

# Layer Guided Acoustic Wave Sensors

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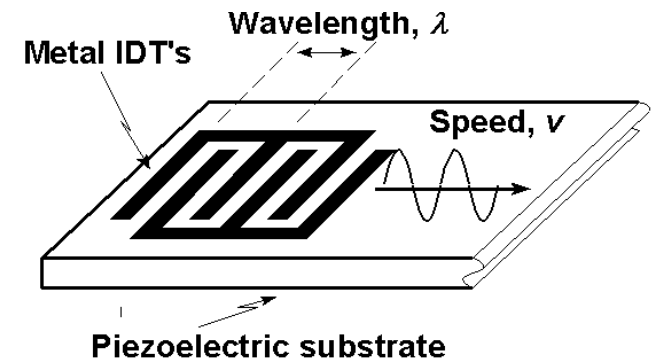
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## Acknowledgements

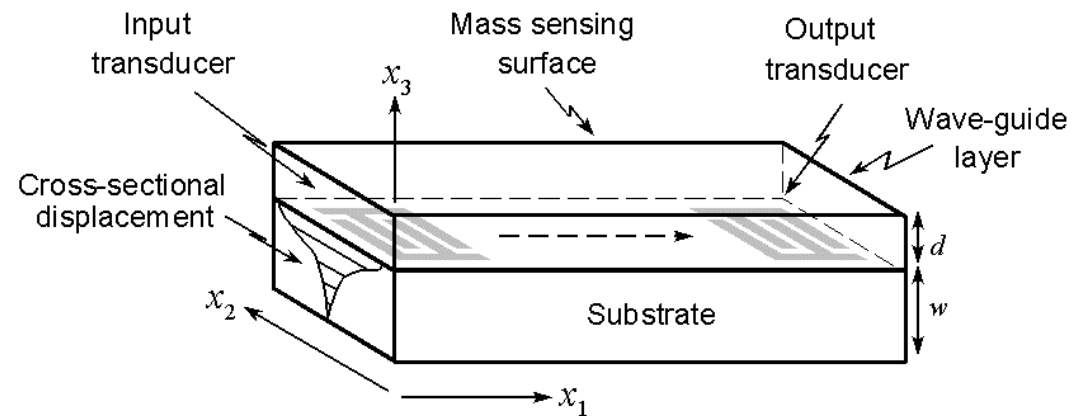
Dr Electra Gizeli and Dr Kathryn Melzak, Institute of Biotechnology, Cambridge University  
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# Love Waves v SH-APMs

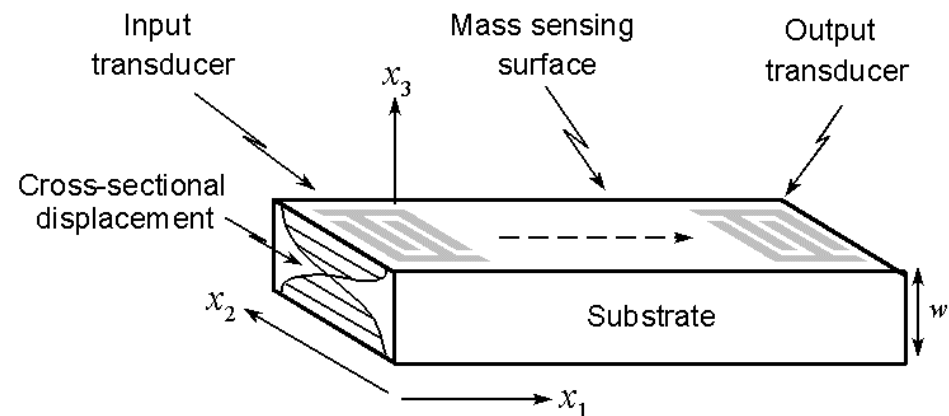
- Surface Acoustic Wave (SAW)



