ICT-2007.8.1 Nano-scale ICT devices and systems

Nano-Optics for Molecules on Chips

CHIMONO

Imperial College
London

SEVENTH FRAMEWORK PROGRAMME

Outlook

CHIMON
Nano-Optics for Molecules on Chips

Goal:

Control of cold molecules in single quantum states realized by means of integrated electric, magnetic, radio frequency, micro wave and optical fields

Strategies:

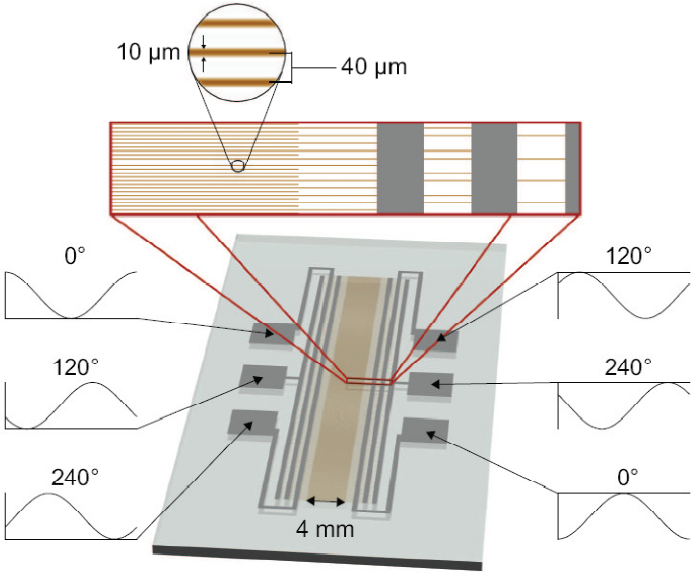
1 Electrostatic deceleration of molecular beams

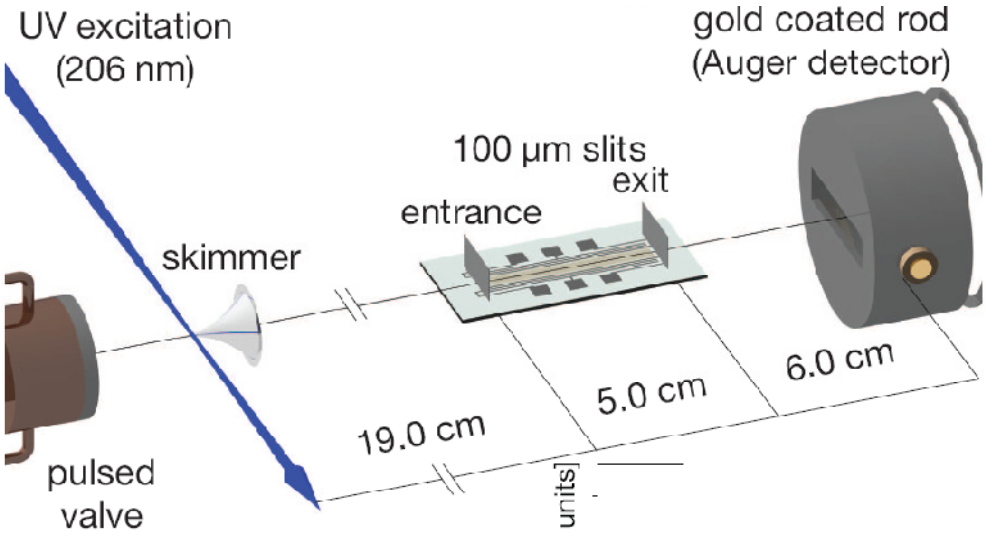
1 Association of precooled atomic samples

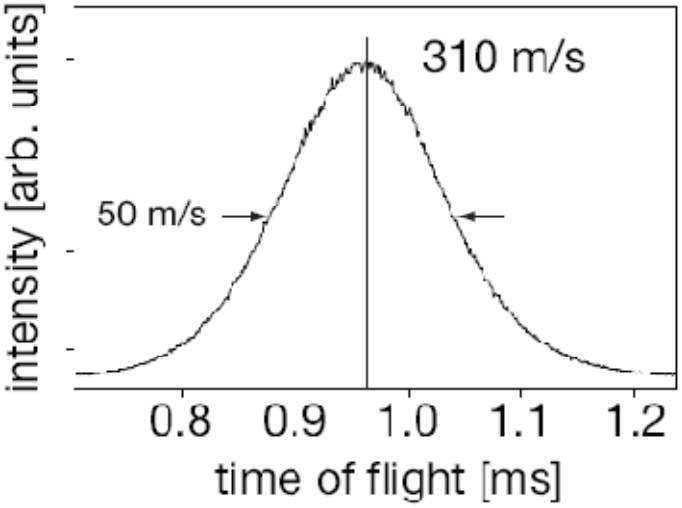
2 Long term storage in integrated magnetic microtraps

