Interfacing Ions with Nanofibres

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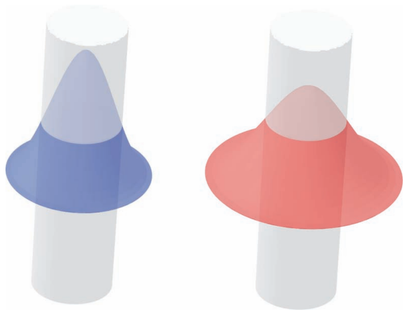
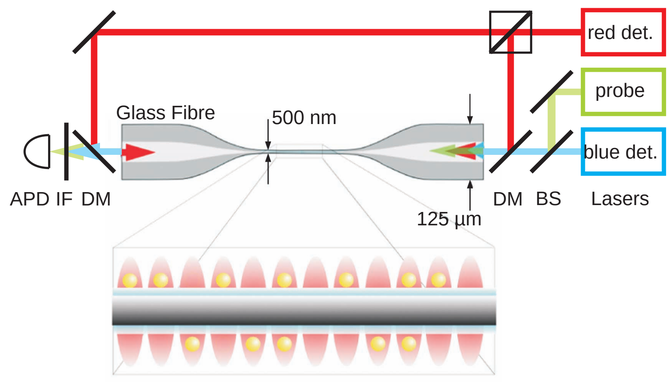
FWF SFB · NanoSci-E+ · QUEST QGATES MICROTRAP SCALA · IQI GmbH · ARO · IARPA

AG Quantenoptik und Spektroskopie

Vision

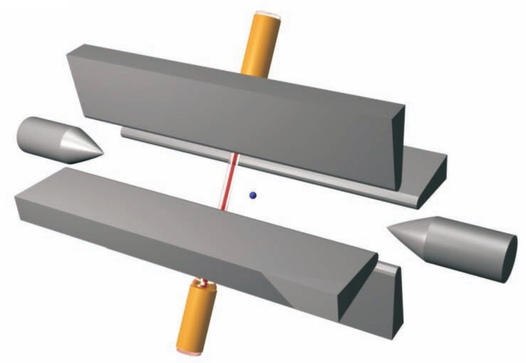


Nano-fibres – with a diameter smaller than an optical wavelength – can support an evanescent field extending significantly outside the fibre.



Recent work has shown progress in coupling neutral atoms to such an evanescent field [1].

[1] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010)



Many new research avenues could be made available by extending such work to ion-fibre coupling. Ions, however, introduce a number of challenges not faced with atoms.

Dielectric Charging

Dielectrics near a trapped ion are often seen as a bad idea.

Light-induced charging has been observed [2] in
- Insulating patches on metals,
- Dielectric coatings on glass.

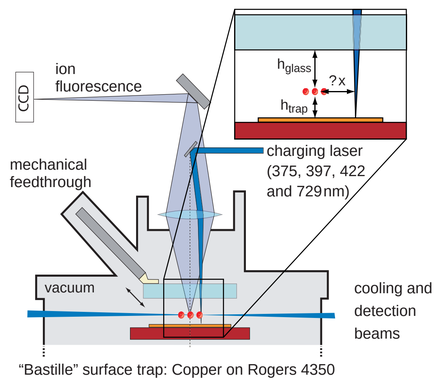
(See figures, right.)

Conversely, bare fibres have been brought within 150 µm of a trapped ion with minimal adverse effects [3].

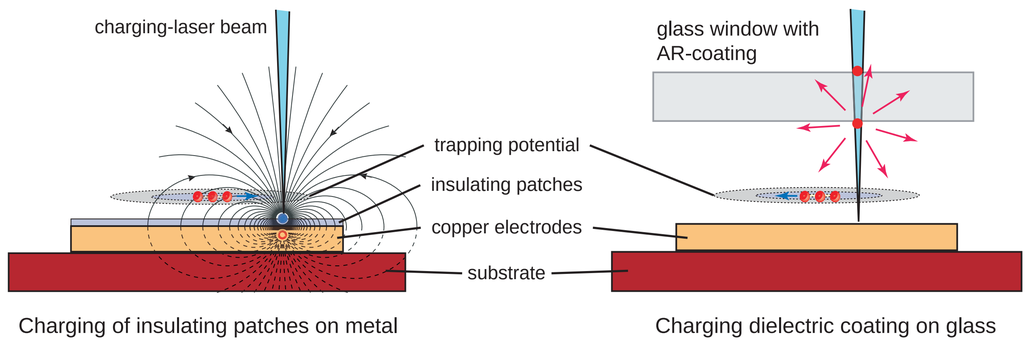
Effect of charging on bare or metal-coated fibres at sub-micron ion-fibre separations is untested.

