Love Waves
Theory and Experiment

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Overview

1. Basic Love Waves

- Layer guided surface wave
- Dispersion curve
- Modes

2. Data for Thick Layers

- Frequency spectrums
- Fitting theory to data/Multiple modes

3. Layer Guided Plate Modes

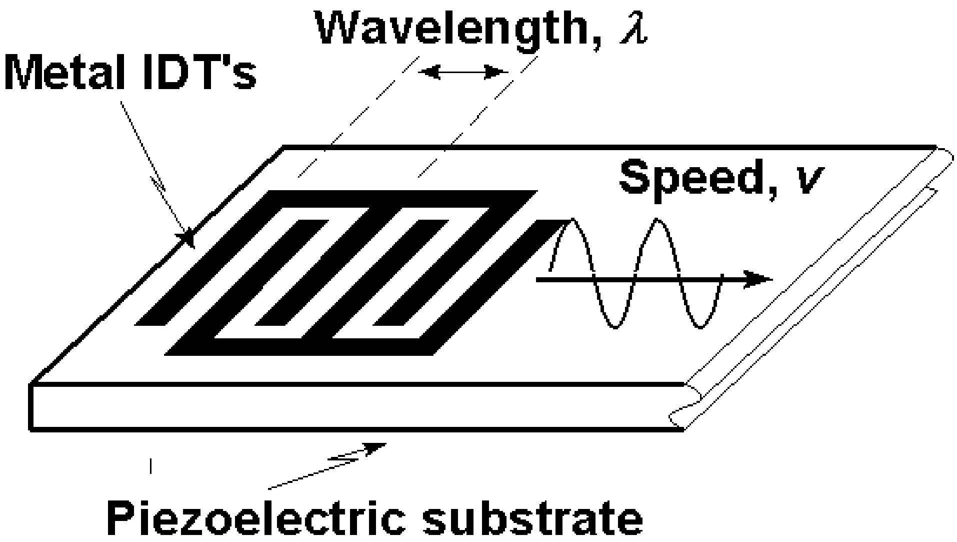
- Generalized dispersion equation
- Dispersion curve
- Mass sensitivity
- Displacements

4. Summary

Basic Love waves

- **Surface Acoustic Wave (SAW)**

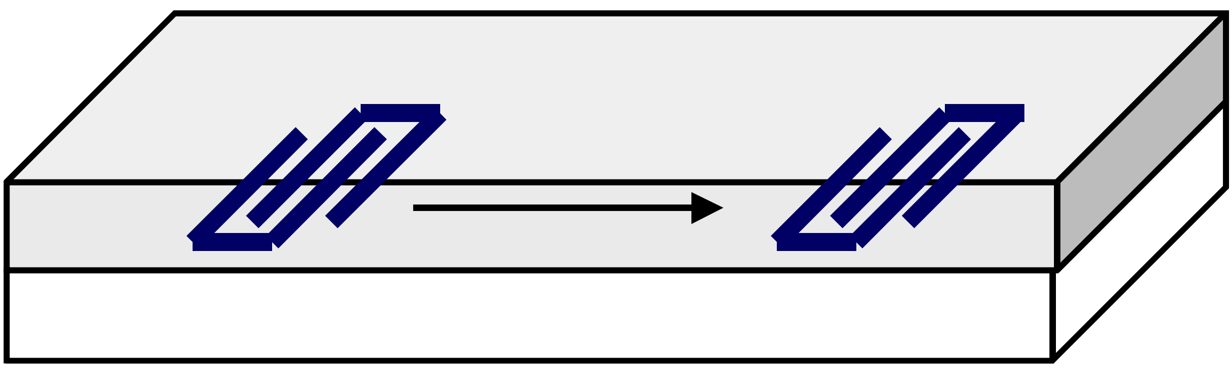
  Mechanical wave traveling along a surface