3 Detection and addressing via integrated nano-optical elements

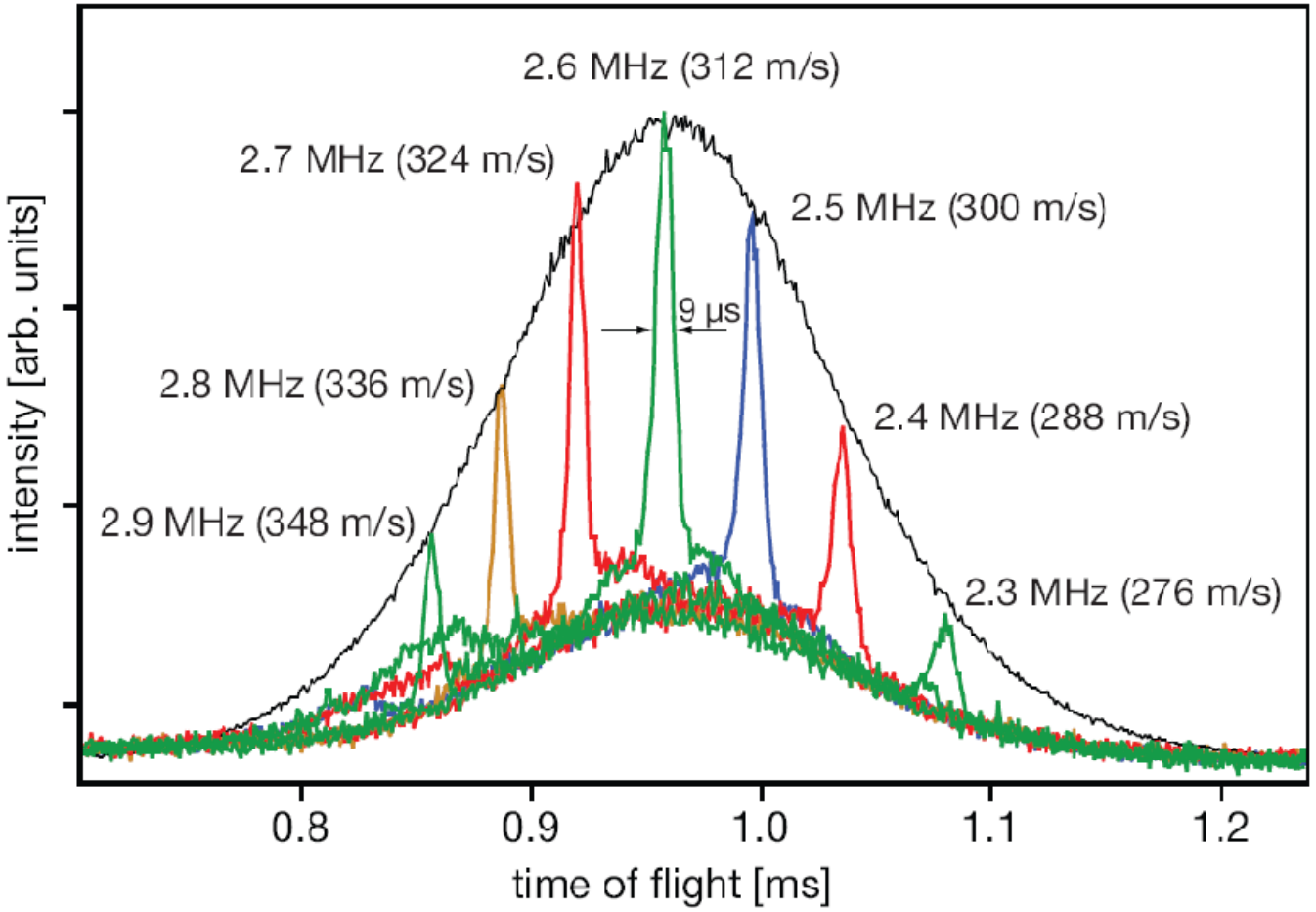
A Stark decelerator on a chip; the experimental set-up







Trapping CO ($a^3\Pi_1$, J=1, v=0) on a chip in traveling potential wells



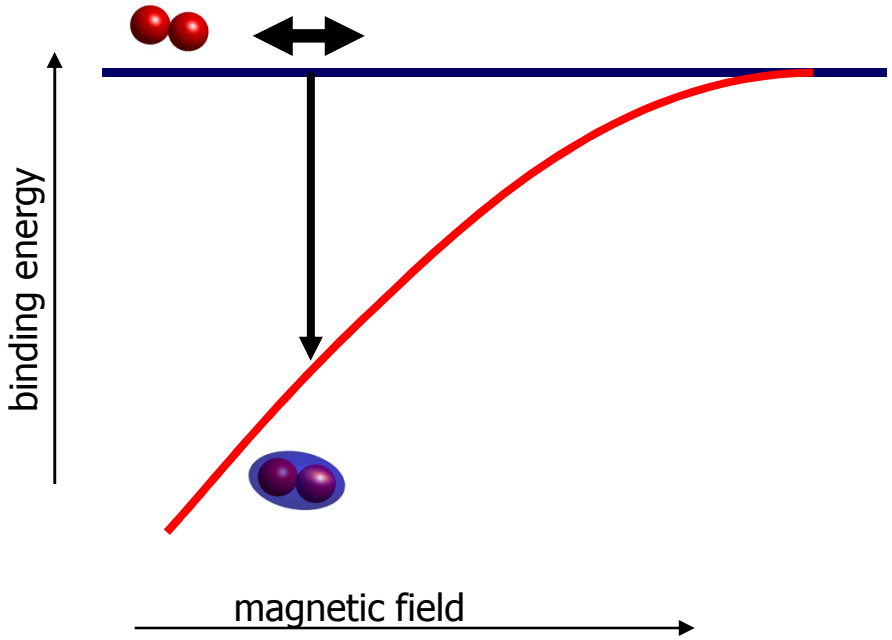
Translational temperature of the guided molecules: ≈ 20 mK

S.A. Meek, H.L. Bethlem, H. Conrad & G. Meijer, PRL 100 (2008) 153003

RF-association of cold molecules

Experiment: modulate magnetic field B

$$B(t) = B_{avg} + B_{mod} \cos(\omega_{mod} t)$$



associate molecules by modulating magnetic field near strong Feshbach resonance
inelastic molecule-atom collisions

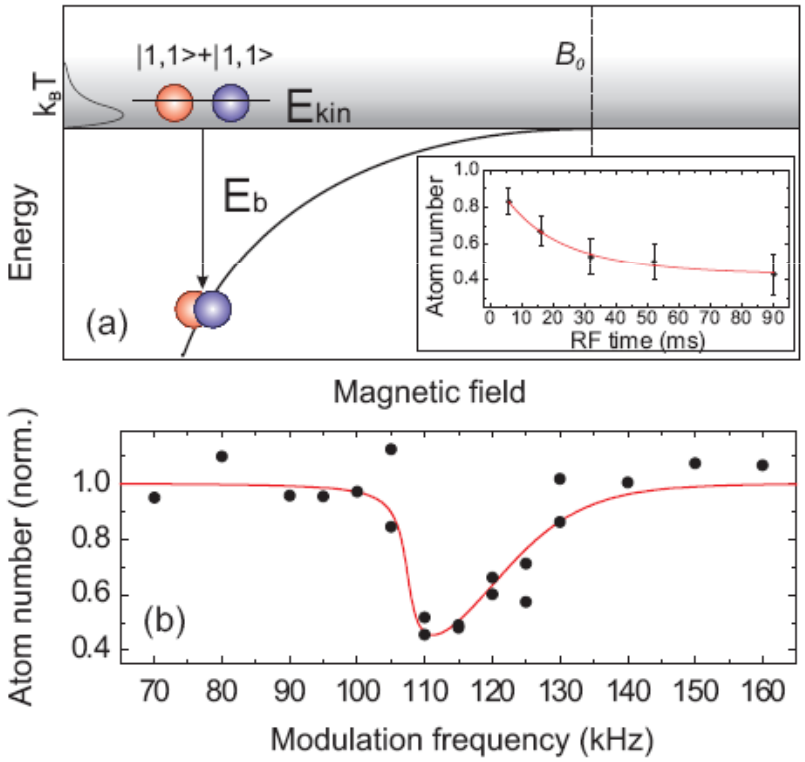
frequency: ~100kHz (binding energy)
amplitude: ~100mG
pulse length: ~10ms

