Design and fabrication of 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 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 $\lambda/4n_{\text{core}}$ 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 lost 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 nanoparticlescoating 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
• Any Questions?