- **Love Wave**

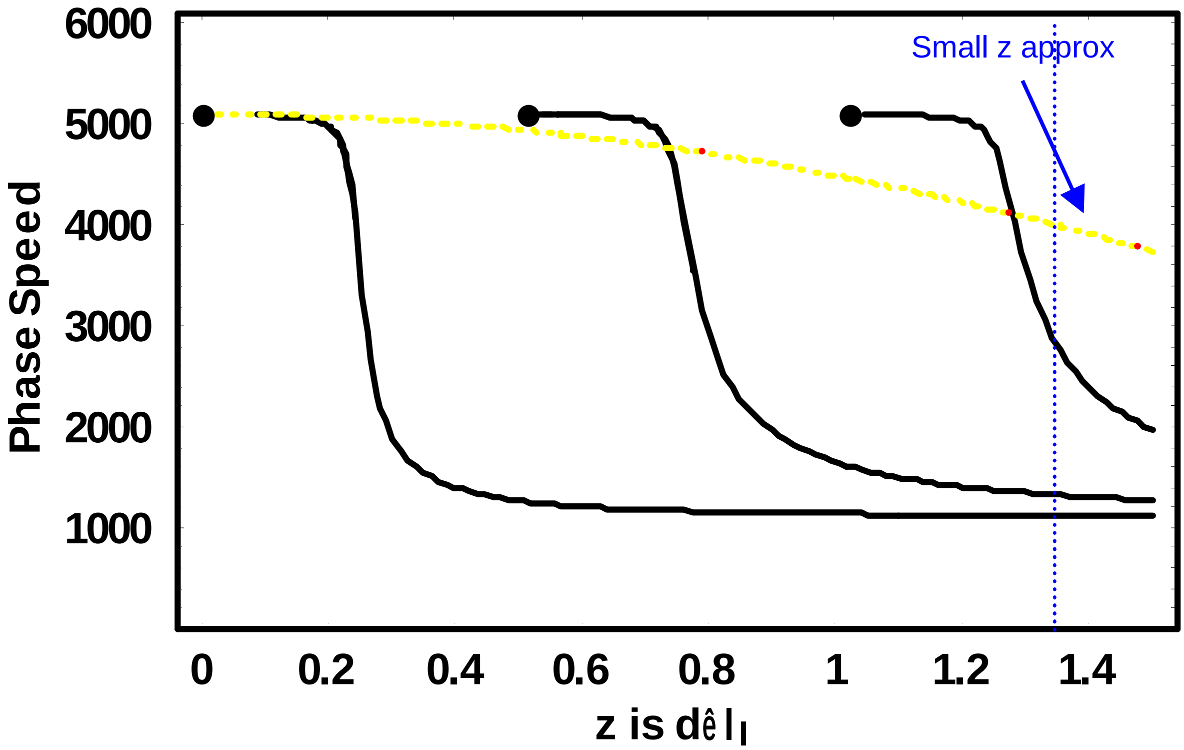
  Layer guided shear polarised surface wave