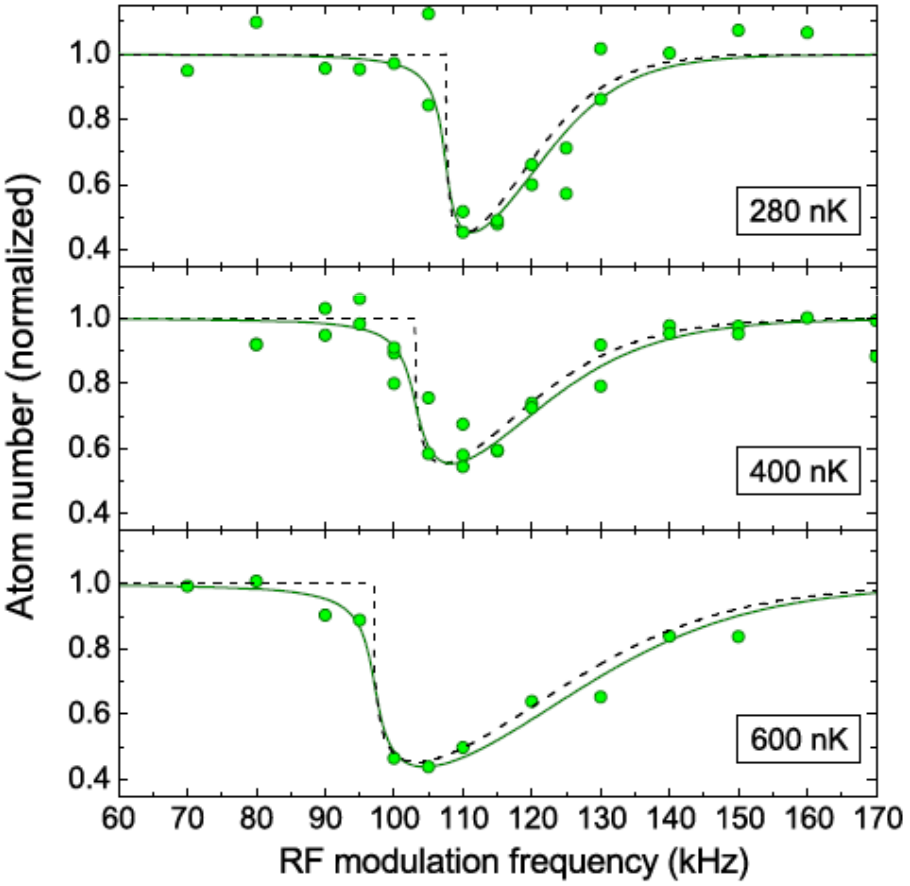
thermal cloud ~100nK

theory:
Th. Hanna, Th. Köhler, K. Burnett,
PRA 75, 013606

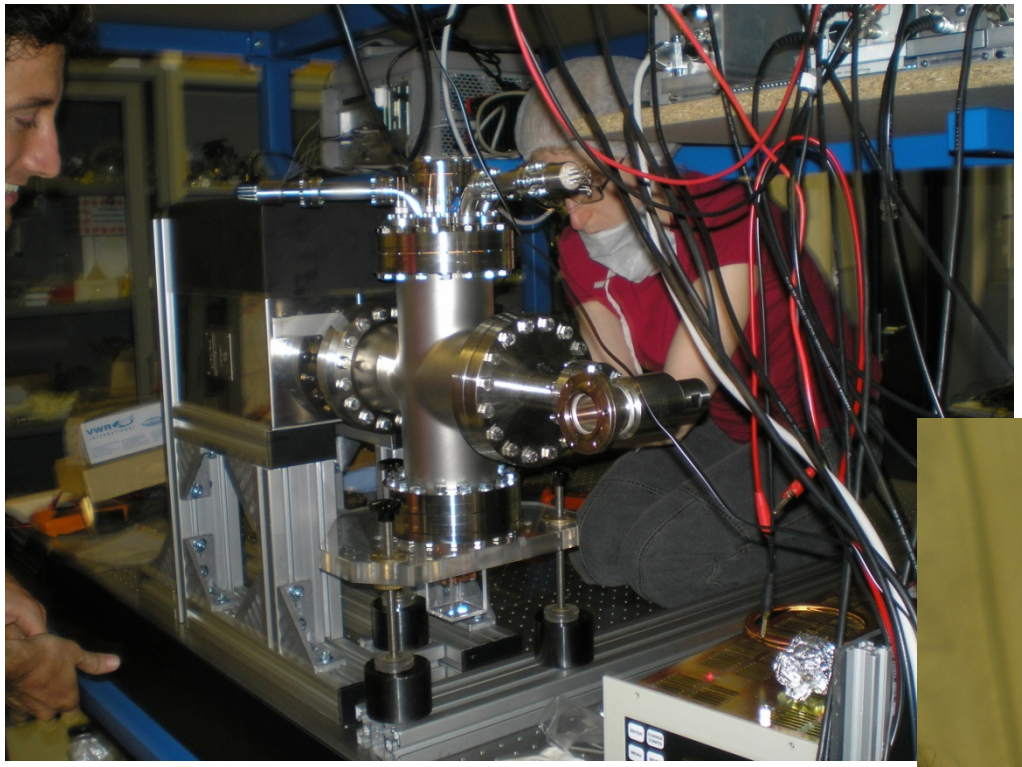
RF-association of cold molecules

Association of ultracold double-species bosonic molecules
C. Weber et al. submitted to Phys. Rev. Lett.



