Can we make arbitrary wave forms like in light pulse shaping?
My personal favorite item on the wishlist:
Altering the CP force

Beyond the trivial concept of using less material??????

Using less material: CNTs and nano gold wires

Trapping cold atoms using surface-grown carbon nanotubes

P. C. Petrov,¹,* S. Machluf,¹ S. Younis,¹,² R. Macaluso,¹,² T. David,¹
B. Hadad,² Y. Japha,¹ M. Keil,¹,† E. Joselevich,³ and R. Folman¹

Also Tubingen

Nanowire atomchip traps for sub-micron atom-surface distances

R. Salem,¹,* Y. Japha,¹ J. Chabó,¹ B. Hadad,² M. Keil,¹ K. A. Milton,³ and R. Folman¹
Some of the many achievements

The BEC survives 10 orders of magnitude in temperature difference over a few micro meters

Fast BEC (e.g. 100,000 atoms in a few secs)

Portable BECs

www.coldquanta.com
The first coherent splitting on a chip:

**An Atom Michelson Interferometer on a Chip Using a Bose-Einstein Condensate**

Ying-Ju Wang, Dana Z. Anderson, Victor M. Bright, Eric A. Cornell, Quentin Diot, Tetsuo Kishimoto, Mara Prentiss, R. A. Saravanam, Stephen R. Segal, and Saijun Wu

1 Department of Physics, University of Colorado, and JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309-0440, USA
2 Department of Mechanical Engineering, University of Colorado, Boulder, Colorado 80309-0427, USA
3 Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

(a) ![Diagram of the atom Michelson interferometer on a chip](image1)

(b) ![Diagram of the atom Michelson interferometer on a chip](image2)

(c) ![Diagram of the atom Michelson interferometer on a chip](image3)

(d) ![Diagram of the atom Michelson interferometer on a chip](image4)

(e) ![Diagram of the atom Michelson interferometer on a chip](image5)
The first “in the dark” deterministic spatial fringes on an atomchip:

Matter-wave interferometry in a double well on an atom chip

Splitting a 1d degenerate Bose gas initializes the system in a phase coherent state coherent.

- Observe the universal parameters of the relaxation to thermal equilibrium in 1d systems:
  - phase locking
  - sub exponential coherence decay with a universal exponent 2/3

- Continuous array of Josephson oscillators coupled to a ‘quantum bath’ (=a few phonons)

Hofferberth et al. [arXiv:0706.2259](https://arxiv.org/abs/0706.2259) Schmiedmayer group
Splitting a 1d degenerate Bose gas initializes the system in a phase coherent state. 

- Observe the universal parameters of the relaxation to thermal equilibrium in 1d systems:
  - phase locking
  - sub exponential coherence decay with a universal exponent $2/3$

Continuous array of Josephson oscillators coupled to a 'quantum bath' (=a few phonons)

Non equilibrium coherence dynamics in 1d super fluid

Hofferberth et al. arXiv:0706.2259 Schmiedmayer group

Cant resist the temptation to show you how they ski in Tyrol…
Coherent manipulation of Bose-Einstein condensates with state-dependent microwave potentials on an atom chip

Pascal Böhi, Max F. Riedel, Johannes Hoffrogge, Jakob Reichel, Theodor W. Hänsch, and Philipp Treutlein

Spin squeezing: data + theory

State of the art: multi-layer atom chips

Compact glass cell vacuum chamber

Periodic revivals of Ramsey contrast

P. Böhi et al., Nature Physics 5, 592 (2009)
Single mode tunneling beam splitter

DC splitting (static magnetic tunneling barrier): why has it never worked? (although many simulations showed feasibility)

\[ \Psi(t) = \exp(-iHt/\hbar)\psi_2 \]
\[ = \frac{1}{\sqrt{2}} \exp(-iE_t/\hbar)(\exp(i\Omega t/\hbar + i\sin \Omega t/\hbar)) \]
\[ = \exp(-iE_t/\hbar)(\cos \Omega t\psi_2 + i \sin \Omega t\psi_n) \]

E. Andersson et al. PRA (2001)
DC splitting (static magnetic tunneling barrier): why has it never worked?

Could the answer be as simple as dynamic range?

