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Non-contact Nanoscale Ultrasonic Transducers

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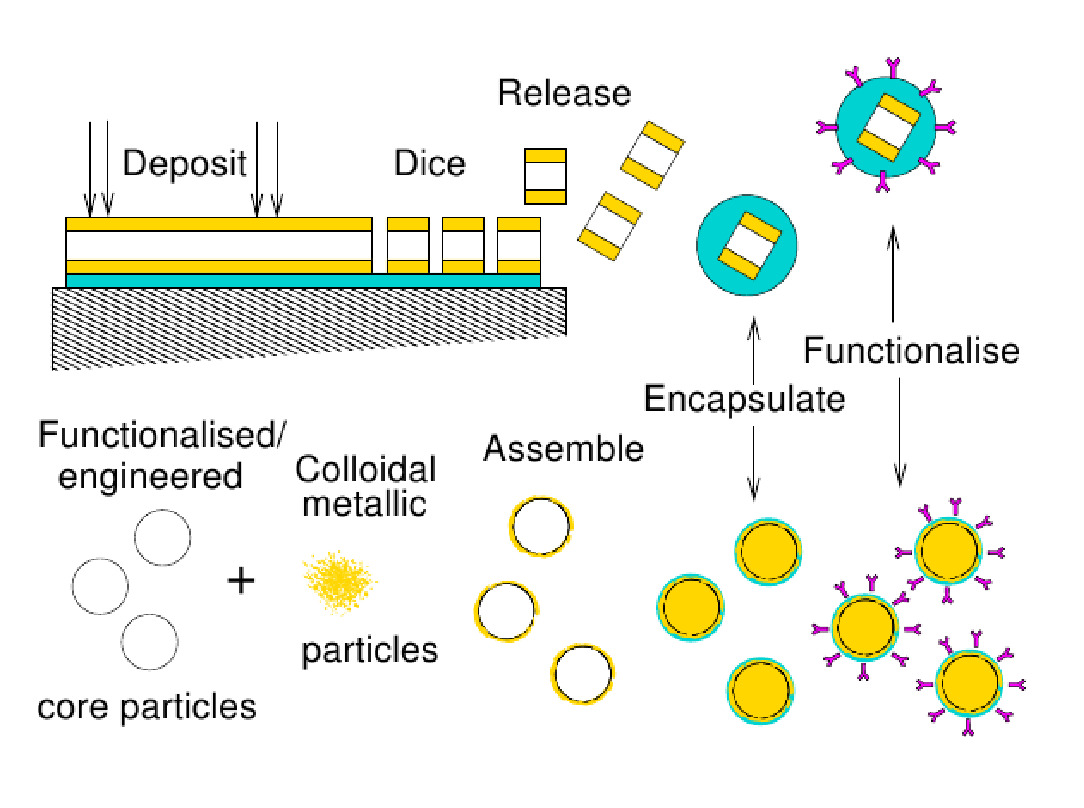
Talk Outline

- Introduction
- Mechanical operation
- Optical operation
- Fabrication of devices
- Testing of devices
- The next step
- Conclusions

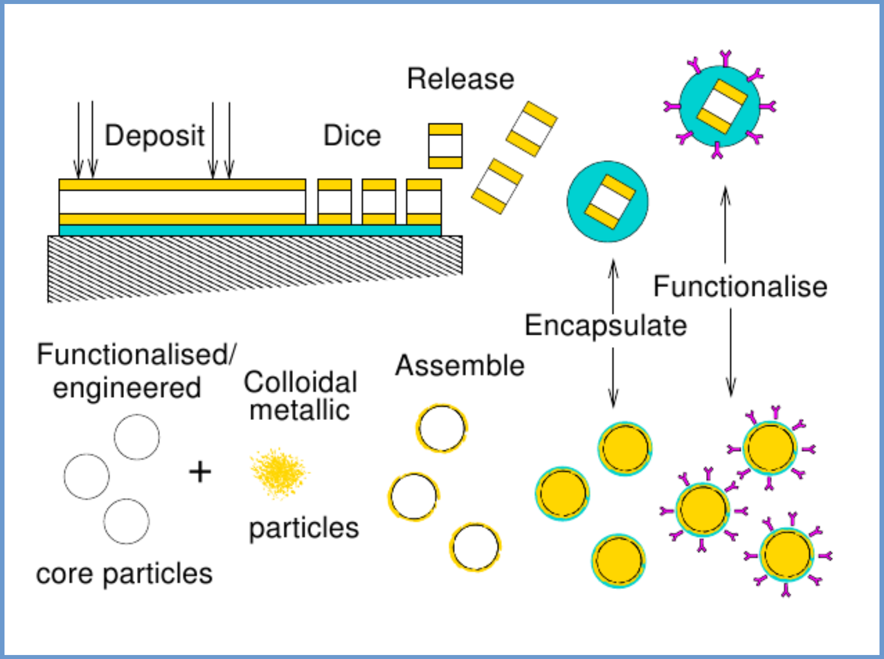
Introduction

- Aim: produce nanoscale transducers
- To couple the acoustic to the optical and vice versa.
- Realised using patterned thin film sandwiches,
- Molecular self assembly of nanoparticles
- Encapsulate and functionalise to allow measurements as specific sites



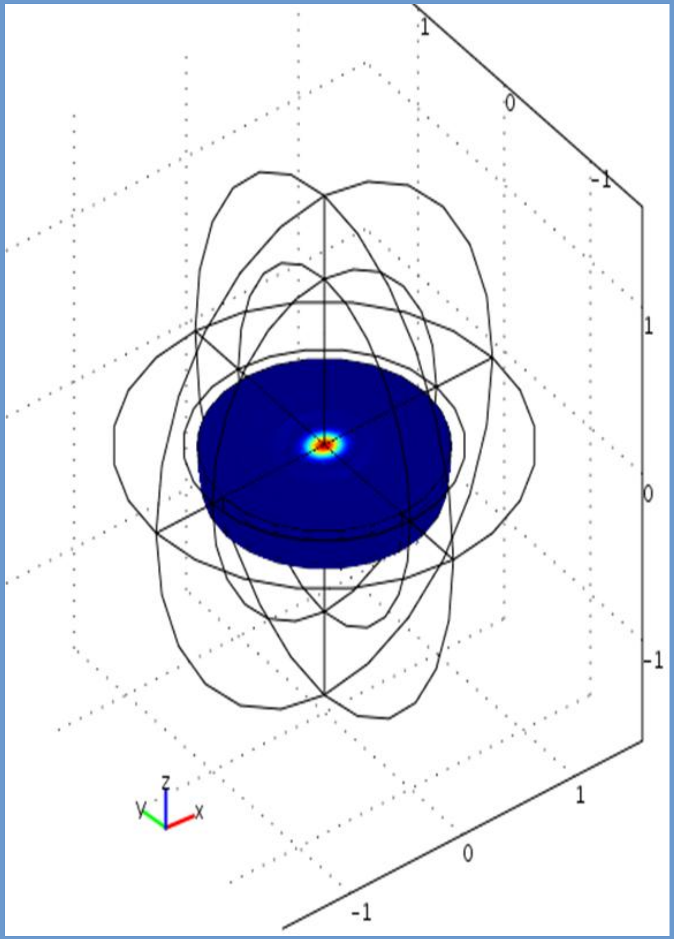
Introduction

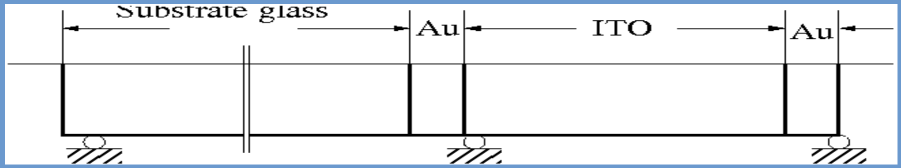
- Transducers will have natural mechanical resonances due to the metal coatings and soft cores.
- The metal outer and transparent cores means that they will have optical resonances where small changes in the metal layer separation will cause large changes in the reflected light.
- Design transducers so they work well for both domains



