AFPAC 19-21st Jan 2011

Design and fabrication of nanoscale ultrasonic transducers

Richard Smith

Xuesheng Chen, Ahmet Arca, Leonel Marques, Jon Aylott, Mike Somekh, Matt Clark.

Applied Optics Group

Electrical Systems and Optics Research Division

University of Nottingham

The University of Nottingham

Applied Optics group

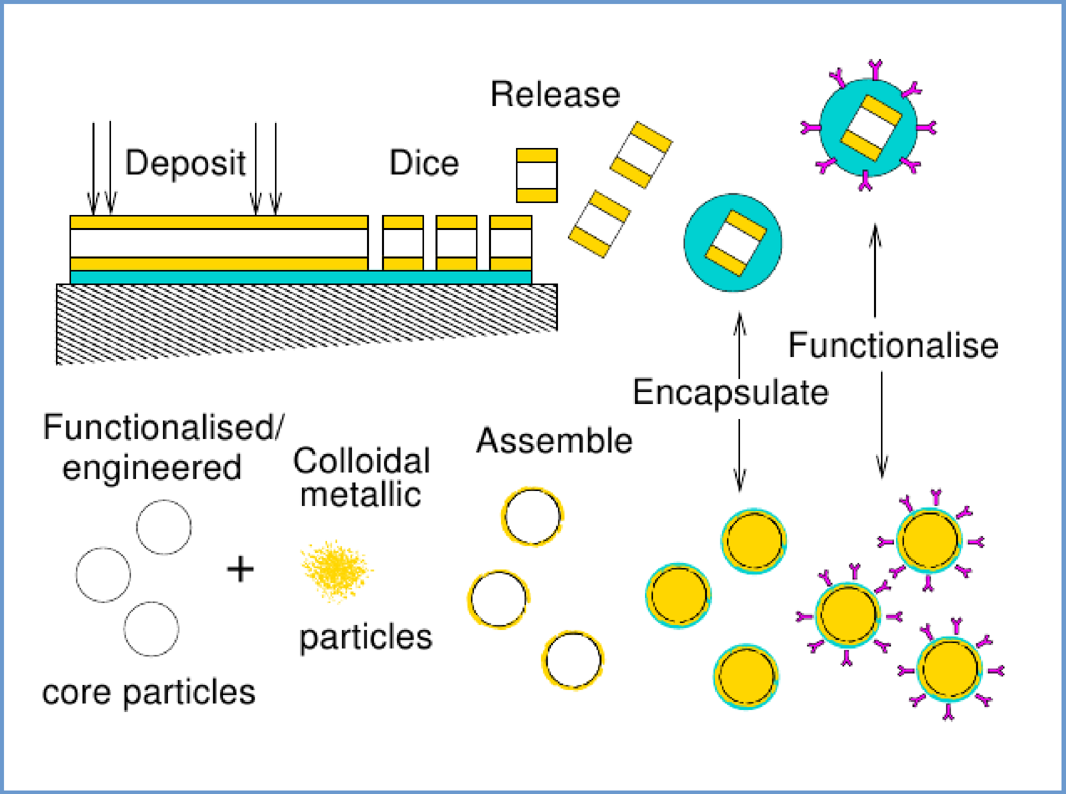
http://optics.eee.nottingham.ac.uk

Talk Outline

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

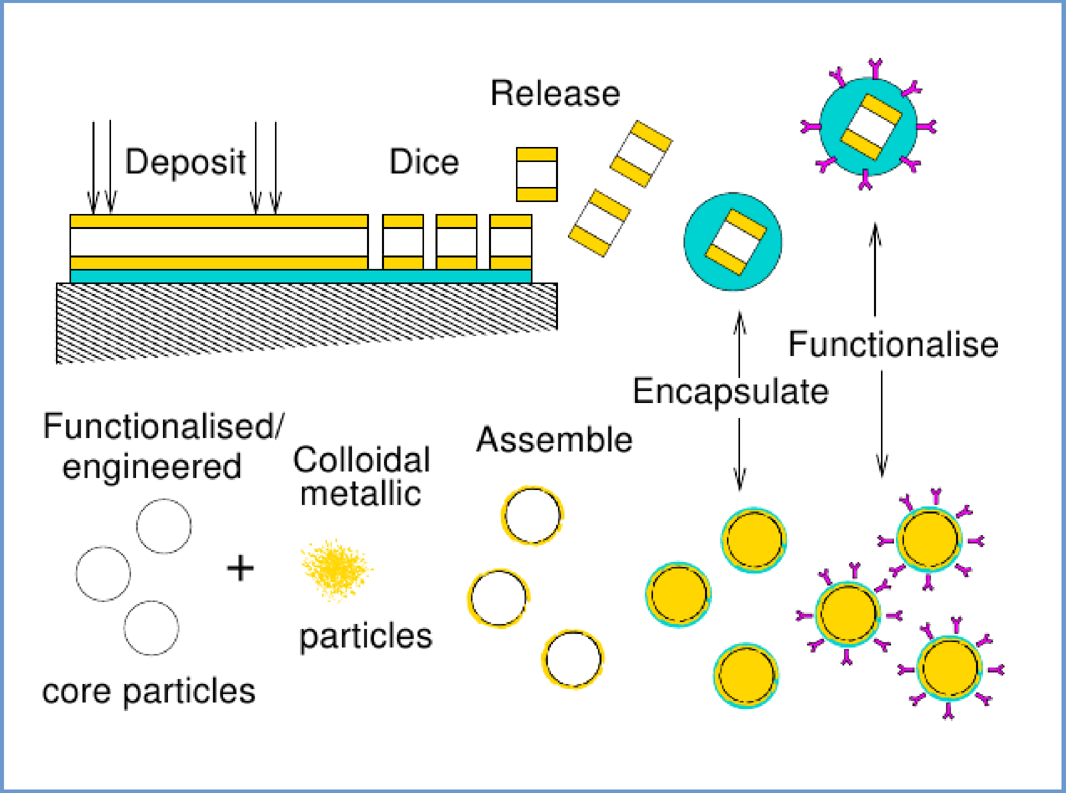