  Layer has shear speed, v_l < substrate speed, v_s



Mass sensitivity is high when Love wave occurs

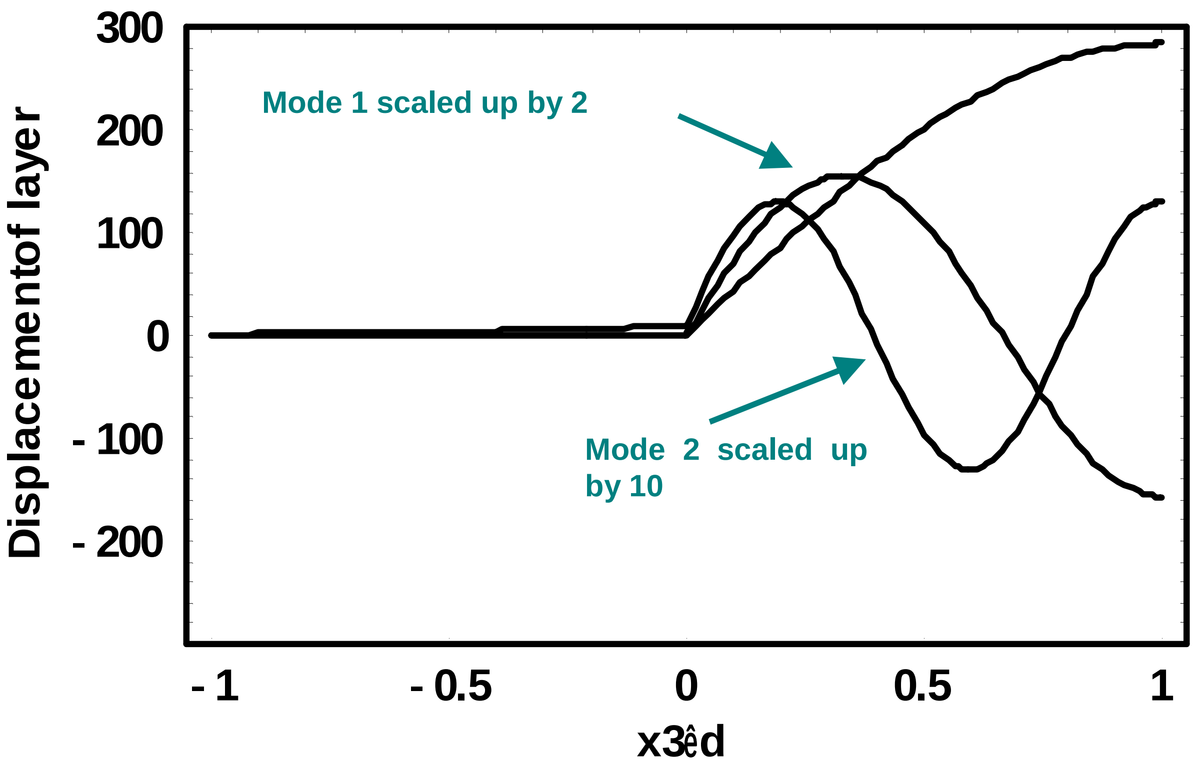
- ## Theoretical Dispersion Curve



Dotted curve is approximation about *z*=0

Insertion loss is unchanged by guiding layer

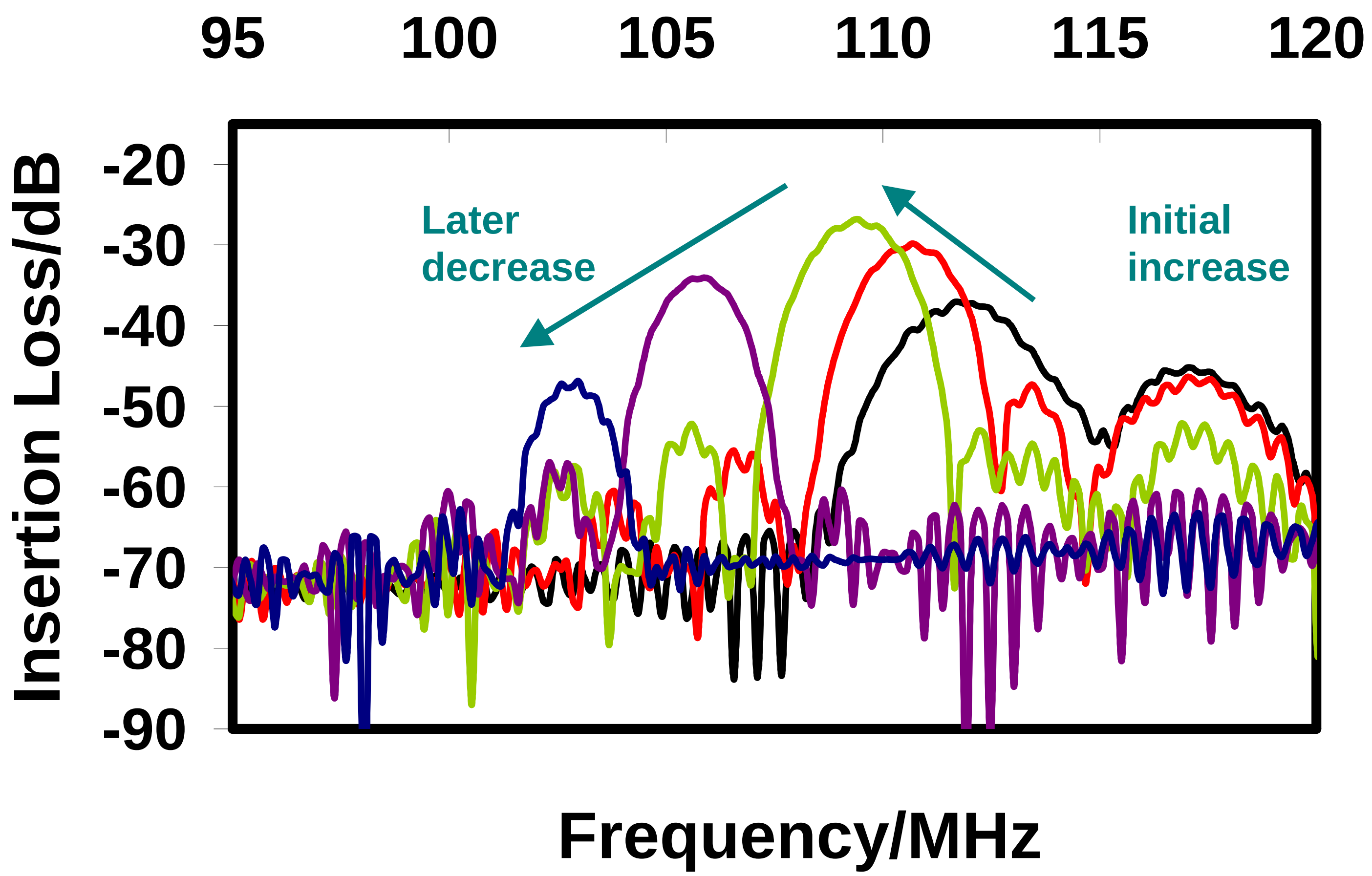
- ## Displacements for first three modes (*z*=1.3)