Mechanical operation

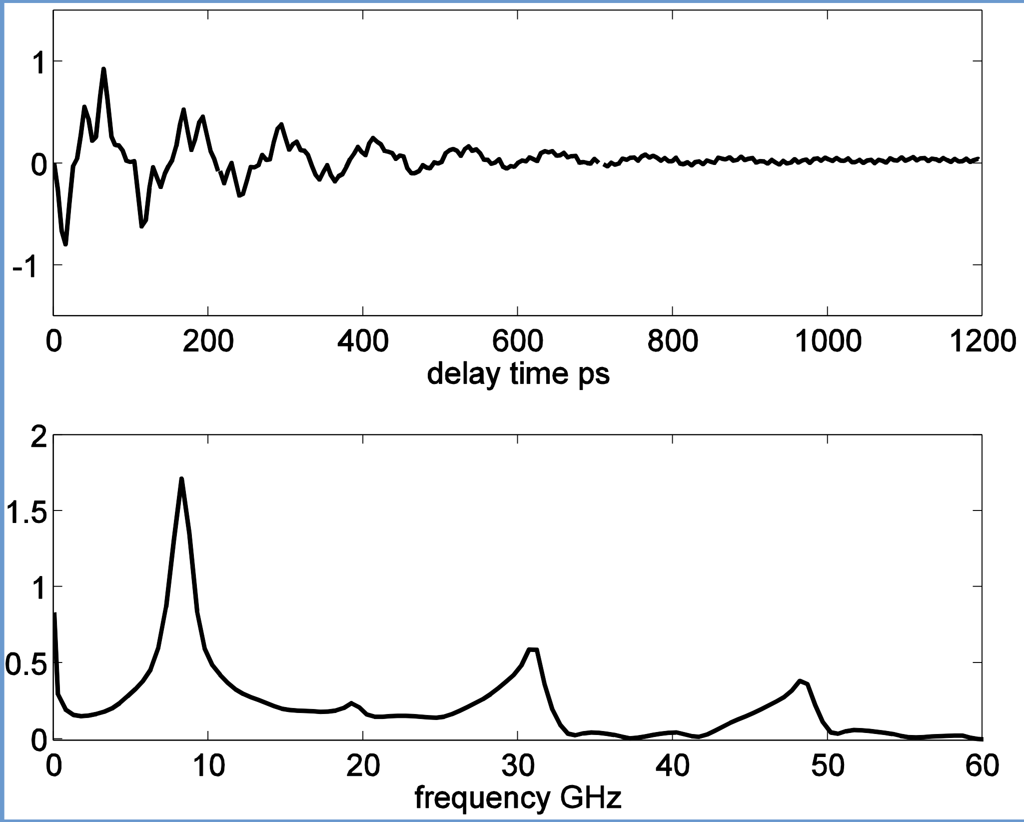
- Structure modelled with a 2D axisymmetrical thermomechanically coupled FE model
- Optical model to calculate the absorption of pump beam to see where the energy is absorbed.
- The absorption is converted to a heat distribution and temperature change
- Calculate the thermal expansion due to the changing temperature
- This leads to the mechanical motion in the structure

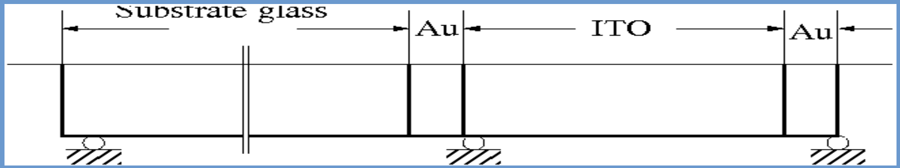




Mechanical operation

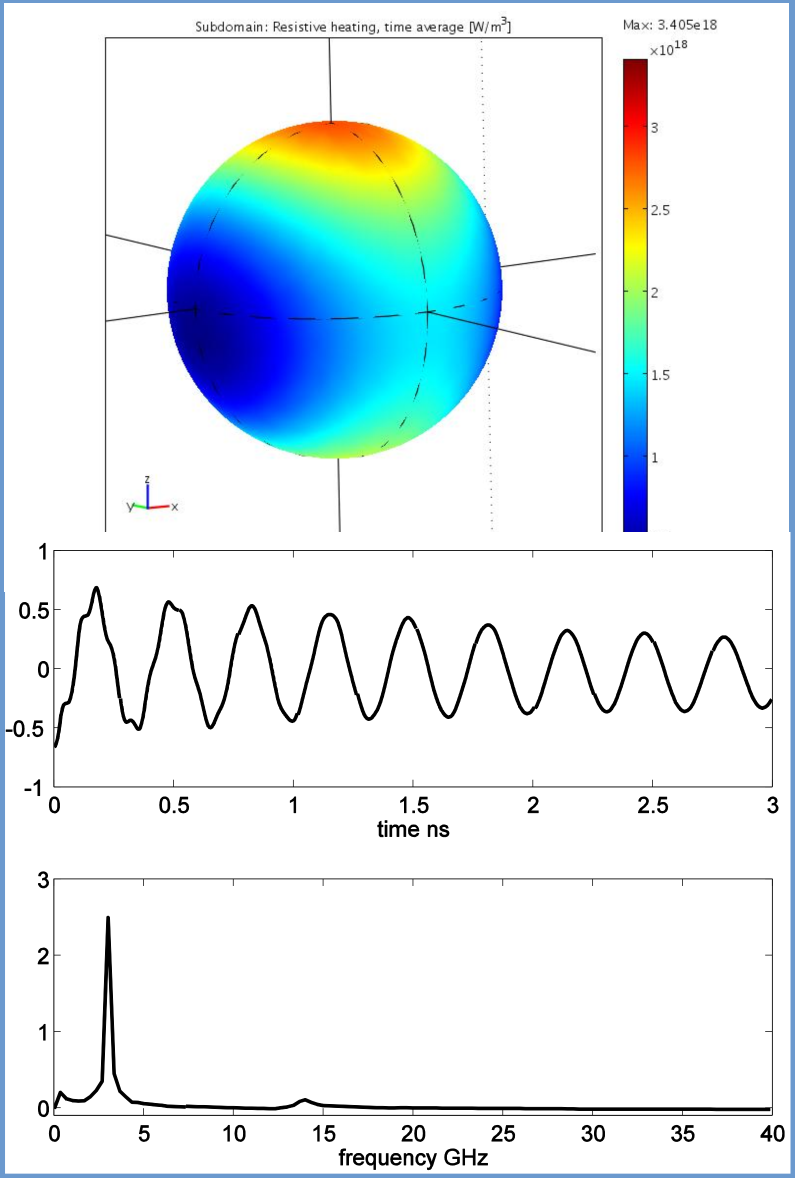
- The difference in displacement between the top metal layer and the bottom one is shown
- There is a large ~8GHz oscillation and other smaller high frequency components.
- Decay is relatively fast due to acoustic wave going into the glass substrate.