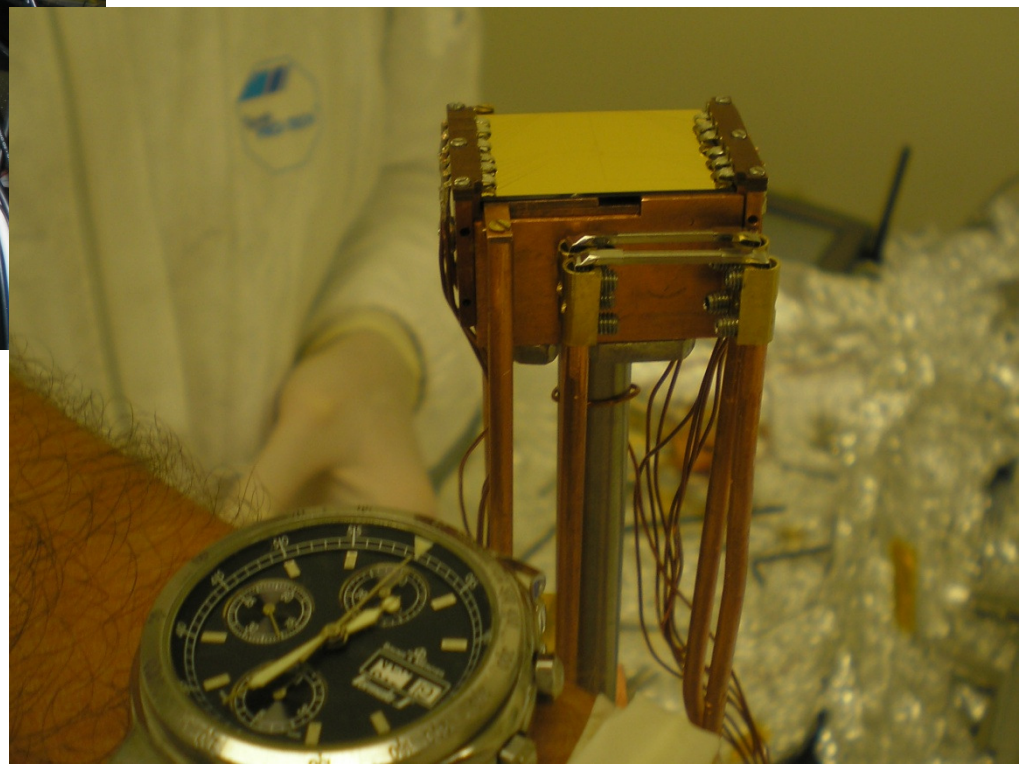


Micro-chip traps



Silicon: 2 cm x 3 cm x 600 μm
Gold microwires: 2.5 μm X 50 ~ 300 μm
Currents: < 2 A

(from AtomChip lab @ Ben gurion)



single MOT system:
Laser power ~ 100 mW

BEC 10^5 atoms
production cycle ~ 1 s

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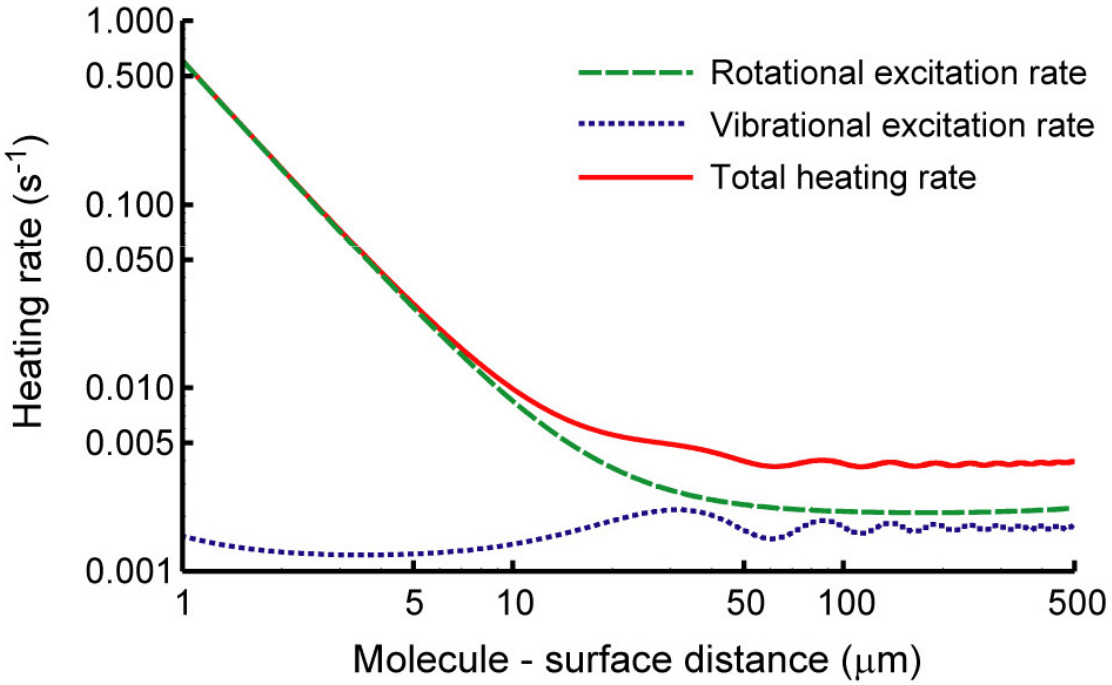
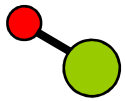
Surface-induced heating of cold polar molecules

- In a molecule chip, ultracold polar molecules will be placed close to warm surfaces
- How quickly are the molecules heated by the warm surface?