Multiple Love Wave Modes

- **Effect of Thick Guiding Layers**[1]
  - 110 MHz devices at fundamental and harmonic (330 MHz)
  - 309 MHz devices operated at fundamental
  - Quartz substrate (basic mode SSBW)
  - Spin coat a photoresist (polymer) across whole device
  - Build up multiple guiding layers

- **Spectrum for 110 MHz**



Guiding layer reduces resonant frequency

Initial enhancement of signal then attenuation

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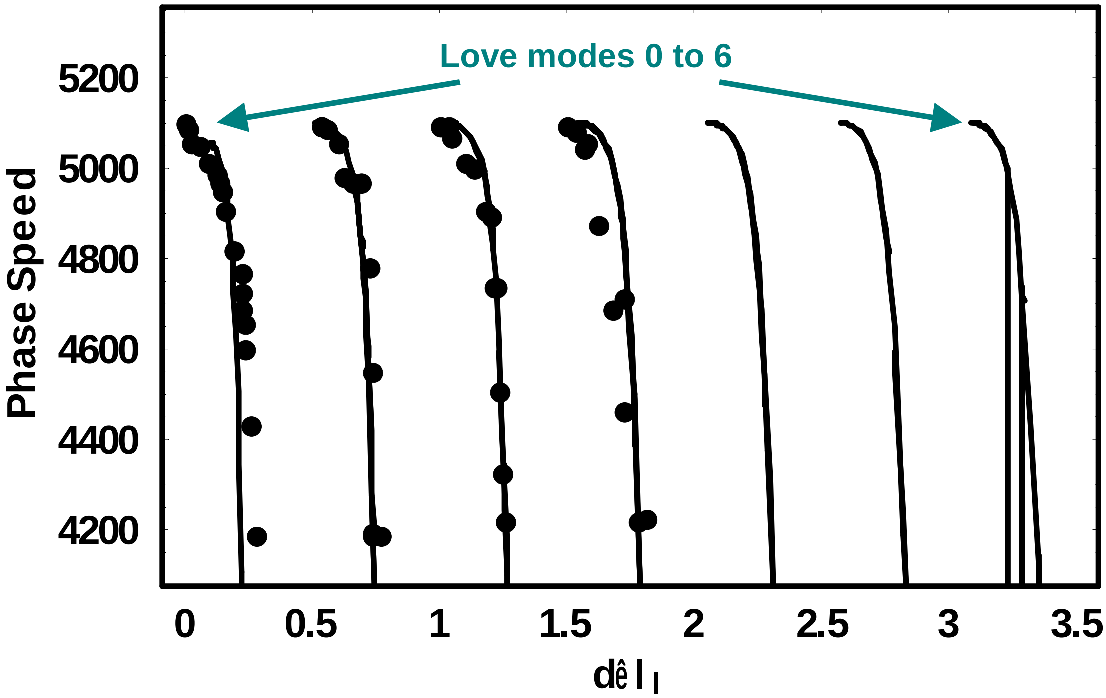
[1] McHale *et al*. Accepted Appl. Phys. Lett. (2001).