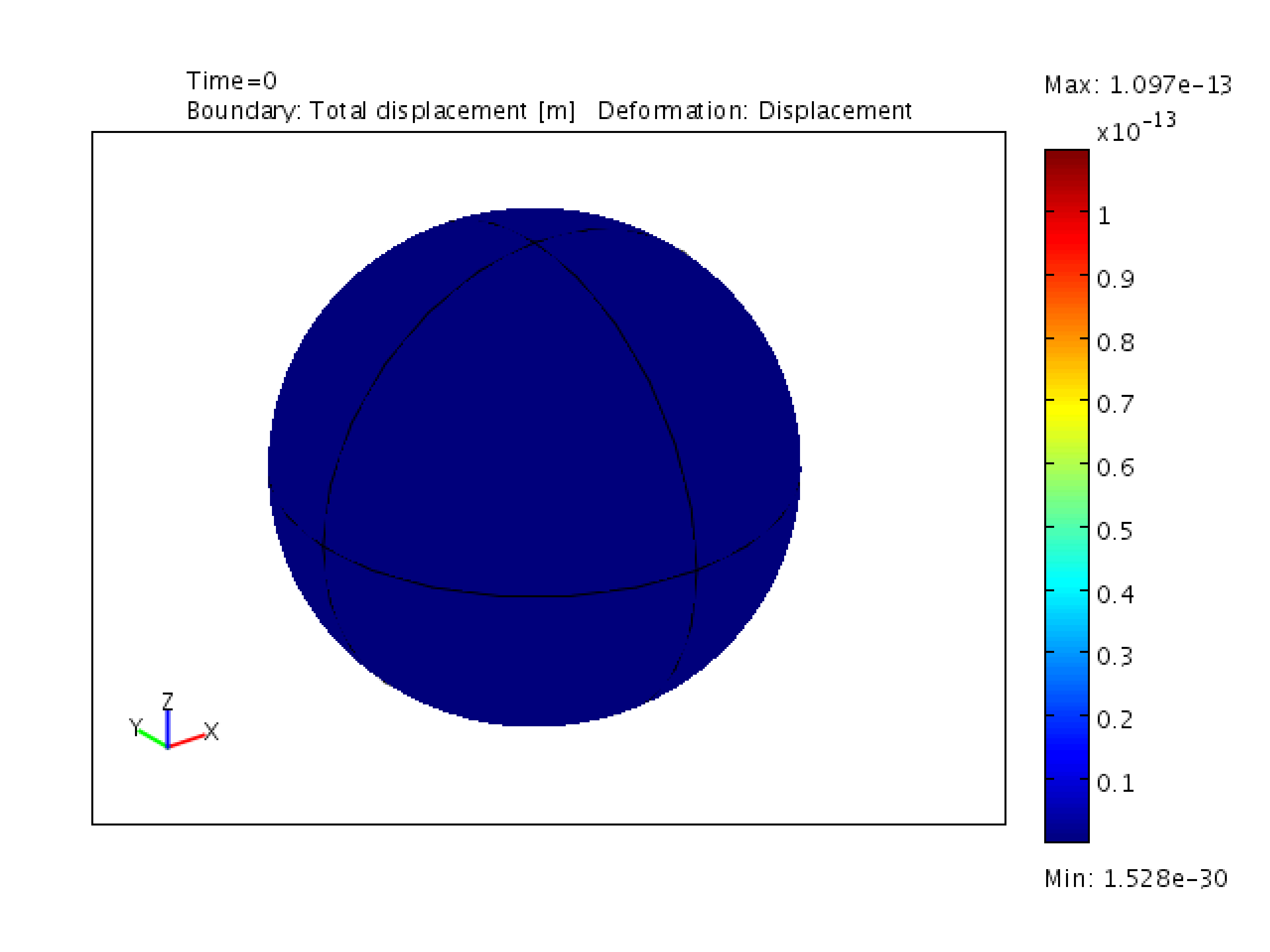




Particle modelling

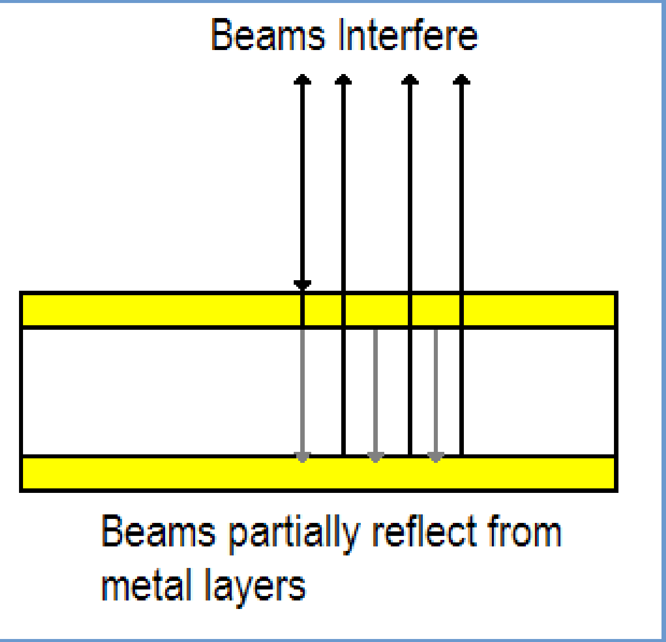
- For the spherical particles we need to do a full 3D model.
- 3D-thermomechanical and fluid coupled FE model.
- Assume the particle is suspended in water
- Response shows a very large ~4GHz oscillation with a much smaller peak at 14 GHz.
- Fewer harmonics present – due to water damping

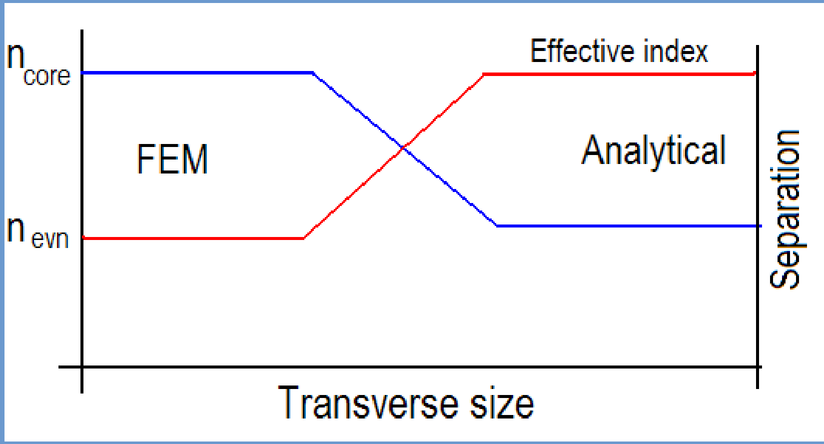



Time=0
Boundary: Total displacement [m]   Deformation: Displacement
Max: 1.097e-13
x10-13
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Min: 1.528e-30
Z
Y
X