Introduction

- 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



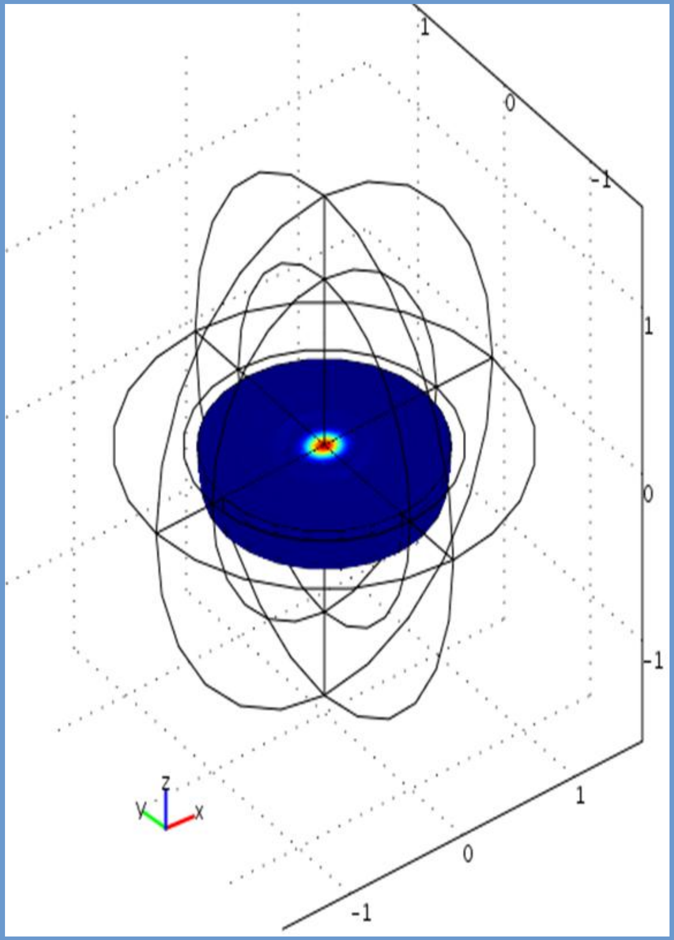
Introduction

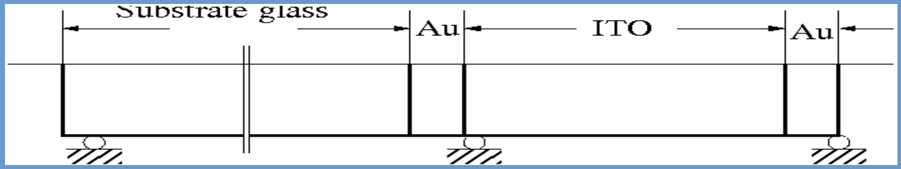
- Transducers will have natural mechanical resonances due to metal coatings and soft cores.
- The partially transparent metal layers and transparent core provide optical resonances
- Small changes in the metal layer separation will cause large changes in the reflected light.
- Design transducers so they work well for both domains