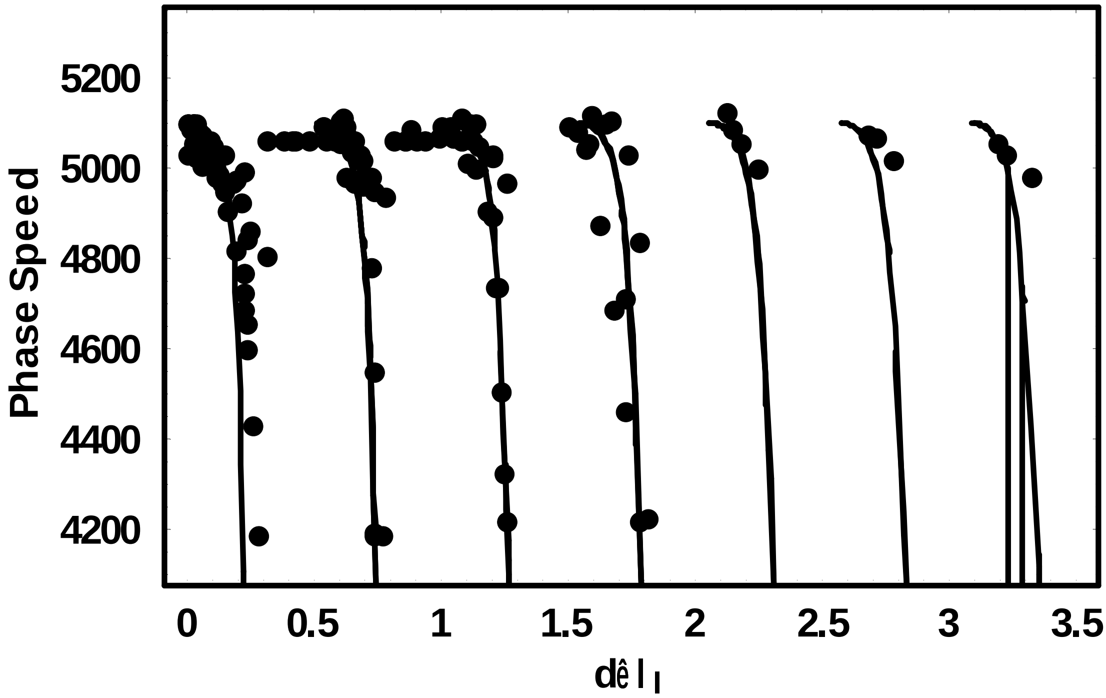
- **Fit Theory to Data for 110 MHz**



Parameters used are: v_l **= 1170 m/s** v_S **= 5100 m/s**

ρ_l **= 2075 kg/m**^{3} ρ_S **= 2655 kg/m**^{3}

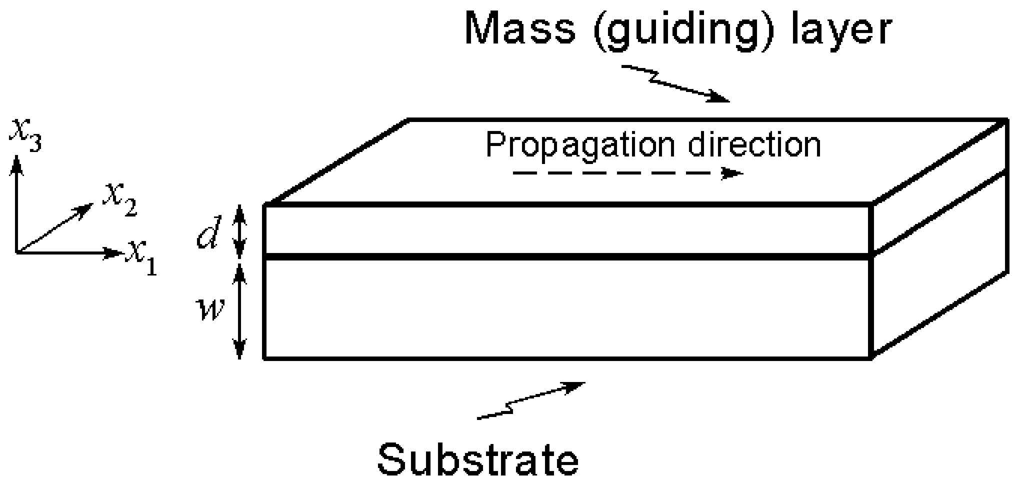
- **110 + 330 MHz Harmonic + 309 MHz Fundamental**