Optical operation

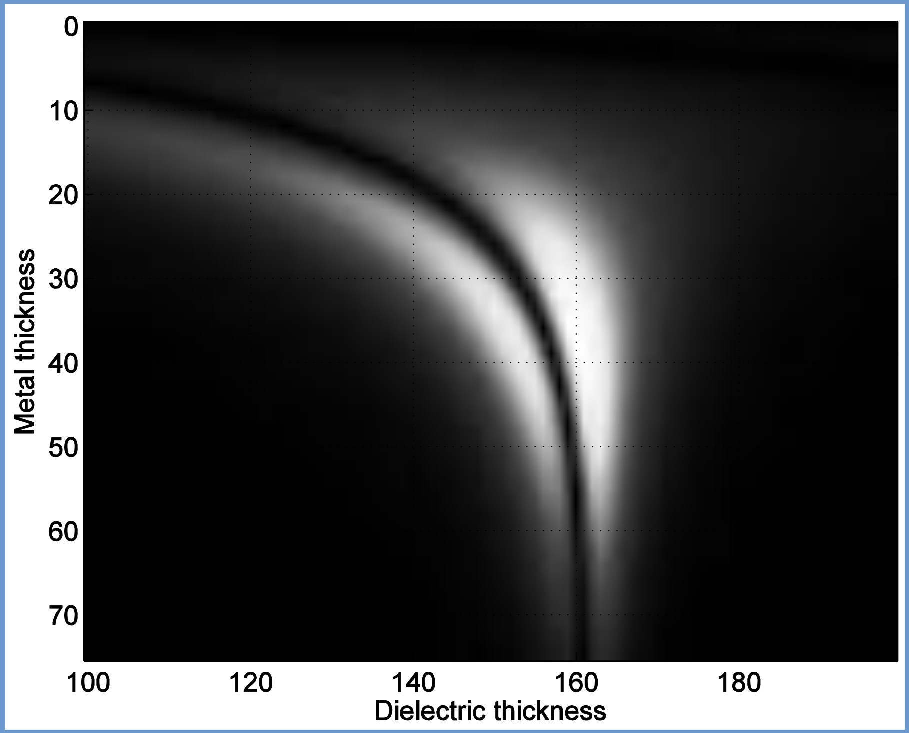
- Devices operate in manner similar to that of a Fabry-Pérot interferometer.
- To obtain maximum sensitivity the ideal thickness of the filling is $\lambda/4n_{core}$ when only one reflection is present
- When devices are large w.r.t the optical spot size they can be modelled analytically
- As the devices get smaller the effective refractive index changes as the surrounding medium plays a bigger role.
- This means that the design parameters for different sizes device will be different.





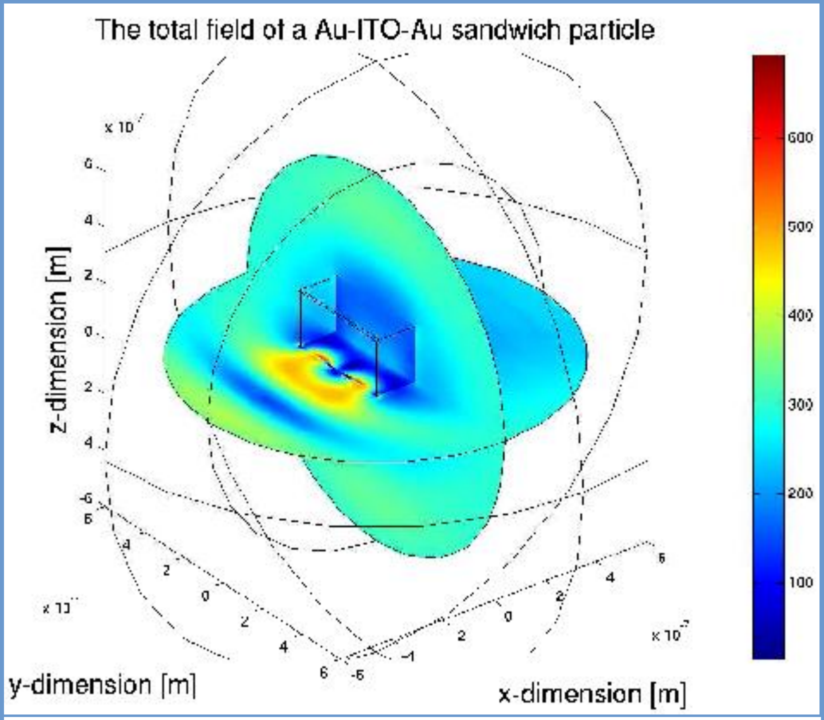
Optical operation

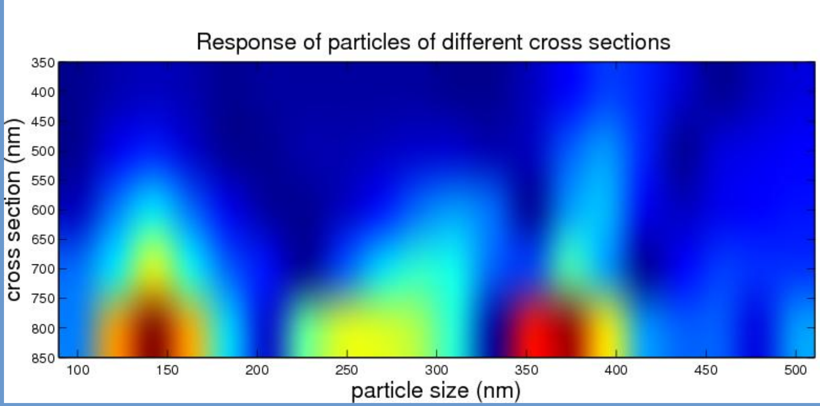
- When devices are larger than the optical spot size they can be modelled analytically under the infinite width assumption using Fresnel coefficients
- We wish to operate at the maximum sensitivity
- For gold ITO sandwich this corresponds to 40:160:40 nm structure