Mechanical operation

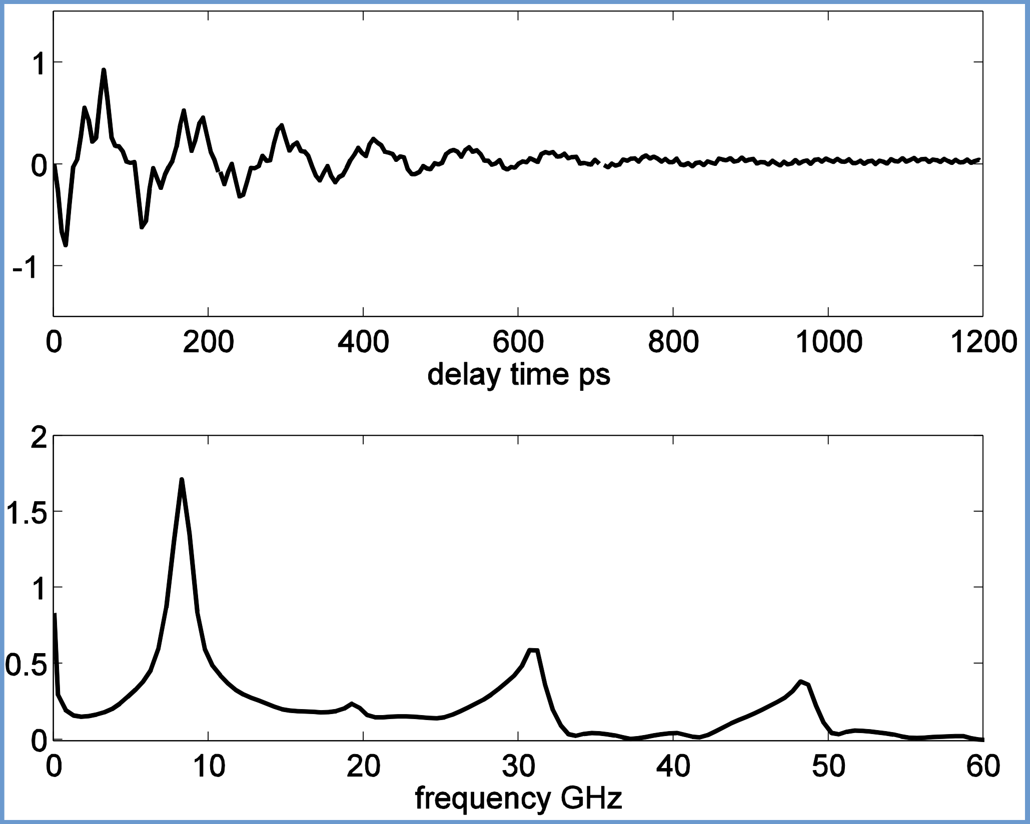
- Structure modelled with a 2D axisymmetrical thermomechanically coupled FE model
- Optical model to calculate the absorption of pump beam to see where the energy is absorbed.
- The absorption is converted to a heat distribution and temperature change
- Calculate the thermal expansion due to the changing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

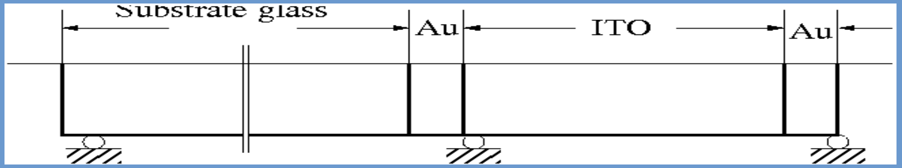




Mechanical operation

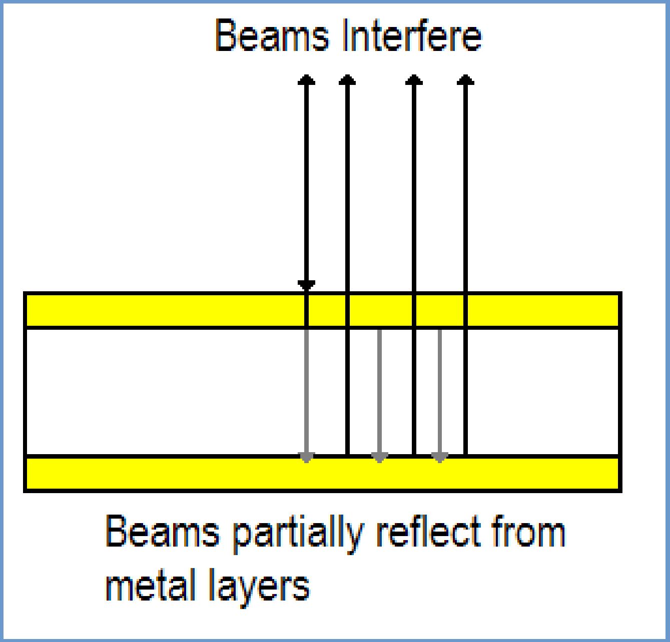
- The difference in displacement between the top metal layer and the bottom one is shown
- There is a large ~8GHz oscillation and other smaller high frequency components.
- Decay is relatively fast due to acoustic wave going into the glass substrate.