NaCs molecule, T = 1μK

Gold chip, T = 300K

- At distances suitable for molecule chips, ~10μm, the heating rates are very low

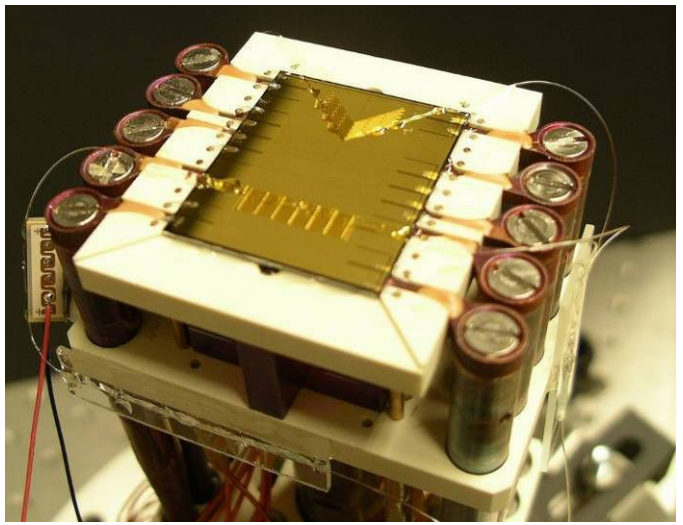
Counting Atoms, Molecules

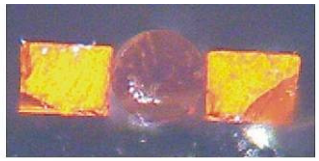
Integrating Fiber Optics on AtomChip

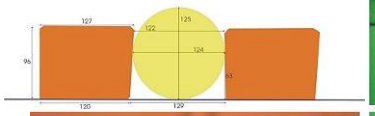
Fibre cavity formed by (gluing) dielectric mirrors at the fibre ends + gap to introduce atoms connecting the cavity to two fiber ends

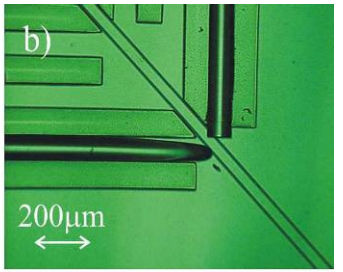
- 2.5 μm waist
- 5 μm gap
- finesse >100
- The cavity length is scanned using a piezo stretcher
- no alignment needed when mounted using SU8 structures
- >99% coupling through the gap

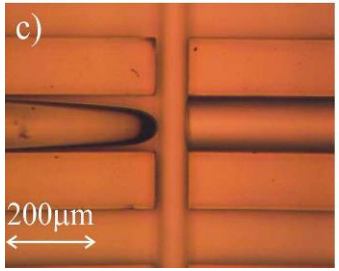
X. Liu, et al, Appl. Opt. 44, 6857 (2005)

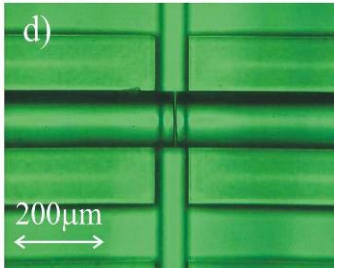








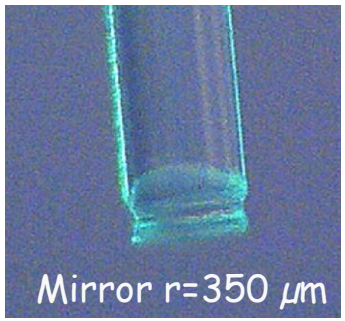




>5σ detection of a single atom in 10 μs

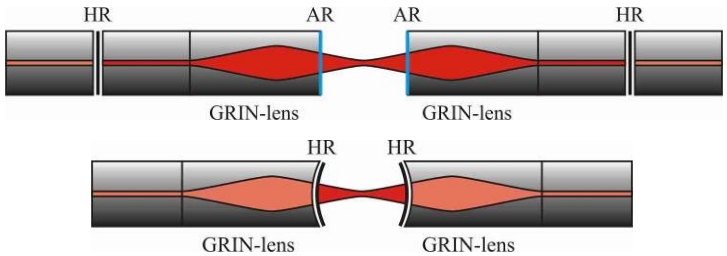
with curved mirrors

- Finesse > 1000,
- w~2.5 μm
- gap up to >50 μm

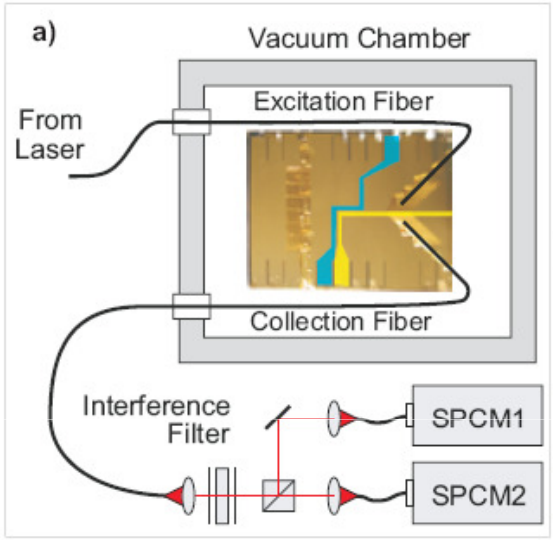


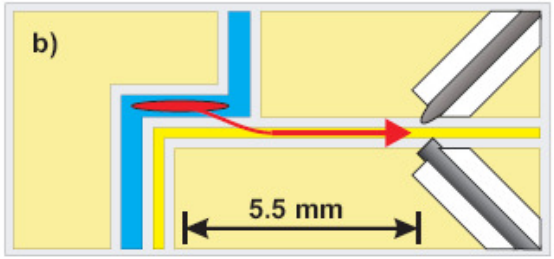
improved alignment free designs

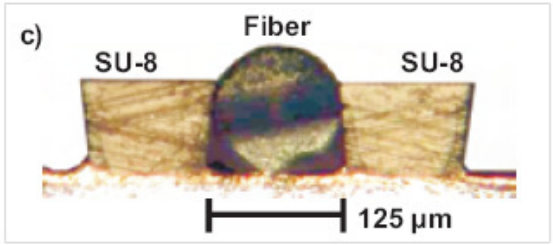
- Finesse up to ~10 000,
- w<2 μm
- $g_0/k>1$, $g_0/G>200$, $C>100$

