Mass Sensing using Sub-Terahertz Vibrations in Thin Polymer Films

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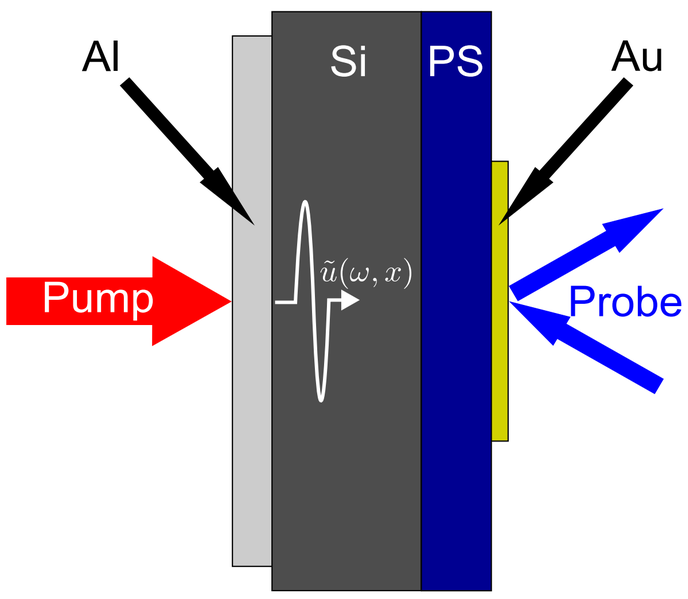
1. Introduction

Coherent quantised vibrational modes can be excited in supported nanoscale polymer films using a state-of-the-art picosecond acoustic technique [1]. The measured vibrational peaks can have frequencies in the low GHz range and are determined by the acoustic properties and thickness of the films.

The potential for these films to be used as mass sensors is demonstrated. Small thicknesses of gold were deposited onto polystyrene (PS) films and a shift in vibrational peaks of coated areas relative to bare PS films was observed. This behaviour can be explained using an elastic model which considers standing wave phonon modes in the samples.