- Love Wave  
Layer guided SH-SAW  
with  $v_l < v_s$



- SH-APM  
Substrate resonance

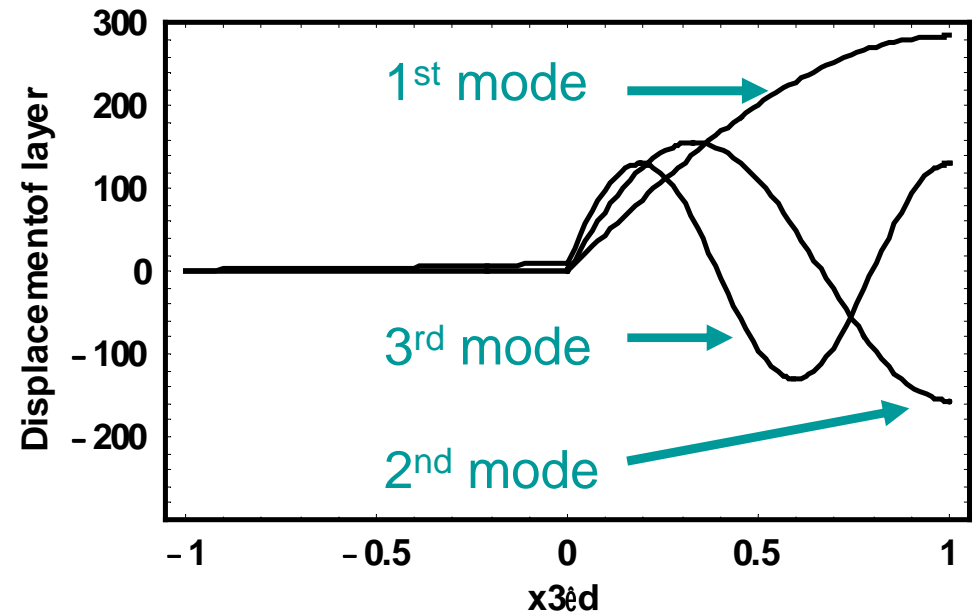
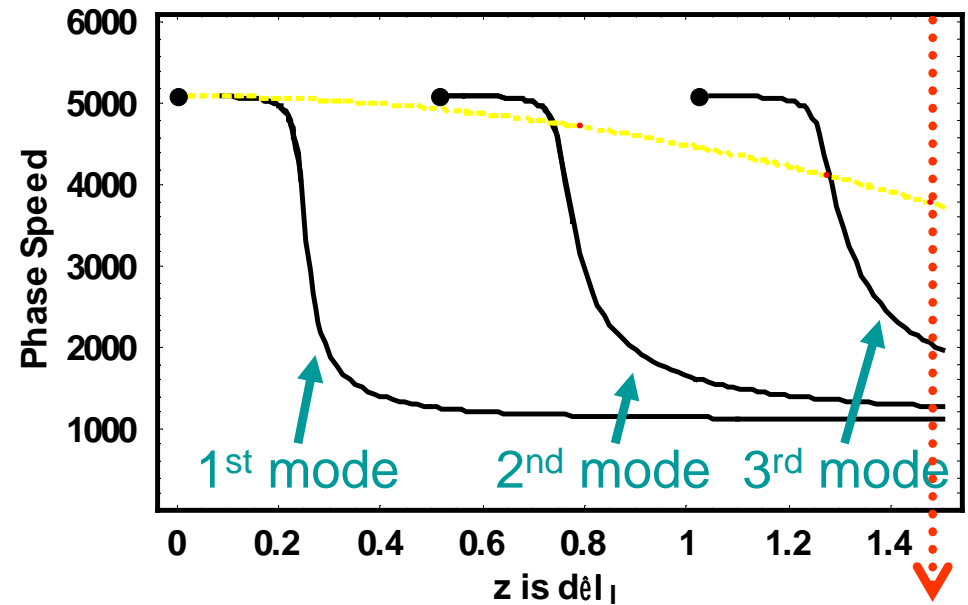


# Love Waves

- Theoretical dispersion curve

(Insertion loss is unchanged by an elastic guiding layer)

- Displacements for first three modes ( $z=1.3$ )