Optical operation

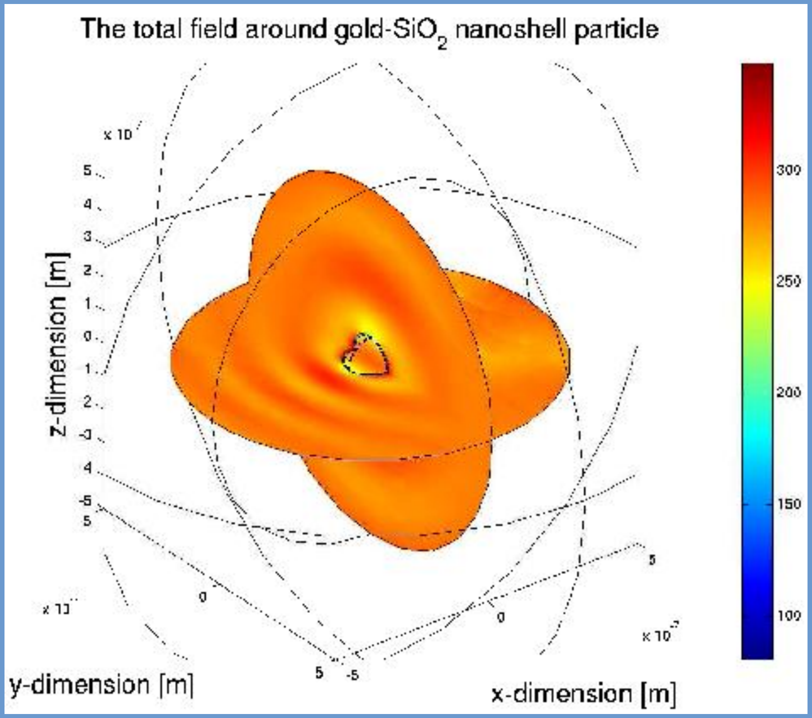
- For the small patches and nanoparticle devices we have to use FEM as analytical model no longer holds true.
- Assume plane wave incident in the positive x direction. We calculate the reflected and transmitted far field spectra which are obtained by doing a near field to far field transformation

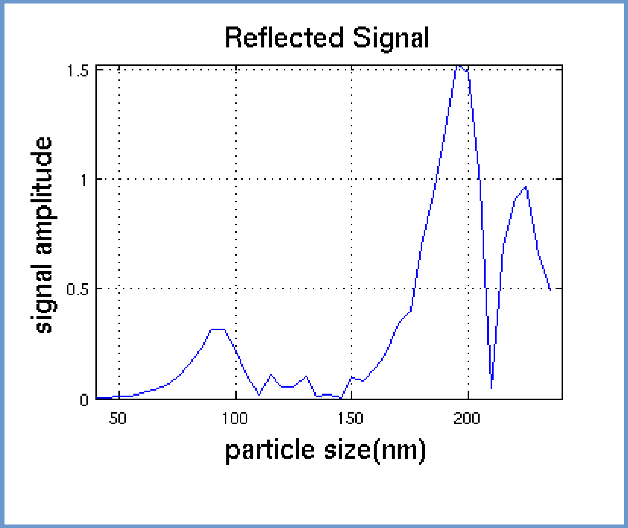




Optical operation

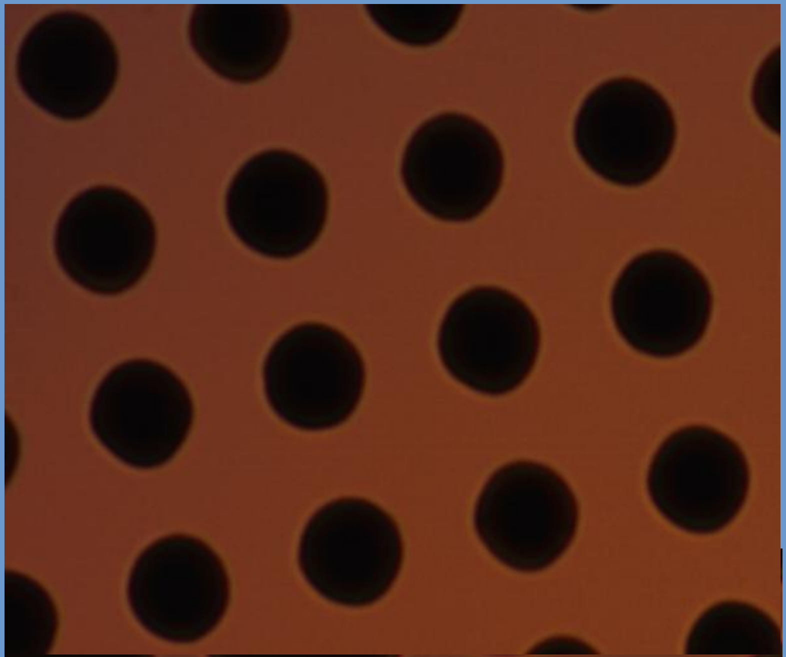
- Similar approach for particle work
- See oscillations in far field reflections
- We get a good sensitivity for ~190nm particles.