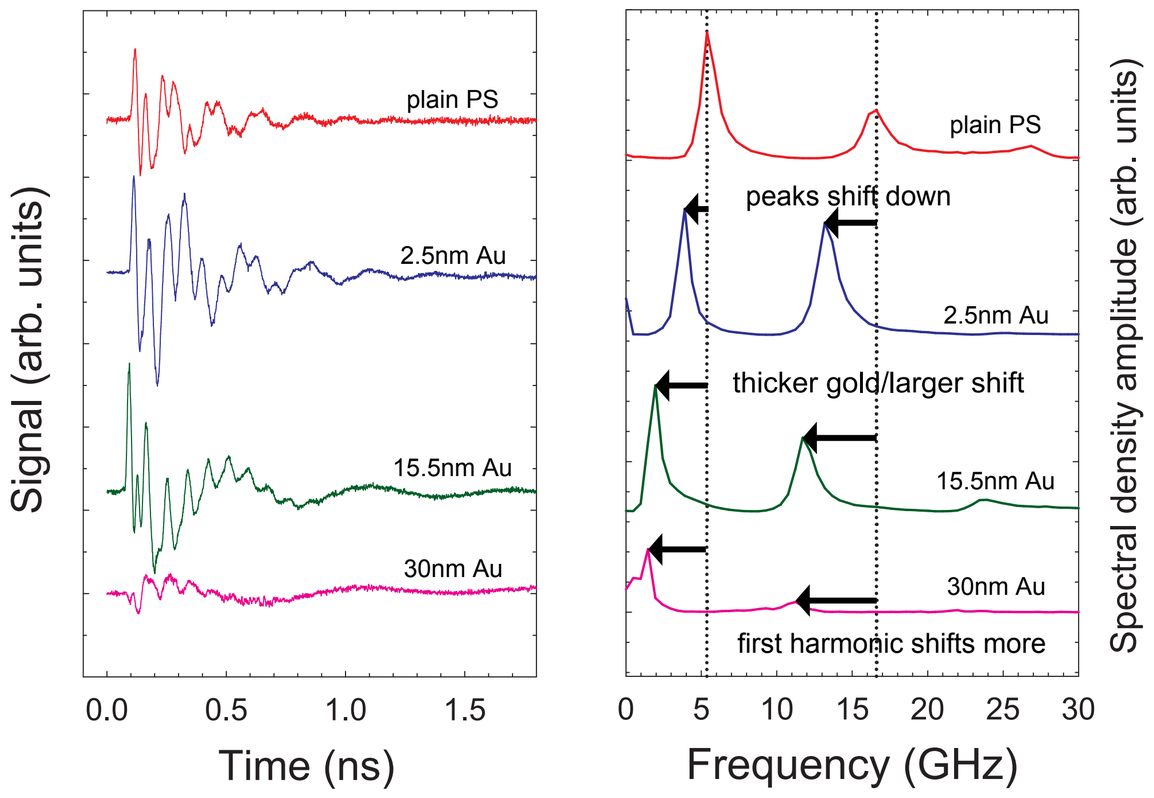
2. The Technique



Ultra-fast, high power laser pulses (the pump) are directed onto a thin (~75 nm) film of aluminium. Thermal expansion in the Al film generates a strain pulse that propagates into the ~100 μm silicon substrate that supports and protects the polymer film. The wavepacket then interacts with the layers on the surface of the Si substrate.

As the free surface of the sample oscillates, its optical reflectance changes. A lower power laser beam (the probe) is reflected off the surface and the intensity measured. If the time delay between pump and probe beams is varied then the temporal oscillation of the reflected beam intensity can be observed and the vibrational frequency in the film calculated.

3. Experimental Data



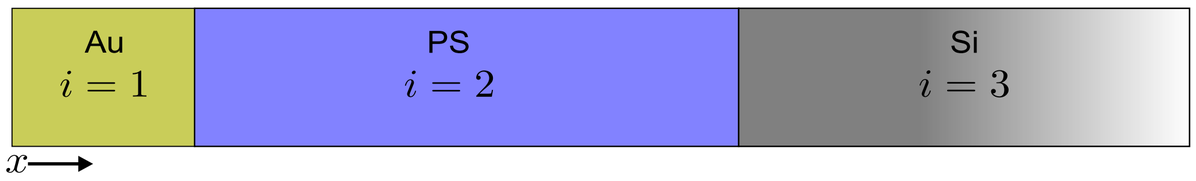
The figure above shows examples of the temporal data obtained for vibrations in the sample . Also shown are the associated frequency spectra, which clearly demonstrate a shift in the resonant peaks when gold is deposited on top of the PS film.

4. Model

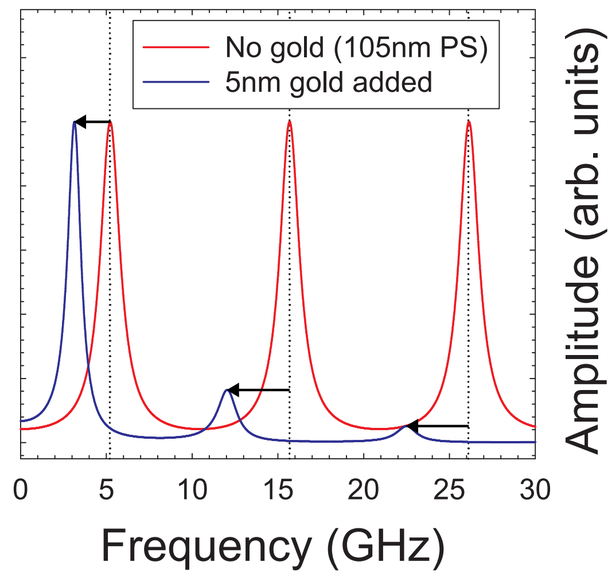
The model considers standing wave states:

$$\tilde{u}(\omega, x) = A_i e^{ik_i x} + B_i e^{-ik_i x}$$

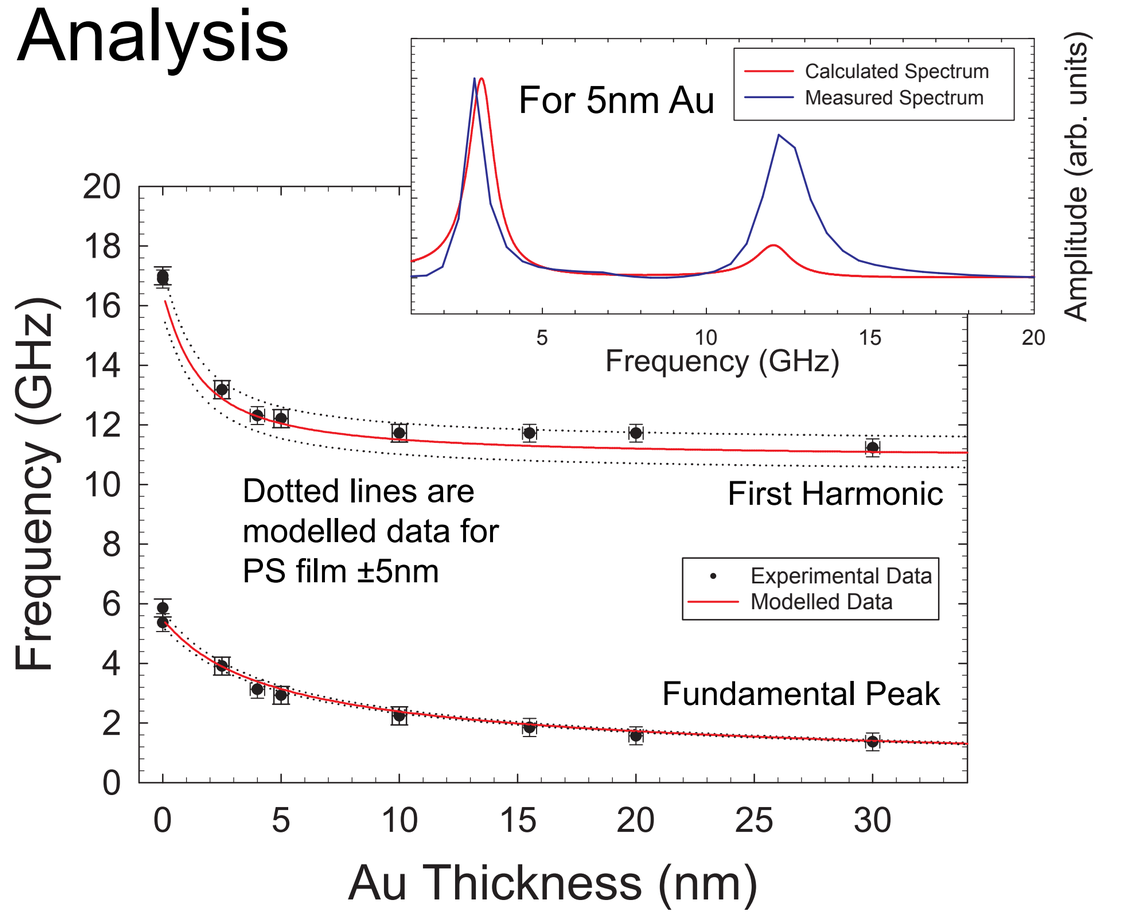
in each section of the sample:



By considering the boundary conditions of equal force and displacement at each interface, a set of linear equations can be formed and solved to produce a calculated frequency spectrum. As shown, adding gold to the model system shifts the frequency of the observed peaks down.



5. Analysis



The above plot shows both experimental and modelled peak frequencies as a function of gold thickness. The agreement is excellent, particularly for the fundamental mode. The first harmonic shows an initially higher sensitivity to small thicknesses of gold. The inset compares a calculated spectrum against a measured one.

6. Conclusions

The extreme mass sensitivity of this technique is apparent. The theoretical sensitivity of this particular system (105nm PS film, 0.5 GHz resolution) is ~ng/mm^2, around a monolayer of gold. However, decreasing the thickness of the polymer film should allow for sub-monolayer sensitivity.

There is potential for a wide range of compounds other than gold to be studied via coating the polymer film with an active layer. The model is well defined and relies only on knowing the acoustic properties of the materials involved.

References

[1] A.V. Akimov, E.S.K. Young, J.S. Sharp, V. Gusev, and A.J. Kent, App. Phys. Lett. **99**, 021912 (2011)

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