# Layer Guided SH-APMs

- Generalized Dispersion Equation<sup>1</sup>

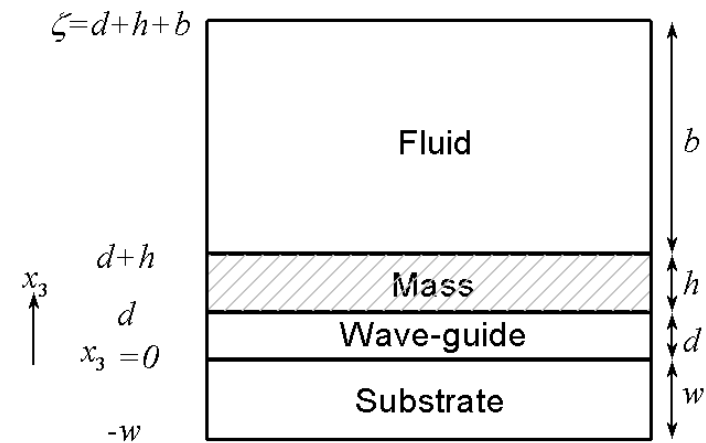
Layer and substrate displacements

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

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

Eqns of motion  $\Rightarrow T_l$ 's and  $T_s$

Boundary conditions  $\Rightarrow$  dispersion eqn



- Substrate + Layer Solutions

$T_s$  real  $\Rightarrow v < v_s \Rightarrow$  "Love" Waves

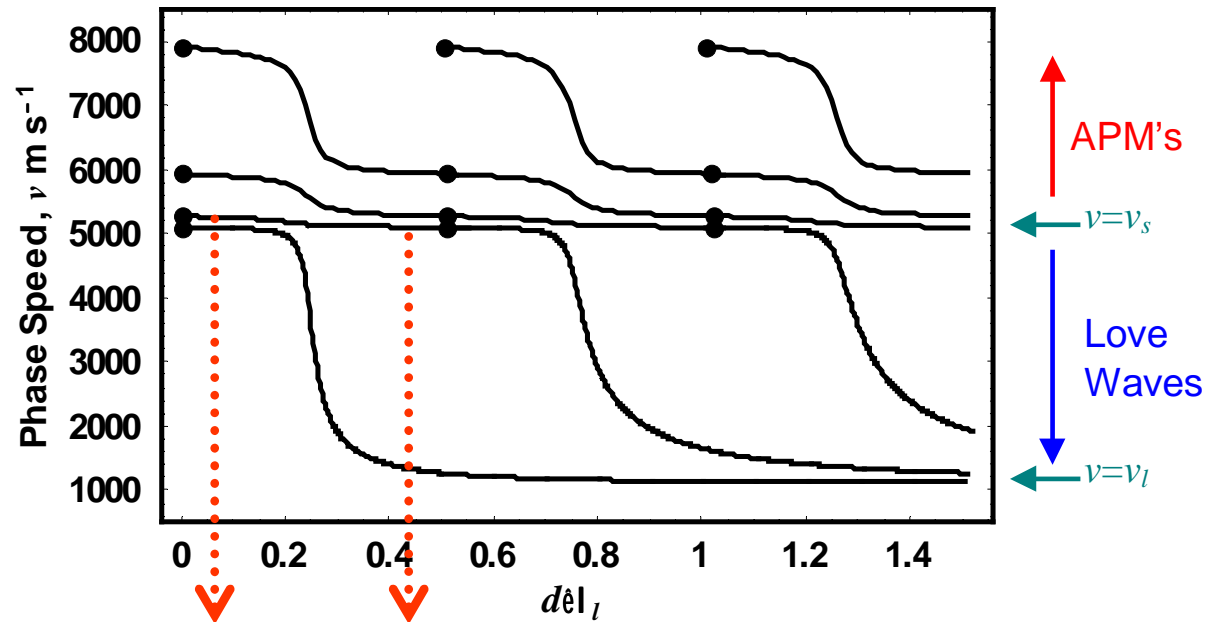
$T_s = jk_s$  with  $k_s$  real  $\Rightarrow v > v_s \Rightarrow$  "Layer guided SH-APMs"

<sup>1</sup>McHale et al, Europhys. Lett. (2002) 58, 818-822, J. Appl. Phys. (2002) 91, 5735-5744.

McHale et al, "Mass, liquid and polymer sensitivity .....", Submitted to J. Appl. Phys. (2002).