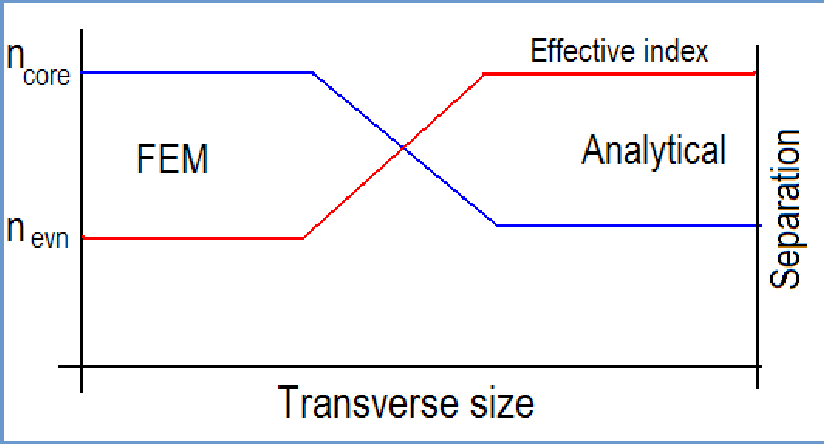




Optical operation

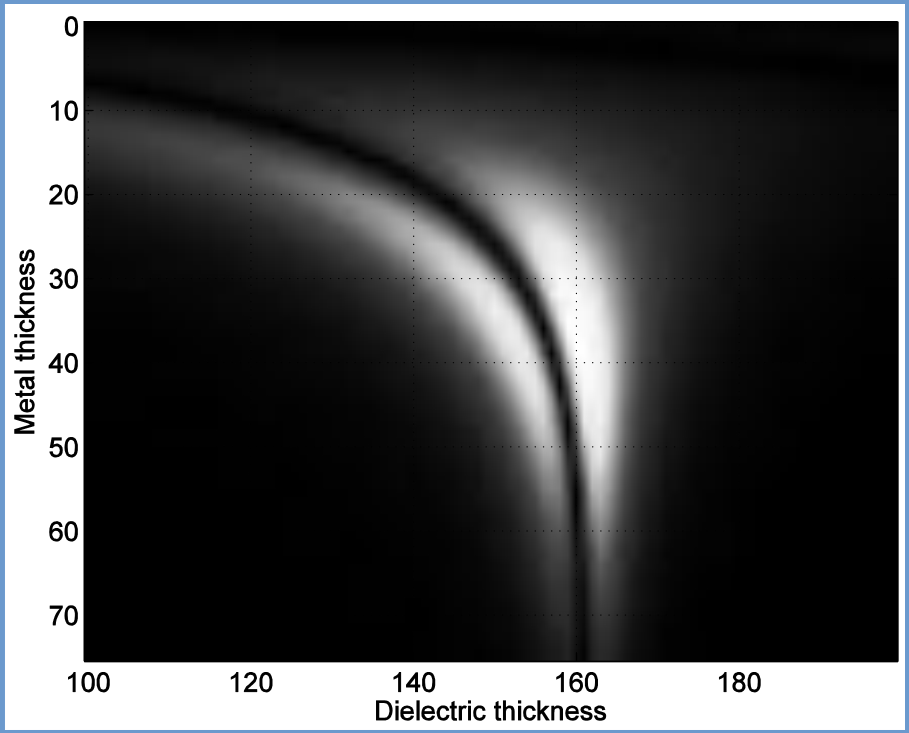
- Devices operate in manner similar to that of a Fabry-Pérot interferometer.
- To obtain maximum sensitivity the ideal thickness of the filling is $\lambda/4n_{core}$ when only one reflection is present
- When devices are large w.r.t the optical spot size they can be modelled analytically
- As the devices 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.





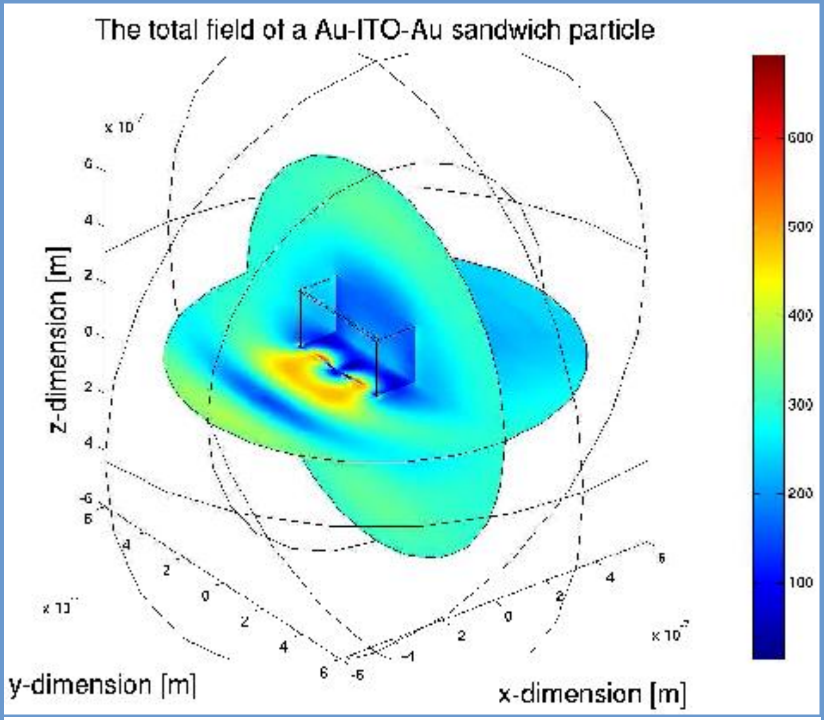
Optical operation

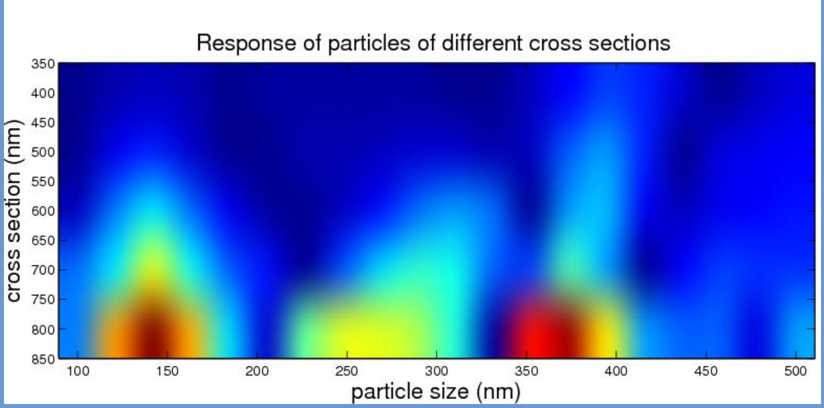
- When devices are larger than the optical spot size they can be modelled analytically under the infinite width assumption using Fresnel coefficients
- We wish to operate at the maximum sensitivity
- For gold ITO sandwich this corresponds to 40:160:40 nm structure