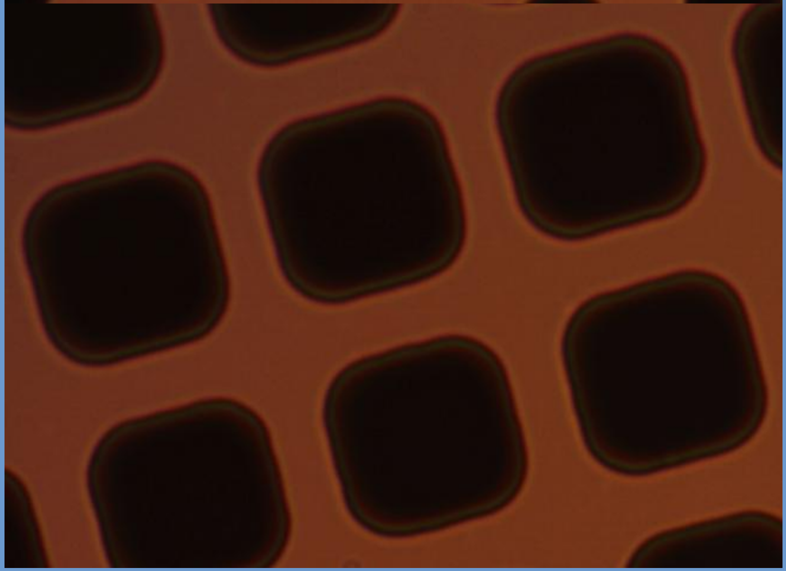




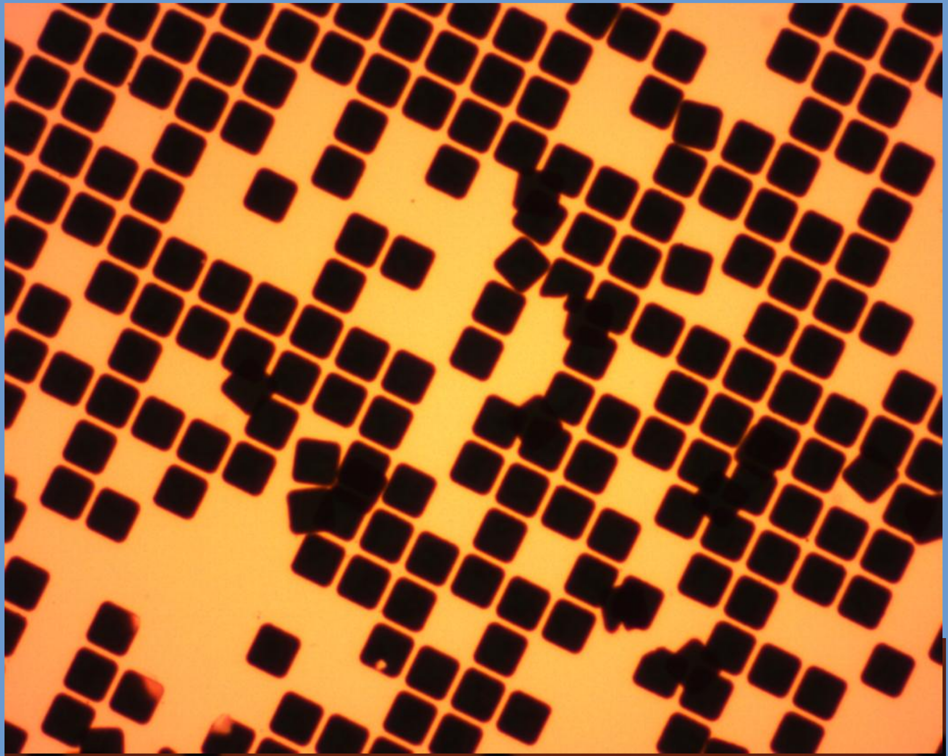
Fabrication of devices

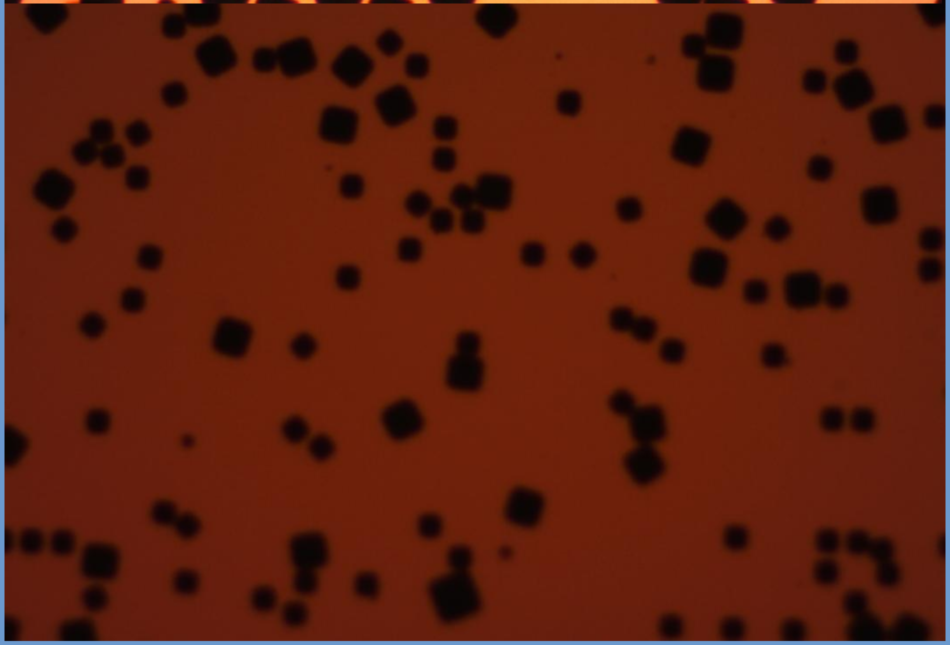
- Spin coat photoresist layer
- Pattern squares using mask and develop
- Coat required films using sputterer
- Lift off rest of pattern to leave transducers on the substrate.
- Can include an extra buffer layer which can then be dissolved to release the transducers into solution
- Transducers can then be reattached





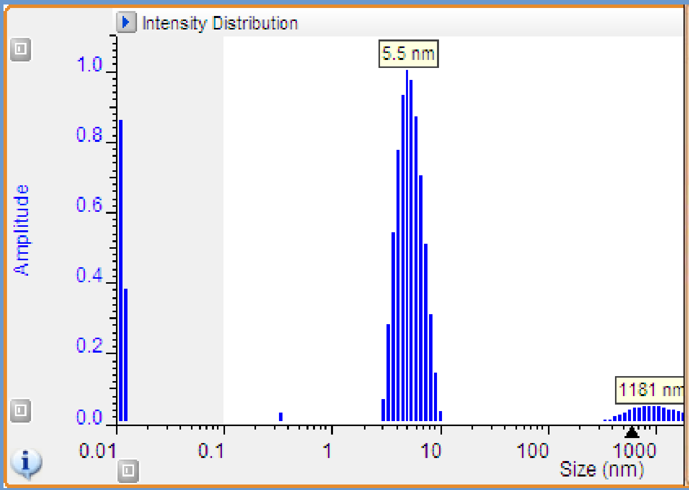
- Making the transducers on a buffer layer is desirable as the measured signals will be longer lived and larger as less energy is lot to the glass substrate in each pass.
- Are early attempts at using a buffer layer have been mixed as some transducers have come away early
- Transducers do survive in solution and can be reattached to slides.
- We can see 5, 10 and 20 micron devices that have reattached to a slide