<u>Only</u> v_l **= 1170 m/s is a fitting parameter (same in both graphs)**

Generalized Love Wave Theory

- **Generalized Dispersion Equation**[1]



$$\underline{u}_l = (0,1,0)\left[Ae^{-jT_l x_3} + Be^{jT_l x_3}\right]e^{j(\omega t - k_1 x_1)}$$ **Layer**

$$\underline{u}_s = (0,1,0)\left[Ce^{T_s x_3} + De^{-T_s x_3}\right]e^{j(\omega t - k_1 x_1)}$$ **Substrate**

Wave vector $k_1=(\omega/v)^{1/2}$ gives speed v of Love wave

Eqns of motion, gives wave vectors T_l and T_s

$$T_l^2 = \omega^2\left(\frac{1}{v_l^2} - \frac{1}{v^2}\right) \quad \textbf{and} \quad T_s^2 = \omega^2\left(\frac{1}{v^2} - \frac{1}{v_s^2}\right)$$

satisfying boundary conditions gives the dispersion eqn

$$\tan(T_l d) = \xi \tanh(T_s w)$$

where $\xi=\mu_s T_s/\mu_l T_l$.

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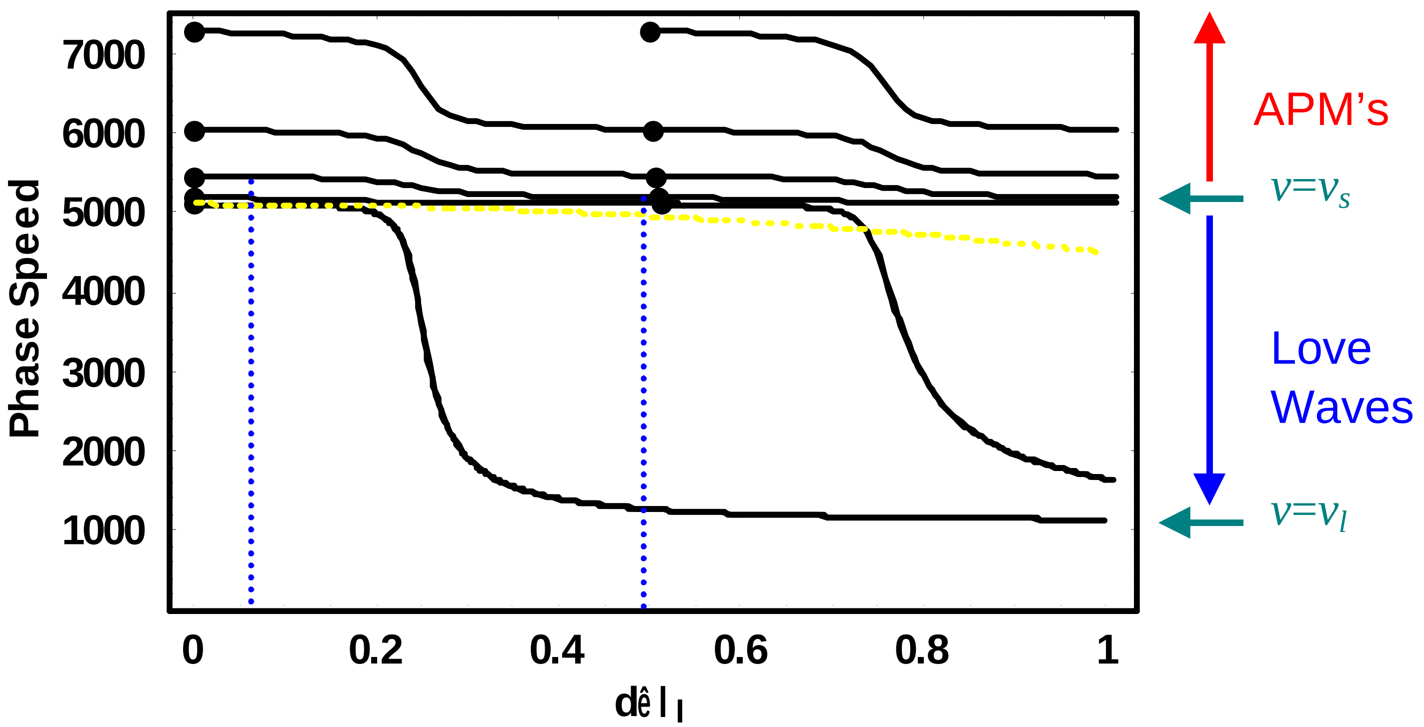
[1] McHale *et al*, Submitted to. Europhys. Lett. (2001); J. Appl. Phys. (2001).