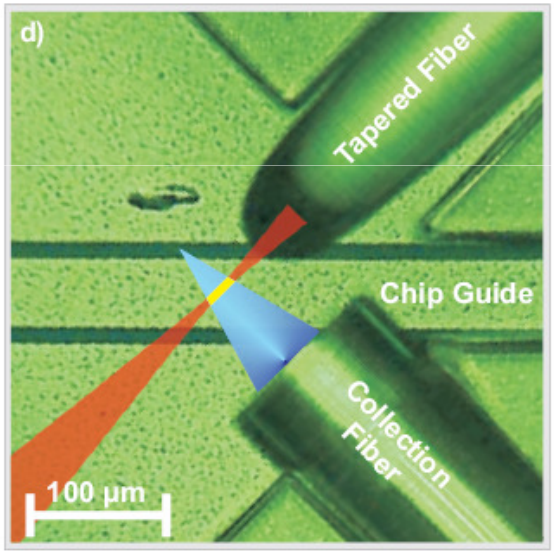


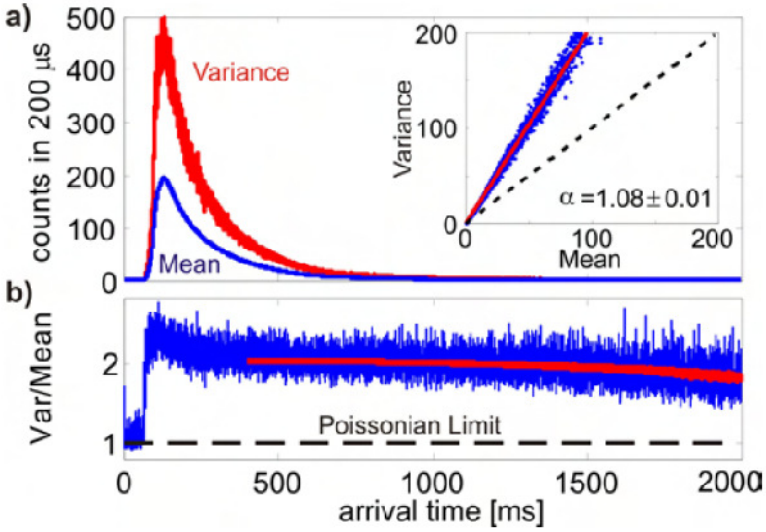
Atom Detector
characterizing by photon statistics

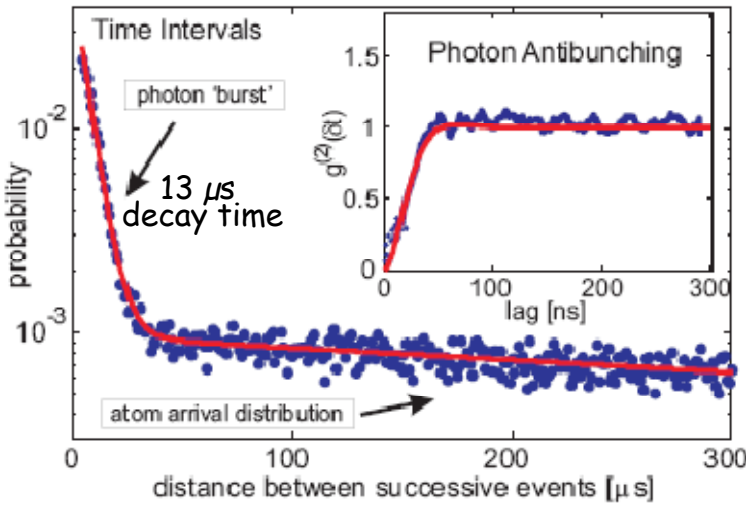












$$\frac{\mathrm{var}[n]}{\langle n \rangle} = 1 + \alpha$$

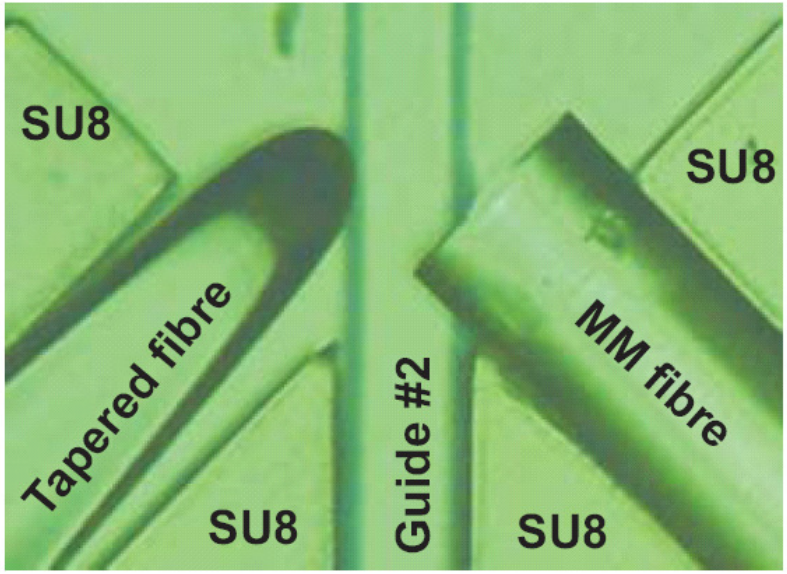
→ 65% detection effitiency

Atom Counter
outlook

- **Integrated Fluorescence Detection**
  - very simple state selective atom counter with very low background
  - detection efficiency (in< 40 µs):

present η~70% @ S/N > 100:1

projected η>99.9% @ S/N > 100:1



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Optical microcavity on a chip – single atom / molecule detection