We see that above a few hundred nano meters the dynamic range is low and technical noise may be causing severe tunneling fluctuations.
First successful step: 2-layer atom chip

Jakob Reichel, Romain Long

Top Layer: trapping in x direction

Bottom layer: trapping in y, z

SiO$_2$ substrate
Squeezing vs. Ramping Time

Ramp of the current in the middle wire: $I_2$

\[ \xi = \left< \frac{n^2}{N_L + N_R} \right> \]

- **Non-Adiabaticity**
- **Technical Heating**
- **Variance of n**
- **Expected Variance for a binomial distribution**

Graph showing the relationship between $T_{\text{ramp}}$ (ms) and $\xi$ (dB) with data points and error bars.
Squeezing vs. Temperature

- Super-Poissonian Fluctuations
- Sub-Poissonian Fluctuations
- Poissonian Fluctuations
- Indistinguishability of Atoms
- Interaction Energy
- BEC

RF knife frequency (MHz)
Coherence of internal degrees of freedom

**Coherence in Microchip Traps**

Philipp Treutlein,* Peter Hommelhoff,† Tilo Steinmetz, Theodor W. Hänsch, and Jakob Reichel

Max-Planck-Institut für Quantenoptik und Sektion Physik der
Ludwig-Maximilians-Universität, Schellingstr.4, 80799 München, Germany

(Dated: April 22, 2004)

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**Graphs:**

1. **Left graph:**
   - Title: Number of atoms in state $|\uparrow\rangle [10^6]$ vs. Delay between $\pi/2$-pulses $T_R$ [ms]
   - Data points show oscillations with a peak at $T_R = 500$ ms.

2. **Right graph:**
   - Title: Ramsey contrast $\psi(T_R)$ [%] vs. Atom-surface distance $d$ [μm]
   - Two data sets are shown: $T_R = 50$ ms (open circles) and $T_R = 1$ s (closed circles).
   - The contrast decreases with increasing distance and time.
Probing the surface and atom-surface physics

Measuring electric fields from surface contaminants with neutral atoms

J. M. Obrecht*, R. J. Wild, E. A. Cornell†

JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309-0440, USA
and Department of Physics, University of Colorado, Boulder, Colorado 80309-0390, USA
(Dated: June 25, 2007)

Measurement of the Temperature Dependence of the Casimir-Polder Force

J. M. Obrecht*, R. J. Wild†, M. Antezza, L. P. Pitaevskii, S. Stringari, E. A. Cornell

1 JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309-0440, USA
2 Dipartimento di Fisica, Università di Trento and CNR-INFM BEC Center, Via Sommarive 14, I-38050 Povo, Trento, Italy
3 Kapitza Institute for Physical Problems, ulitsa Kosygina 2, 119334 Moscow, Russia
(Dated: April 3, 2007)

Thermally induced spin flips above an atom chip

M. P. A. Jones, C. J. Vale, D. Sahagun, B. V. Hall and E. A. Hinds*

Blackett Laboratory, Imperial College, London SW7 2BW, United Kingdom
(Dated: December 15, 2009)

Impact of the Casimir-Polder Potential and Johnson Noise on Bose-Einstein Condensate Stability near Surfaces

Yu-ju Lin, Igor Teper, Cheng Chin, and Vlada Vuletić

Department of Physics, Stanford University, Stanford, California 94305-4060*
Probing electron transport

Schmiedmayer
Folman
Science 2008
The surprise: long range order in electron flow in a wire without any structural long range order

\[ \beta(x, y, z_0) = \frac{\delta B_x(x, y, z_0)}{B_y} \]

First mystery:
Why correlation length 1000 times more than expected from grain size or diffusion length?

Second mystery:
Why 45 degrees?

Third mystery:
Why does the wire with largest grains have smallest corrugation?

Fourth mystery:
Why do the wires have such a different spectral behavior?

\[ \lambda_\beta = 77 \mu m, \quad 46 \mu m, \quad 48 \mu m \]

\[ \lambda_\beta = \frac{2\pi}{\sqrt{k^2}} \]
Predictions of our model: less width=less scattering

Y. Japha et al., PRB (2008)
Predictions of our model: anisotropic materials change the 45 and the corrugation amplitude

Y. Japha et al., PRB (2008)
Novel potentials: permanent magnets, electric, SC vortex, multi directional

Two-dimensional array of microtraps with atomic shift register on a chip

S Whitlock^1, R Gerritsma^2, T Fernholz^3 and R J C Spreeuw
Van der Waals-Zeeman Institute, University of Amsterdam, Amsterdam, The Netherlands
E-mail: S.M.Whitlock@uva.nl
The matter-wave pulse shaping discussed earlier is based on this electric traps: 300 V magnetic guide: 1.6 A, 44 G height: 70μm

P. Krueger, Folman, Schmiedmayer, et al. (PRL 2003)

simulation

defocusing of the electric field lines

de-focusing of the electric field lines

results
Could this be the first step towards the Atom-Electron entanglement we discussed previously?
Atom-Light

The first real integrated device:

An integrated atom-photon junction

Centre for Cold Matter, Blackett Laboratory, Imperial College London,
Prince Consort Road, SW7 2BW, United Kingdom
(Dated: December 23, 2009)

Many previous works, e.g.:

Birkl, Ertmer

Vienna and Rochester
Strong atom-field coupling for Bose-Einstein condensates in an optical cavity on a chip

Yves Colombe\textsuperscript{1,*}, Tilo Steinmetz\textsuperscript{1,2,*}, Guilhem Dubois\textsuperscript{1}, Felix Linke\textsuperscript{1,†}, David Hunger\textsuperscript{2} & Jakob Reichel\textsuperscript{1}
Observation of strong coupling between one atom and a monolithic microresonator

Takao Aoki, Barak Dayan, E. Wilcut, W. P. Bowen, A. S. Parkins, T. J. Kippenberg, K. J. Vahala, & H. J. Kimble

Integration of fiber coupled high-$Q$ SiN$_x$ microdisks with magnetostatic atom chips

Paul E. Barclay, Kartik Srinivasan, and Oskar Painter
Thomas J. Watson, Sr. Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA 91125, USA.

Benjamin Lev and Hideo Mabuchi
Norman Bridge Laboratory of Physics, California Institute of Technology, Pasadena, CA 91125, USA.
(Dated: May 30, 2006)

FIG. 1: (a) Scanning electron microscope (SEM) image of a SiN$_x$ cavity coupled to an optical fiber taper. The fiber taper is permanently aligned to the silicon nitride microresonator with epoxy microjoins to SiN$_x$ supports. (b) Side-view SEM image of a 250 nm diameter microdisk. (c) FEM calculated field distribution (E-E) of a 250 nm microdisk, TE-like mode of the microdisk. (d) Schematic of the integrated hybrid atom-cavity chip.
Novel atom detection
Another example of „where material engineering meets atom optics“

Integrated Atom Detector Based on
Field Ionization near Carbon Nanotubes

B. Grüner,1 M. Jag,1 A. Stibor,1 G. Visanescu,1 M. Häffner,1 D. Kern,1 A. Günther,1,* and J. Fortágh1

1CQ Center for Collective Quantum Phenomena and their Applications,
Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany
(Dated: November 9, 2009)
Always note the alternatives to AtomChips

Miniaturization of non guided atoms

All in a box, Mark Kasevich

e.g. single path vs. multi path interferometers

A compact dual atom interferometer gyroscope based on laser-cooled rubidium

Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Multi-function sensor measures gravity gradient, rotation and linear acceleration along a single input axis.
Hot atoms: clocks, magnetic sensors, gyros

TOPICAL REVIEW

The development of micro-gyroscope technology

Kai Liu, Weiping Zhang, Wenyuan Chen, Kai Li, Fuyan Dai, Feng Cui, Xiaoqiang Wu, Gaoyin Ma and Qijun Xiao

Figure 26. NMRG principle.

Nuclear Spin Gyroscope Based on an Atomic Comagnetometer

T. W. Komack, R. K. Ghosh, and M. V. Romalis
Department of Physics, Princeton University, Princeton, New Jersey 08550 USA
(Received 6 May 2005; published 29 November 2005)

Also Kitching
High-sensitivity diamond magnetometer with nanoscale resolution

J. M. Taylor\textsuperscript{1,*}, P. Cappellaro\textsuperscript{2,3,*}, L. Childress\textsuperscript{2,4}, L. Jiang\textsuperscript{2}, D. Budker\textsuperscript{5}, P. R. Hemmer\textsuperscript{6}, A. Yacoby\textsuperscript{2}, R. Walsworth\textsuperscript{2,3} and M. D. Lukin\textsuperscript{2,5+}

\textsuperscript{1}Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
\textsuperscript{2}Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
\textsuperscript{3}Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138, USA
\textsuperscript{4}Department of Physics, Bates College, Lewiston, Maine 04240, USA
\textsuperscript{5}Department of Physics, University of California, Berkeley, California 94720, USA
\textsuperscript{6}Department of Electrical and Computer Engineering, Texas A\&M University, College Station, Texas 77843, USA

*These authors contributed equally to this work
+e-mail: lukin@physics.harvard.edu

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Israeli company named 4D, uses NV centers for a solid state atomic clock:

Apparently, there is a working prototype with which they won the 2009 European Galileo award.
Take home message: A lot of great physics, however
Ultimate atom chip...
is not in the labs or the shops just yet,
But recent 10 years give room for optimism

reservoir (BEC)

qubit transport
loading

processing in
arrays of micro traps

detector

light for
processing

micro trap

control pad for selective
addressing of each qubit, or non destructive light elements
Thank you also to the fab team!

Our smallest structure to date
(a 6nm hole through a SiN membrane)

We go on hikes in the desert around our university and learn fabrication from mother nature ...and you are welcome to join!

The chip used in our Science 2008 paper

Our smallest periodical structure to date
(a 45nm wires)
Positions for PhD/Post-Docs in theory and experiment

Thanks for your attention!