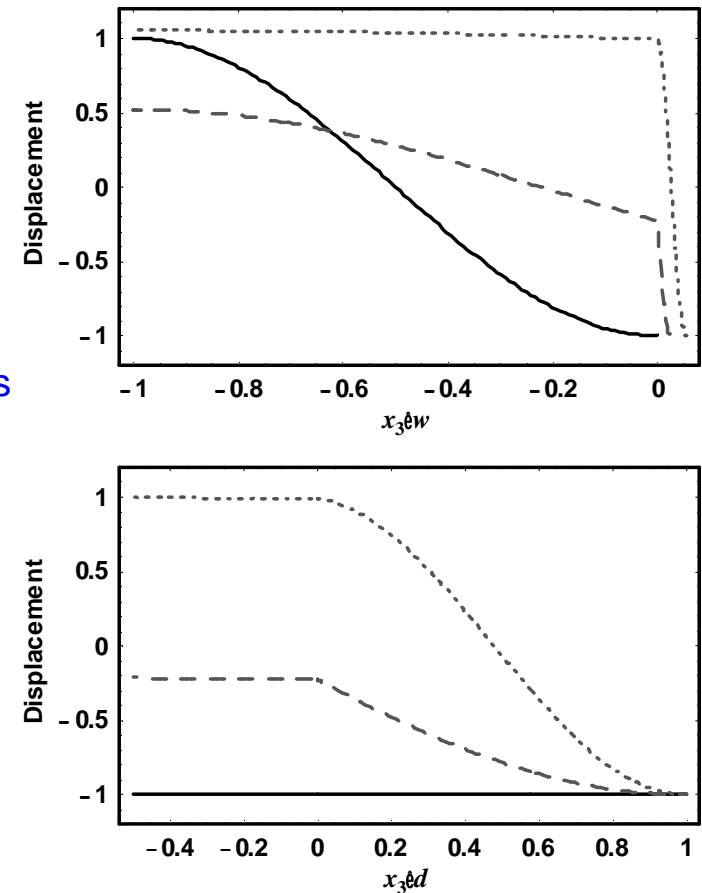
# Substrate + Guiding Layer

## Dispersion Curve



Points = Anti-node moving from substrate to layer

## Evolution of 1st SH-APM



Solid  $\rightarrow$  dashed  
with increasing guiding

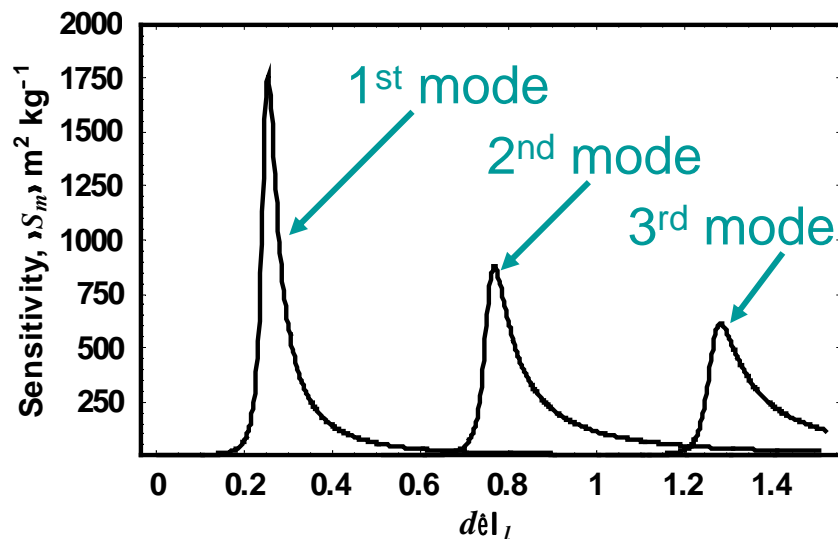
# Phase Speed Mass Sensitivity

$$S_m = \lim_{\Delta m \rightarrow 0} \frac{1}{\Delta m} \left( \frac{\Delta v}{v_o} \right) \approx \frac{f_o}{\rho_l |v_l|} \left( \frac{d \log_e v}{dz} \right)_{z_0}$$

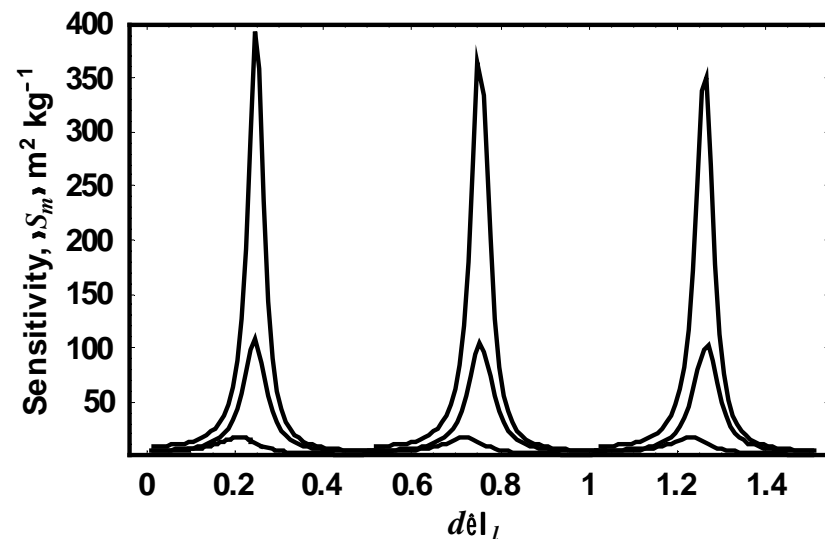
$\Delta m$  is mass per unit area being sensed,  $z = df/v_l$  is the normalized thickness