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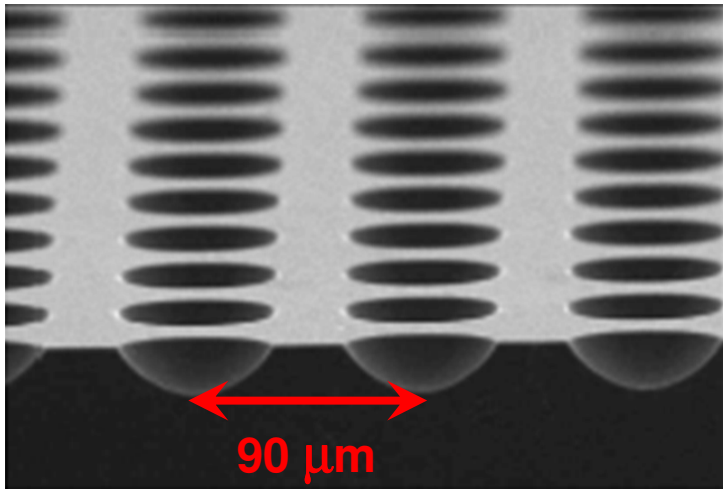
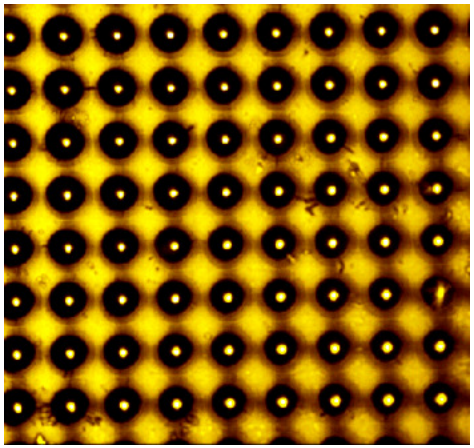
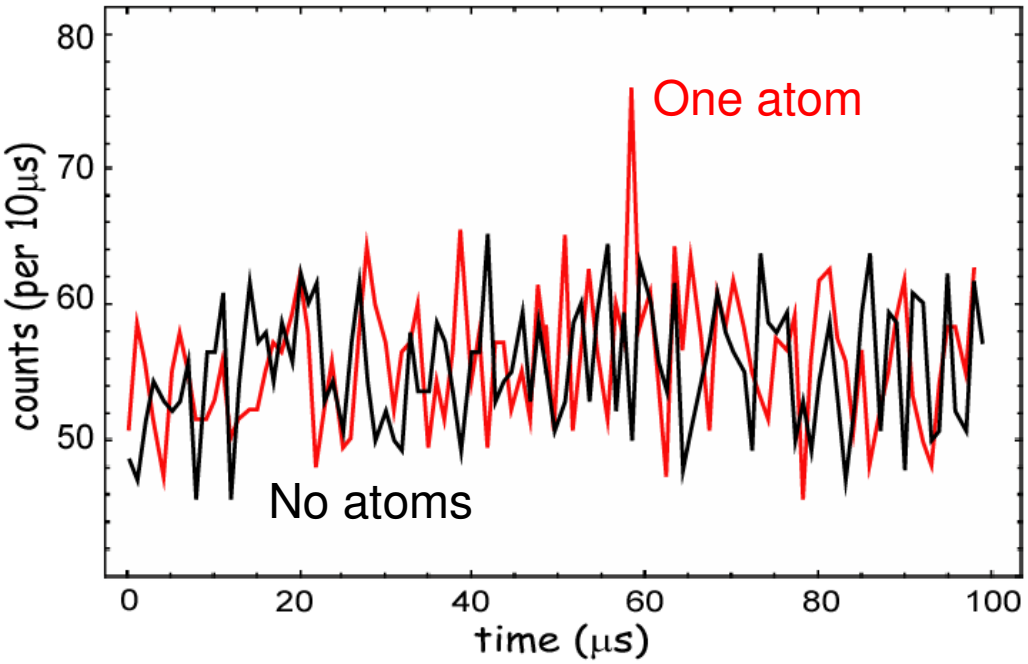
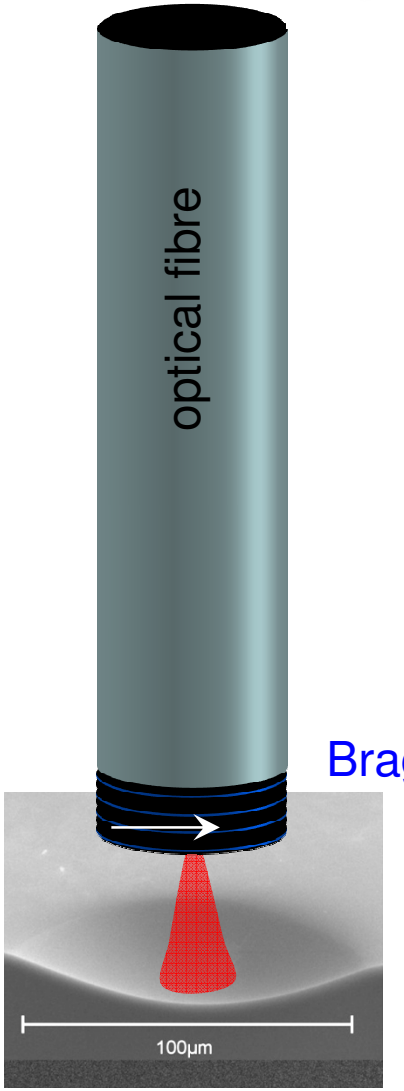