- **Solutions**

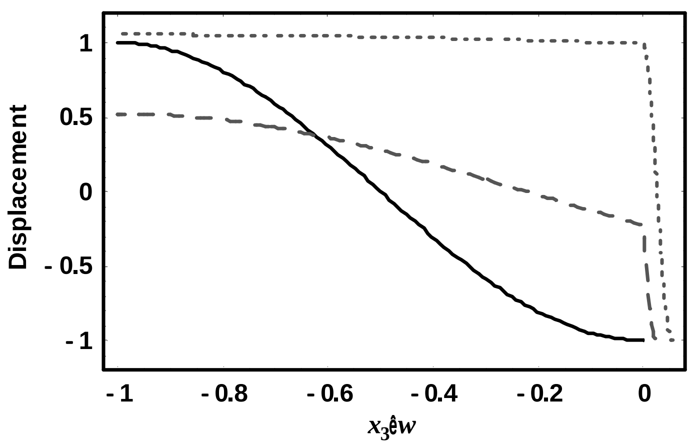
T_s **real** ⇒ $v<v_S$ ⇒ **"Love" Waves**

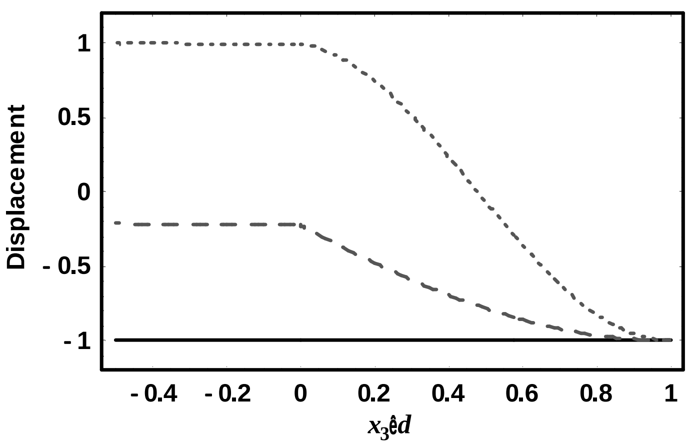
$T_s=jk_s$ **with** k_s **real** ⇒ $v>v_S$ ⇒ **"Layer guided SH-APM"**