[2] M. Harlander *et al.*, arXiv:1004.4842v2 (2010) (Accepted New J. Phys.)
[3] G. Brady *et al.*, arXiv:1008.2977v1 (2010)

By imaging trapped ions near the site of charging, the charging process could be characterised with a measurement sensitivity of ~ 50 elementary charges / Hz at a distance of ~1 mm. Using the ion as a sensitive field probe, charging of a nanofibre will be investigated.



"Bastille" surface trap: Copper on Rogers 4350

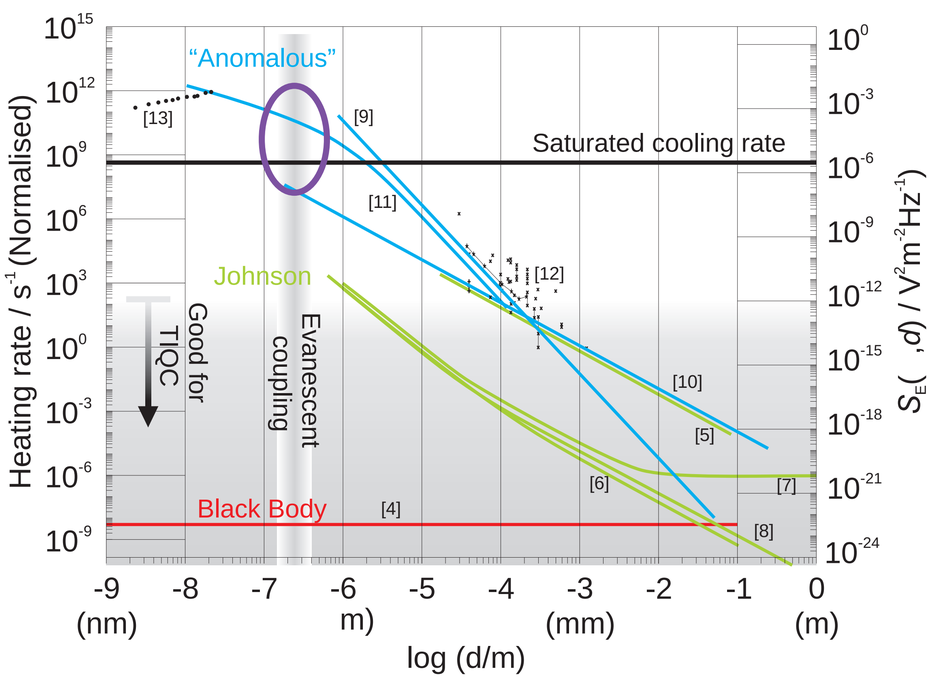


Charging of insulating patches on metal

Charging dielectric coating on glass

Anomalous heating

Ion- heating rates above electrodes are higher than expected from black-body heating or Johnson noise. Various possible heating models are summarised here (heating rates normalised to $^{40}Ca^{+}$, 1MHz trap frequency).

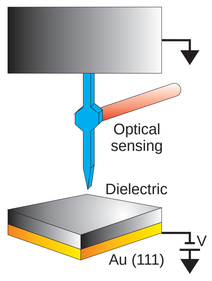


Good ion-evanescent wave coupling dn/dt ~10^{11} s^{-1}

Problems:
- Heating rate higher than any cooling rate,
- Heating rate well above that requireme for quantum gates,
- Trapping lifetime of ~50 ns.

Possible solutions

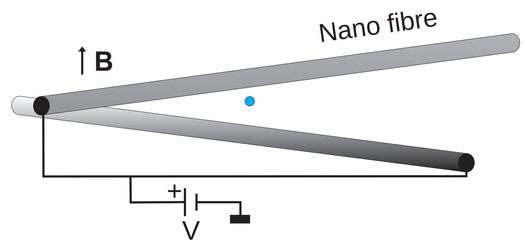
Insulator?



What if the fibre is left bare, instead of metal coated?

Cantilever experiments show that insulators have worse anomalous heating than conductors [14].

Penning trap?

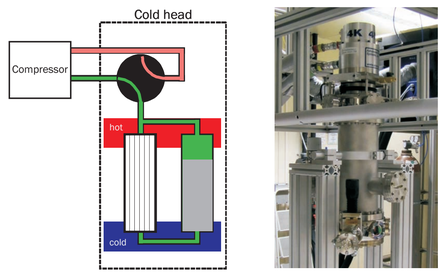


What if 2 fibres (~1 µm separation) are used to make a Penning trap?