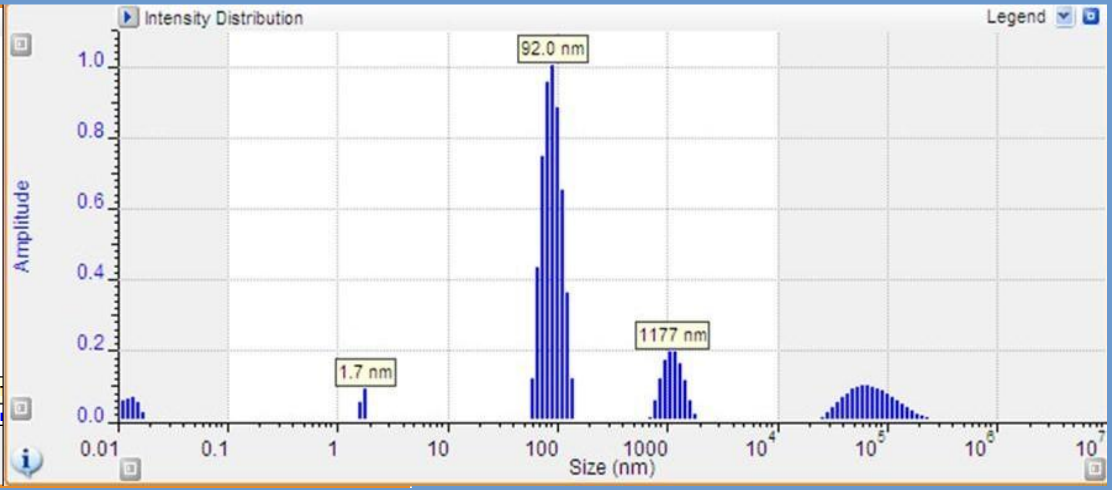




Making nps version

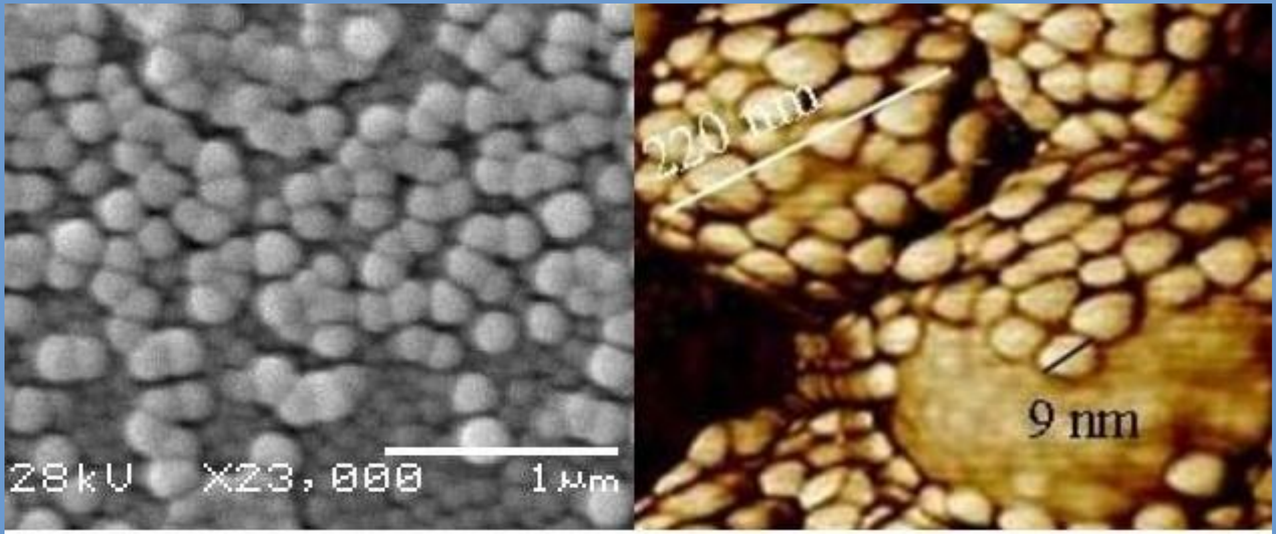
- Different recipes / protocols developed depending on the required size
- Make gold nanoparticles of required size
- Make amine functionalised core particles of required size
- Mix together, the gold particles will coat the core particle due to electrostatic attraction with the amine group
- Measure particle sizes using dynamic light scattering.
- Aim to produce particles with a low variance in size.





Making nanoparticles

- We have made many different batches of particles of different sizes. In an attempt to learn how to control the process.
- Modelling results show that a particle of ~200nm should work well.
- We have made a 200nm particle with ~10nm gold coating.
- Each batch produces trillions of transducers suspended in solution.



Gold Coated Silica nanoparticles

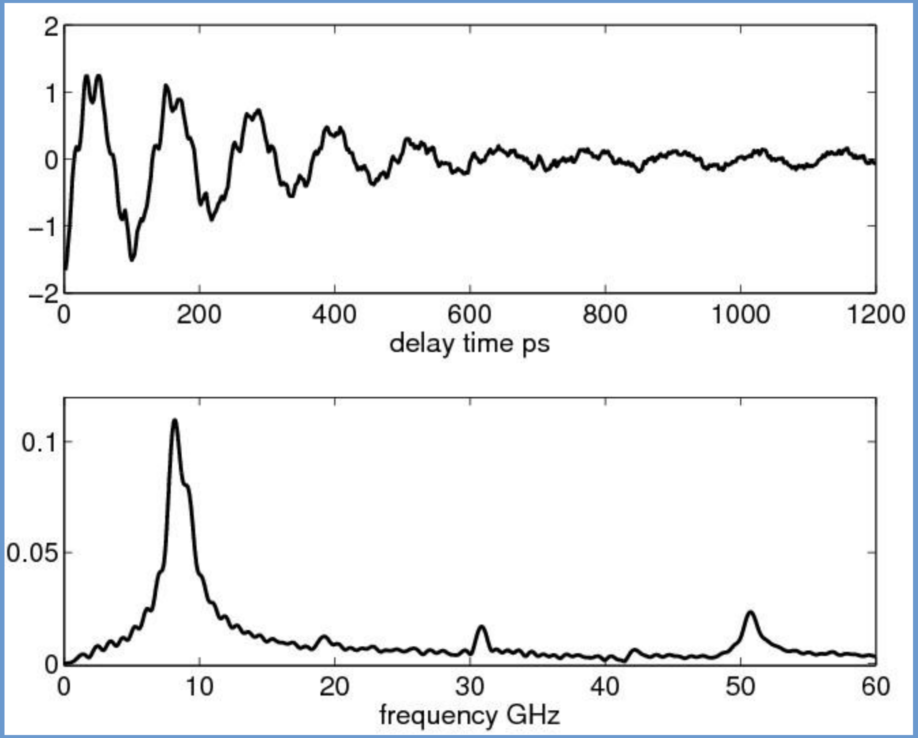
zoom showing gold nanoparticles coating a silica core

Experimental System

- ASOPS system with a 10ns optical delay in 100 microseconds
- Pump 390nm beam
- Probe 780nm beam
- Photodiode, amp and AC coupled to scope
- 100MSa/s → 1ps/point
- We use low frequency chopper to get a reading of probe beam without the pump for noise cancellation

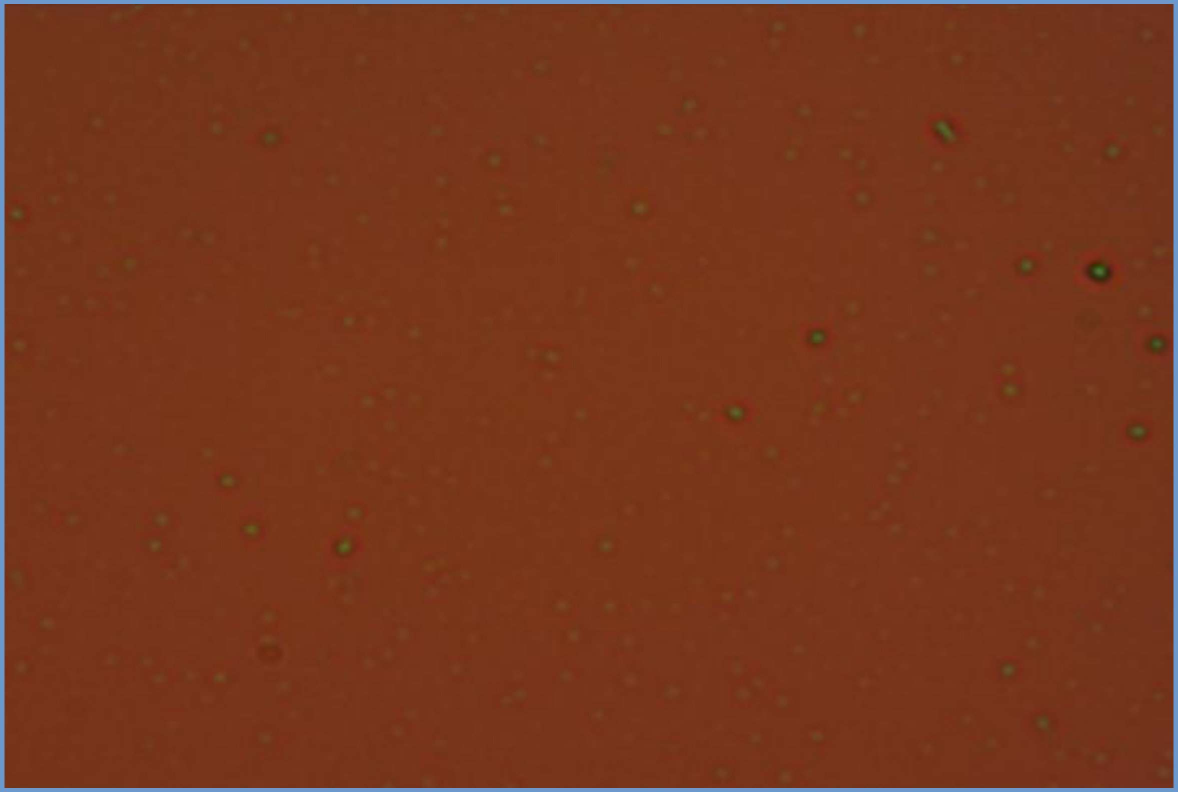
Experimental results

- Tested Au:ITO:Au sample on polymer buffer
- Measured on a 10 micron patch
- Similar frequency content to model
- Oscillations are longer lived - due to buffer layer.