Optical operation

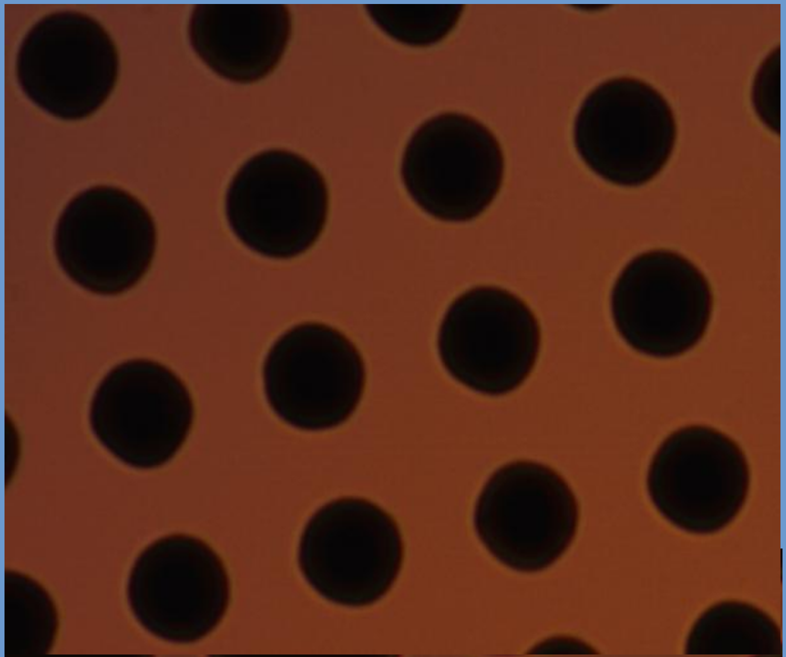
- For the small patches and nanoparticle devices we have to use FEM as analytical model no longer holds true.
- Assume plane wave incident in the positive x direction. We calculate the reflected and transmitted far field spectra which are obtained by doing a near field to far field transformation