<u>Example</u> 110 MHz, PMMA on Quartz w**=130 µm**



- Evolution of 1st SH-APM with guiding layer thickness

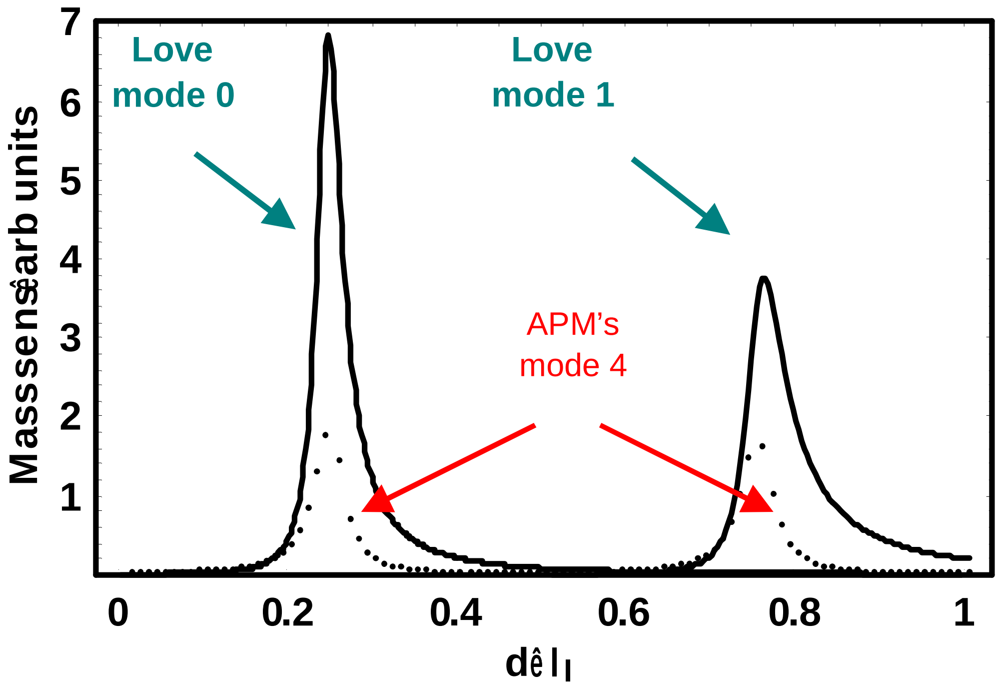




- **Love Wave and APM Mass Sensitivity (Arb. *d*)**

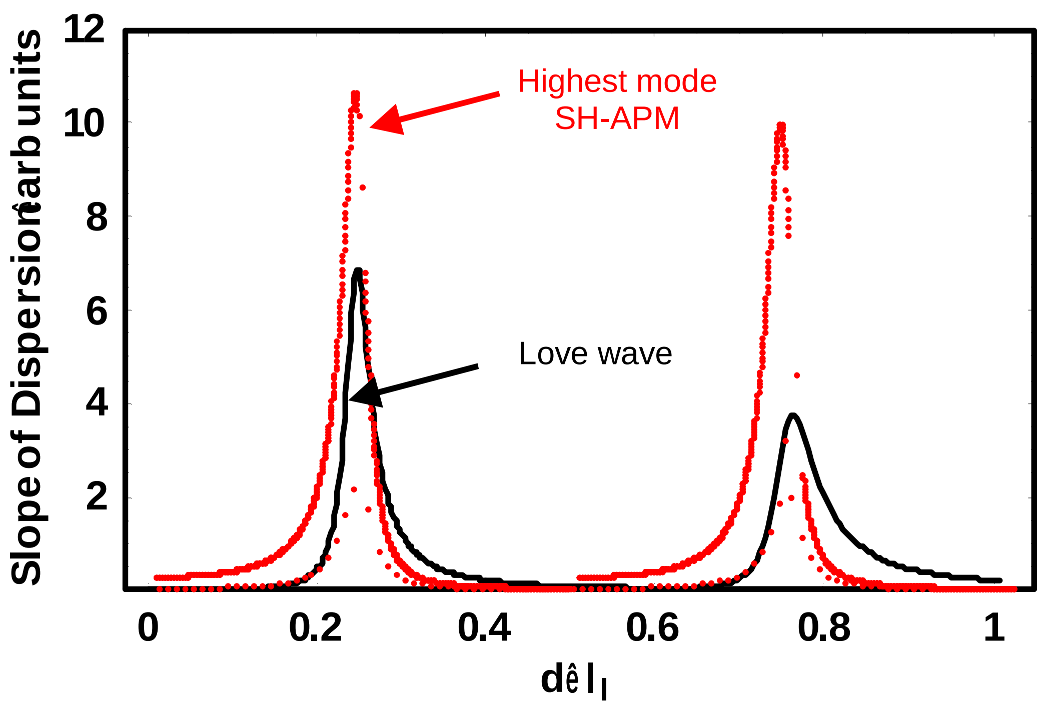
  $\Delta v/v = \Delta h_m \times \rho_m \times$ function of substrate and 1st layer

  Rigid mass $\Rightarrow$ Mass sensitivity is slope of dispersion curve w.r.t thickness



Possible to create a more sensitive APM than a Love wave

<u>Example</u> 110 MHz, PMMA on Quartz w=125 μm



Summary

Achievements

- Theory/data on multiple Love wave modes
- Theory unifying Love wave and SH-APM's
- Mass sensitivity predictions
- Experimental data for rigid mass + liquids (incl. $\omega\tau$>1) across range of operating thicknesses

Lessons

- Love wave data in literature may include SH-APM effects
- Higher order Love waves from SH-APM's
- SH-APM's with a guiding layer may be more mass sensitive than Love waves

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The End