$_c$ (MHz/2 = 0.4B
$_c$ = 2 x 1 MHz B = 2.5 T
Trap depth ~ 5 µeV

High B field and low trap depth unfeasible

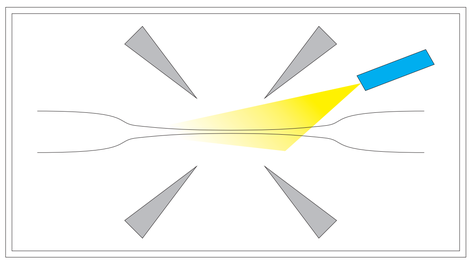
Cryostat?



Cryo-temperatures will decrease heating rate by ~2 orders of magnitude [15].

This alone is not enough to perform quantum information processing.

Vacuum fabrication?



What if adsorbates were totally eliminated by coating the fibre *in situ*, in vacuum, and *keeping* it there?

Worth a try!

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C. Henkel *et al.*, Appl. Phys. B **69**, 379 (1999).
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S. Lamoreaux, PRA **56**, 4970 (1997).
[6] Thermal voltage fluctuations
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[7] Thermal electronic noise (RF)
Q. Turchette *et al.*, Phys. Rev. A **61**, 063418 (2000).
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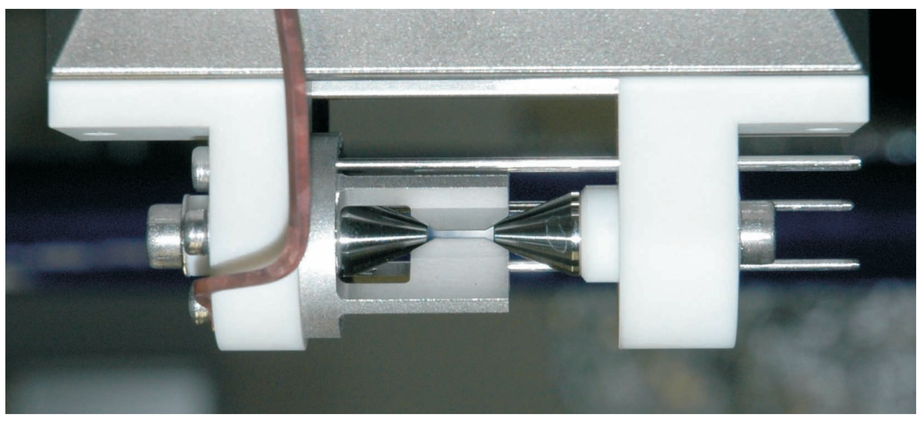
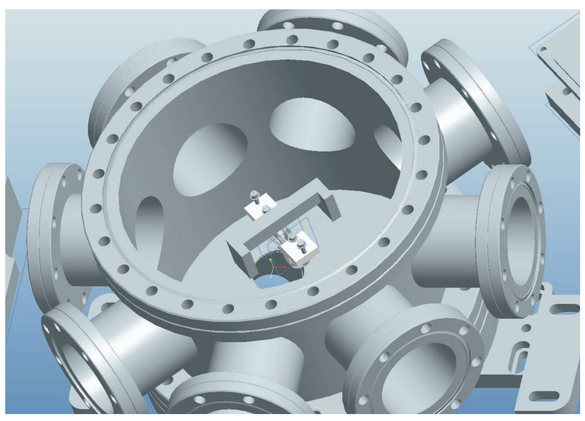
[9] Fluctuating patch potentials
Q. Turchette *et al.*, Phys. Rev. A **61**, 063418 (2000) assuming surface adsorbate coverage of 10%
J. Labaziewicz, Ph.D. Thesis, MIT (2009).
[10] Fluctuating patch potentials with optimised trap geometry
L. Deslauriers *et al.*, Phys. Rev. Lett. **97**, 103007 (2006).
[11] Patch potentials with near field effects
R. Dubessy *et al.*, Phys. Rev. A **80**, 031402 (2009).
[12] Experimental ion-trap heating rates (room temperature)
[13] Experimental caltilever "heating rates"
B. Stipe *et al.*, Phys. Rev. Lett. **87**, 096801 (2001) scaled to ion-trap frequencies.
[14] S. Kuehn *et al.*, Phys. Rev. Lett. **96**, 156103 (2006).
[15] J. Labaziewicz *et al.*, Phys. Rev. Lett. **101**, 180602 (2008).

The experiment

Linear Paul trap with removable end cap to allow fibre insertion.



Chamber design to mount nanofibre



Outlook

- Assemble linear Paul trap in chamber with integrated fibre.
- Investigate light-induced charging of bare and coated nano fibres
- Investigate heating rates of bare and coated nanofibres over the range 100 µm - 100 nm.
- Test vacuum-fabricated surfaces