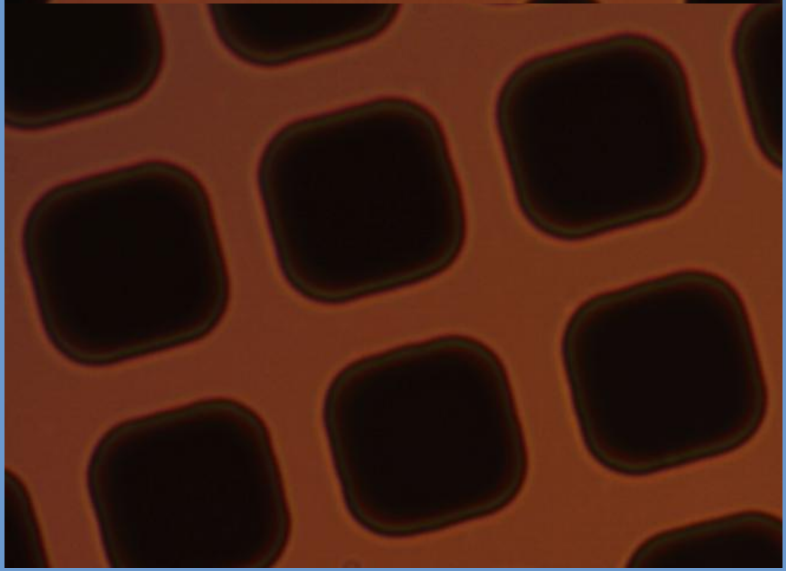




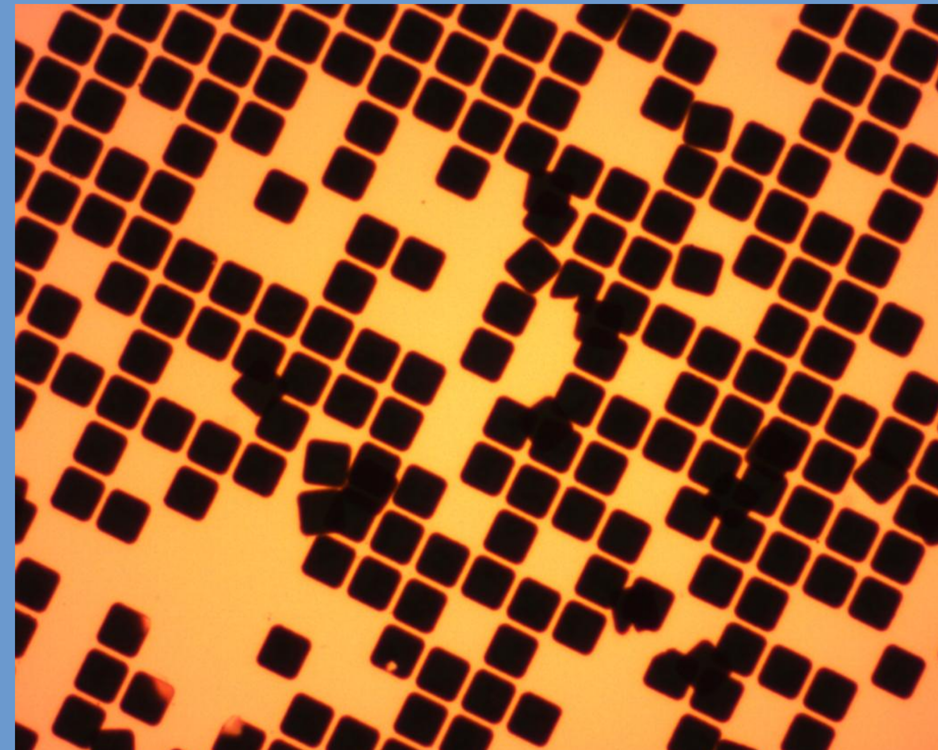
Fabrication of devices

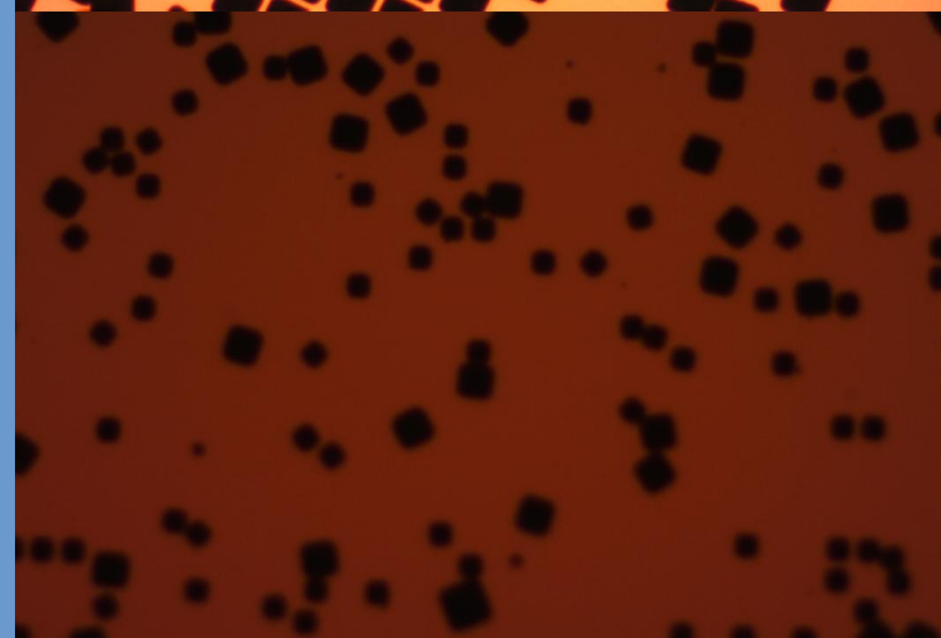
- Spin coat photoresist layer
- Pattern squares using mask and develop
- Coat required films using sputterer
- Lift off rest of pattern to leave transducers on the substrate.
- Can include an extra buffer layer which can then be dissolved to release the transducers into solution
- Transducers can then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





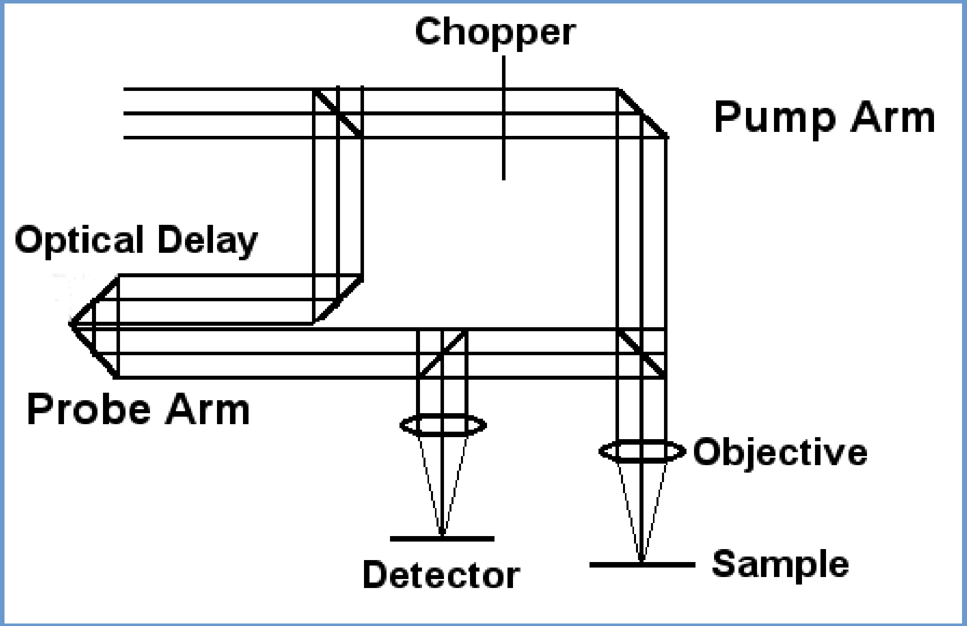
- Making the transducers on a buffer layer is desirable as the measured signals will be longer lived and larger as less energy is lot to the glass substrate in each pass.
- Are early attempts at using a buffer layer have been mixed as some transducers have come away early
- Transducers do survive in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