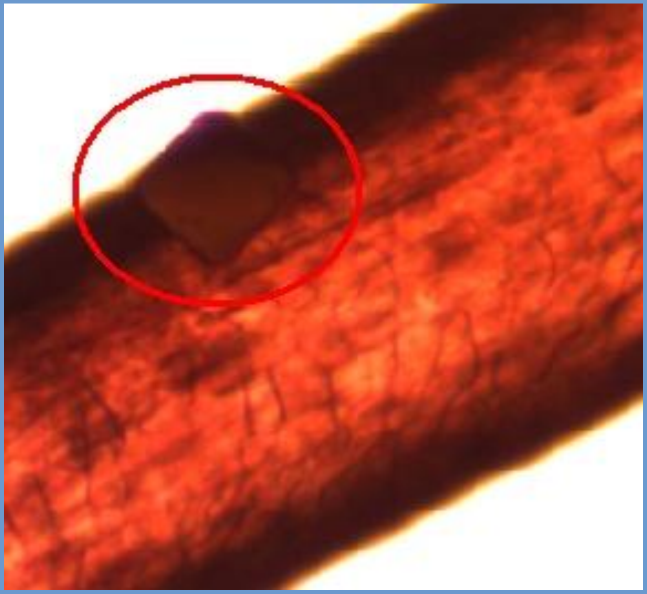
Nanoparticles

- No measurements yet...
- Trying to redeposit to slide sparsely enough that they don't clump but dense enough to find
- Modifying the experiment to help locate the particles.
- future batches will include a fluorescence marker to make it easier to find them.



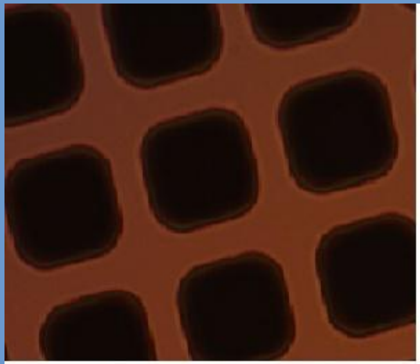
The next steps

- Lift off, free floating, filtering reattach
- How to make them smaller - use FIB, ebeam lithography, better photolithography process
- Encapsulation and functionalisation
- Applications for measurements

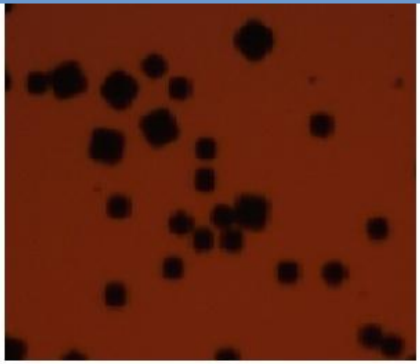


Conclusions

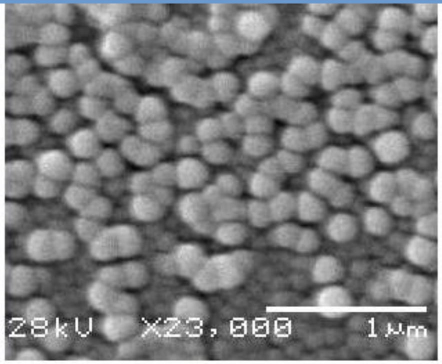
- Modelled, fabricated and tested acoustic/optical transducers of 10 – 5 microns
- Modelled and fabricated 200nm transducers using molecular self assembly



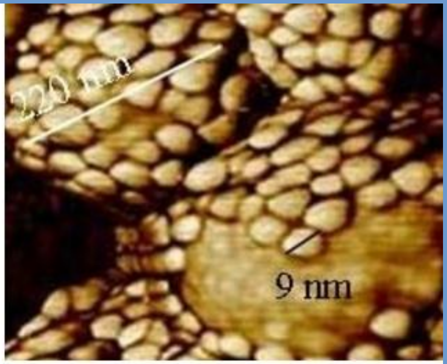
10 micron patches



Assortment of patches re-attached

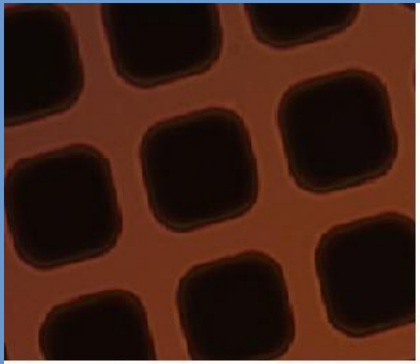


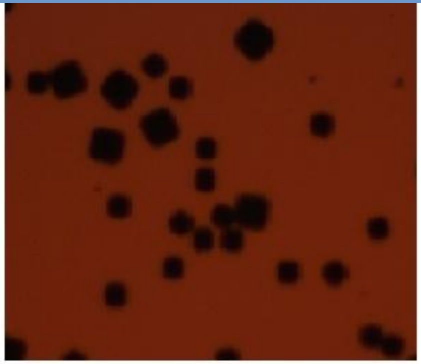
gold coated sillica particles



zoom showing gold coating

- Any Questions?


10 micron patches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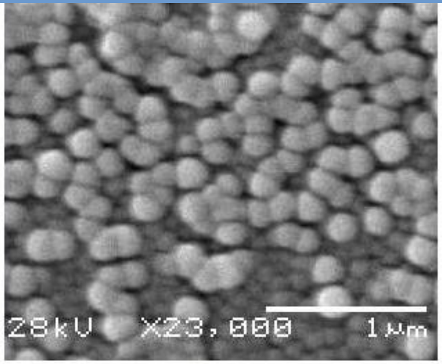
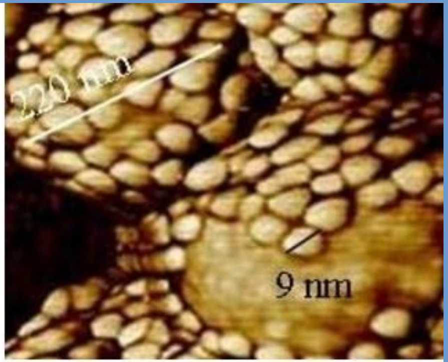


gold coated sillica particles



zoom showing gold coating