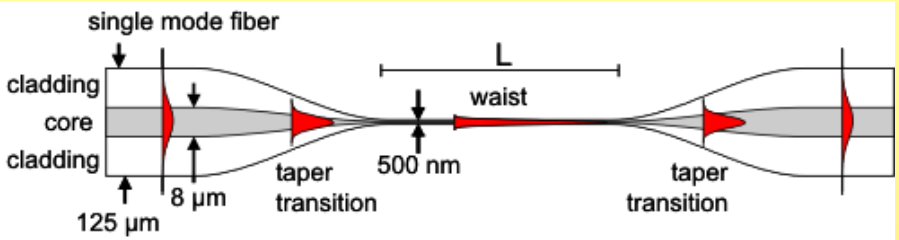




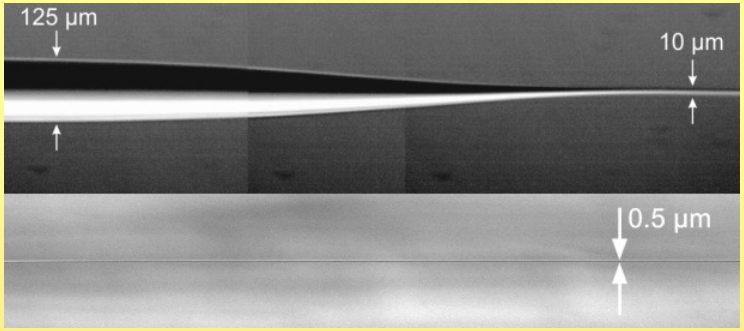
Bragg stack

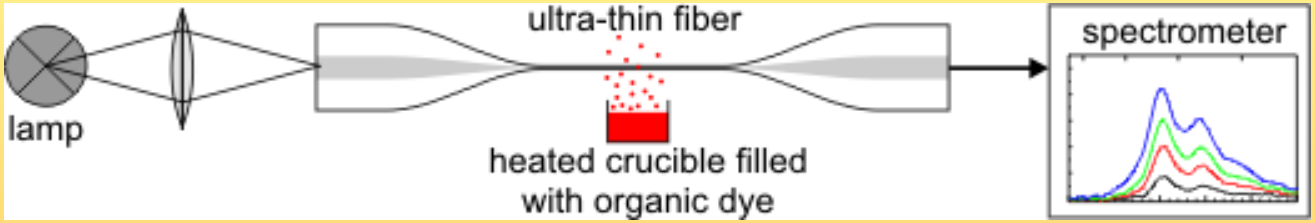
Dielectric coated micro-mirror

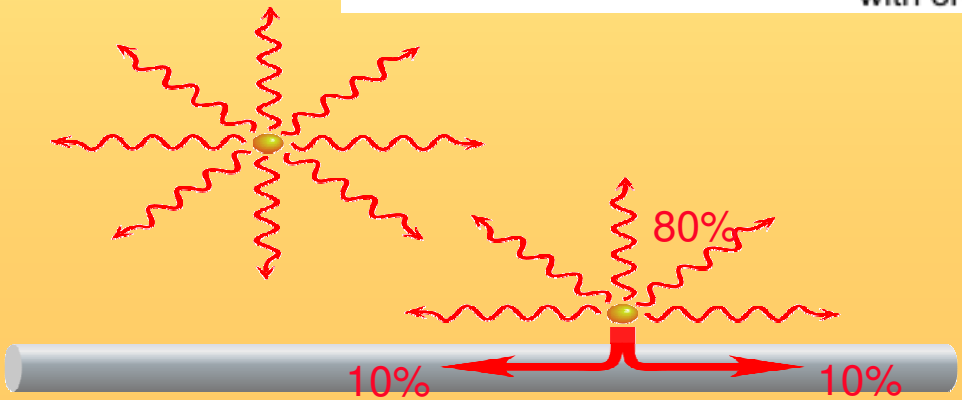
Evanescent Coupling of Fluorescence



Guiding of light in a tapered single-mode fiber.

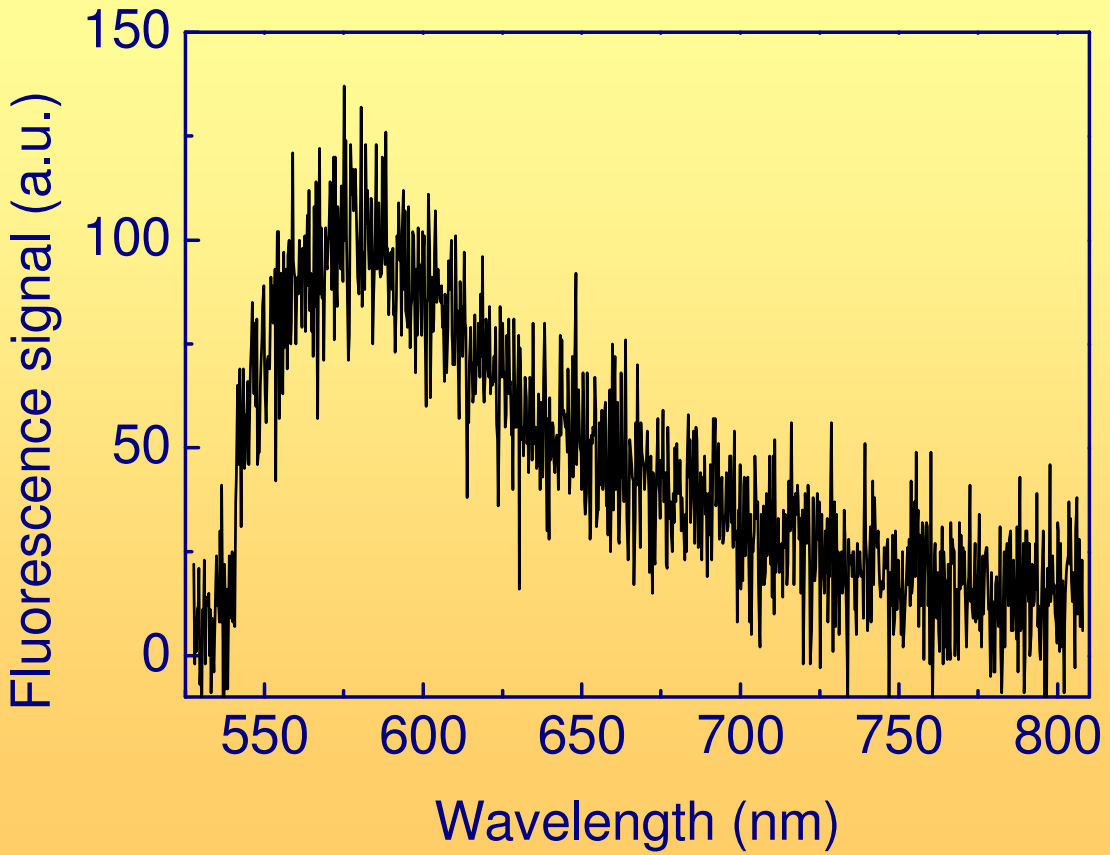






Large efficiency collection of light

Evanescent Coupling of Fluorescence



Signal from
PTCDA molecules

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SEVENTH FRAMEWORK PROGRAMME

ICT-2007.8.1 Nano-scale ICT devices and systems

Foreseen Outcome:

- ***Development of "MoleculeChip"***

Long Term Goals:

1. *Ultimate precision/control of a single atom or molecule functionality, control of the connectivity and of addressability of a single atom/molecule. Control of state and conformation, where the conformation is connected to the function.*
2. *An appropriate technology to exchange energy, data and instructions within a single atom or molecule and between different atoms or molecules*
3. *Control and synthesis down to the sub-nano scale, constructing the system one-by-one from atomic and molecular building blocks*