Experimental System

- Picosecond laser ultrasound system.
- Frequency doubled pump beam (400nm)
- 800nm probe beam
- Focused to same spot on sample
- Typically optical delay is provided with a large mechanical stage
- In our case this is done with electronics controlling 2 separate femtosecond lasers

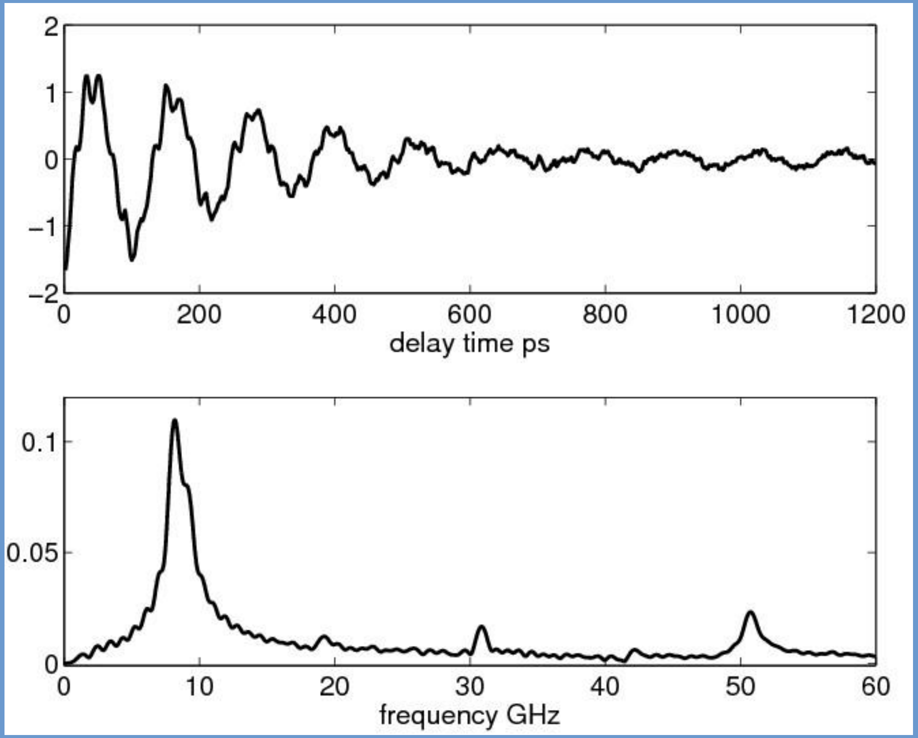


Experimental System

- 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

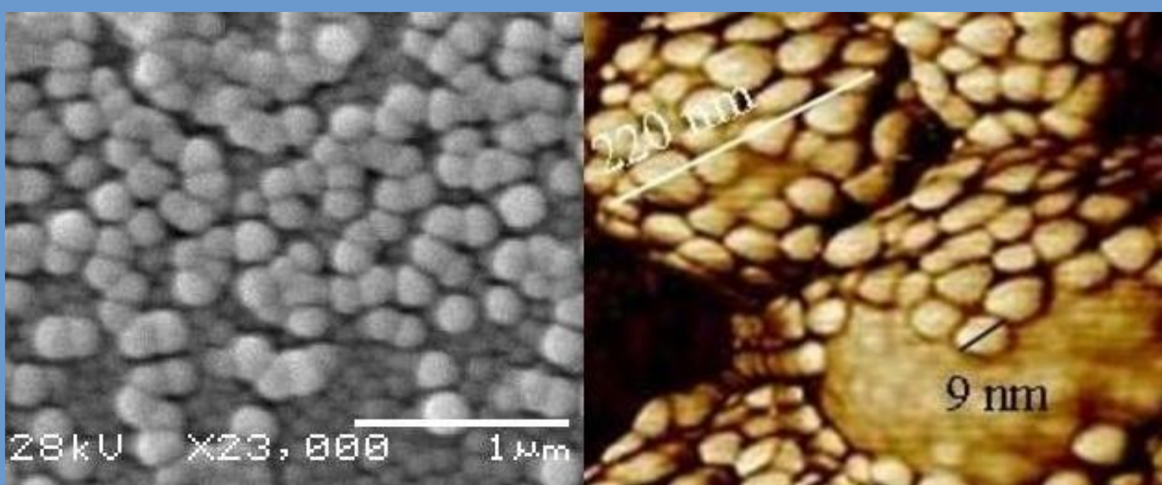
Experimental results

- 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.



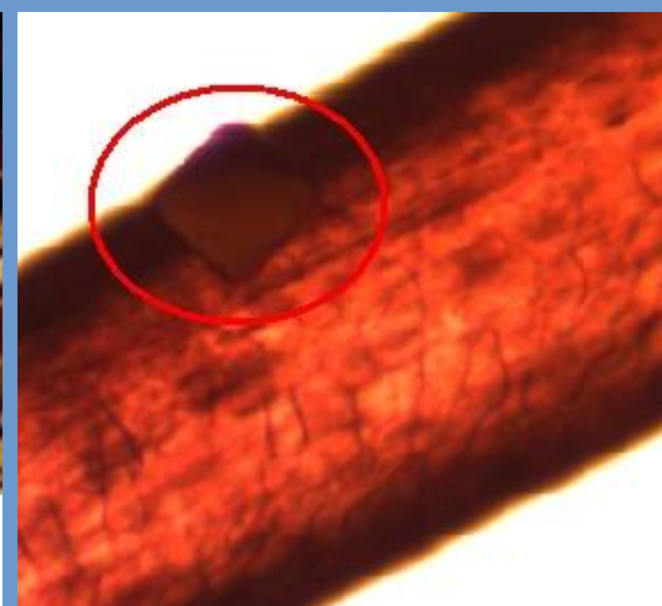
The next steps

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



Gold Coated Silica nanoparticles

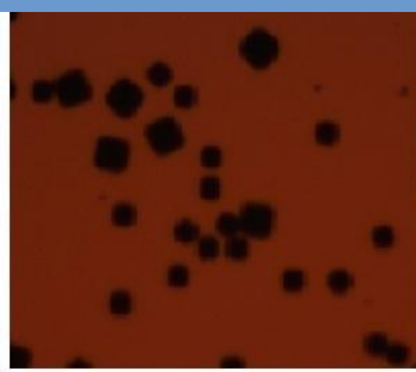
zoom showing gold nanoparticles coating a silica core



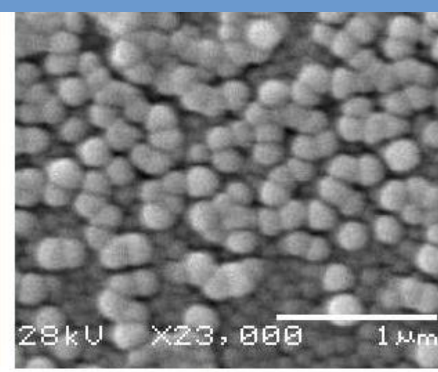
Conclusions

- Modelled, fabricated and tested acoustic/optical transducers of ~240nm by 10 – 5 microns
- Modelled and fabricating 200nm transducers using molecular self assembly

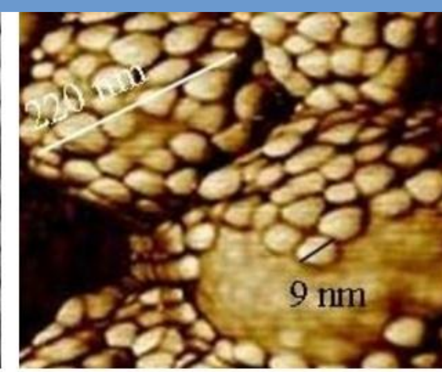
10 micron patches



Assortment of patches re-attached

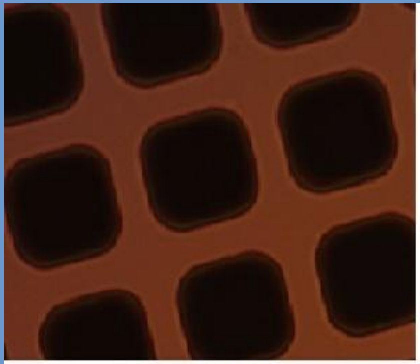


gold coated sillica particles

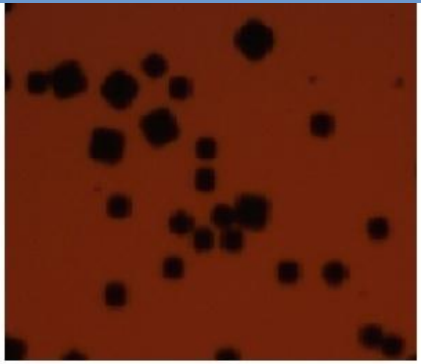


zoom showing gold coating

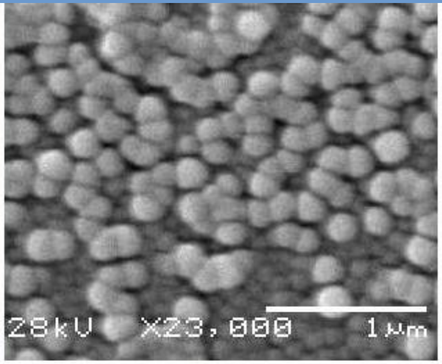
- Any Questions?



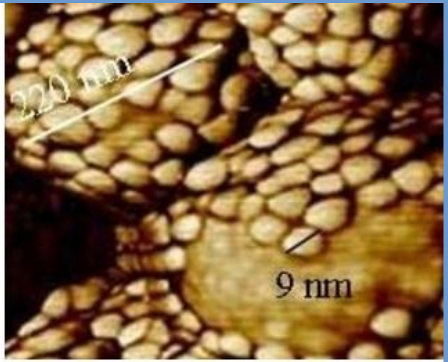
10 micron patches



Assortment of patches re-attached



gold coated sillica particles



zoom showing gold coating