"Rigid" mass  $\Rightarrow$  Mass sensitivity is slope of dispersion curve<sup>1</sup>

## Love Waves



## Layer-Guided SH-APMs

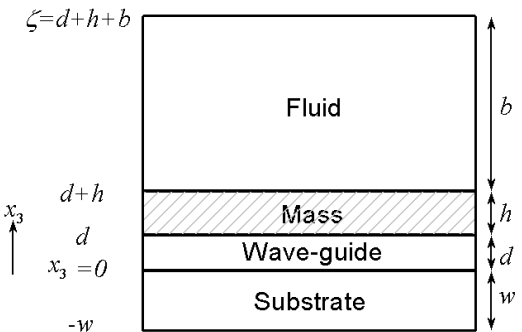


<sup>1</sup>McHale *et al*, J. Appl. Phys. (2002) 91, 9701-9710.

# Insertion Loss for Polymer Waveguide

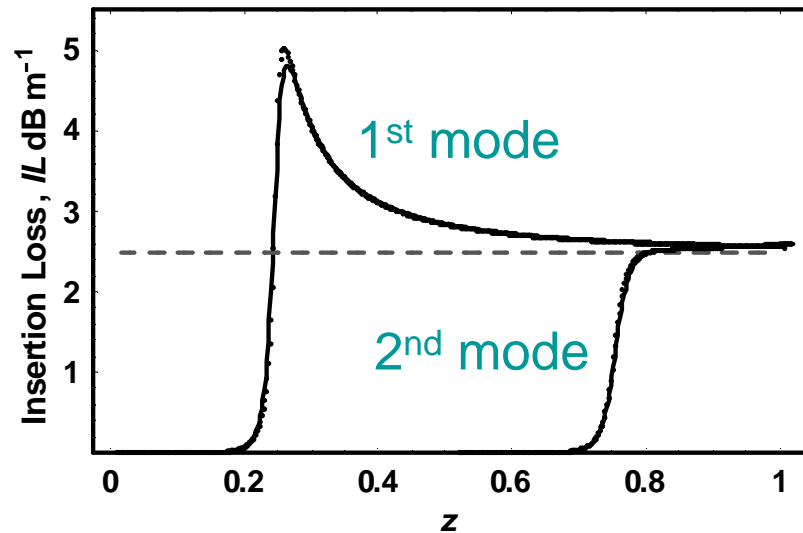
## Cases considered

1. Wave-guide layer is viscoelastic
2. Mass layer deposited from liquid or from vacuum
3. Mass may be omitted (i.e. liquid phase sensitivity)

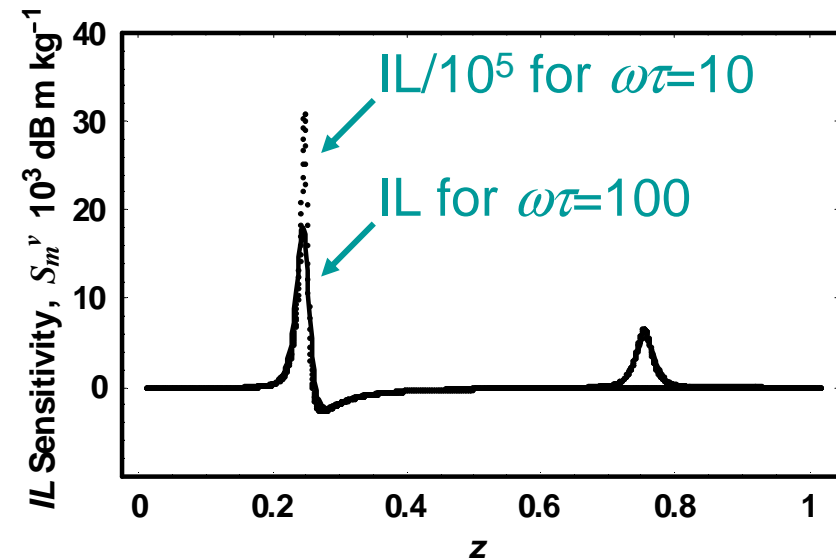


Mass/liquid sensitivity can be derived for phase velocity & insertion loss

## Love Wave Insertion Loss



## Love Wave IL Sensitivity



<sup>1</sup>McHale et al, "Mass, liquid and polymer sensitivity .....", Submitted to J. Appl. Phys. (2002).

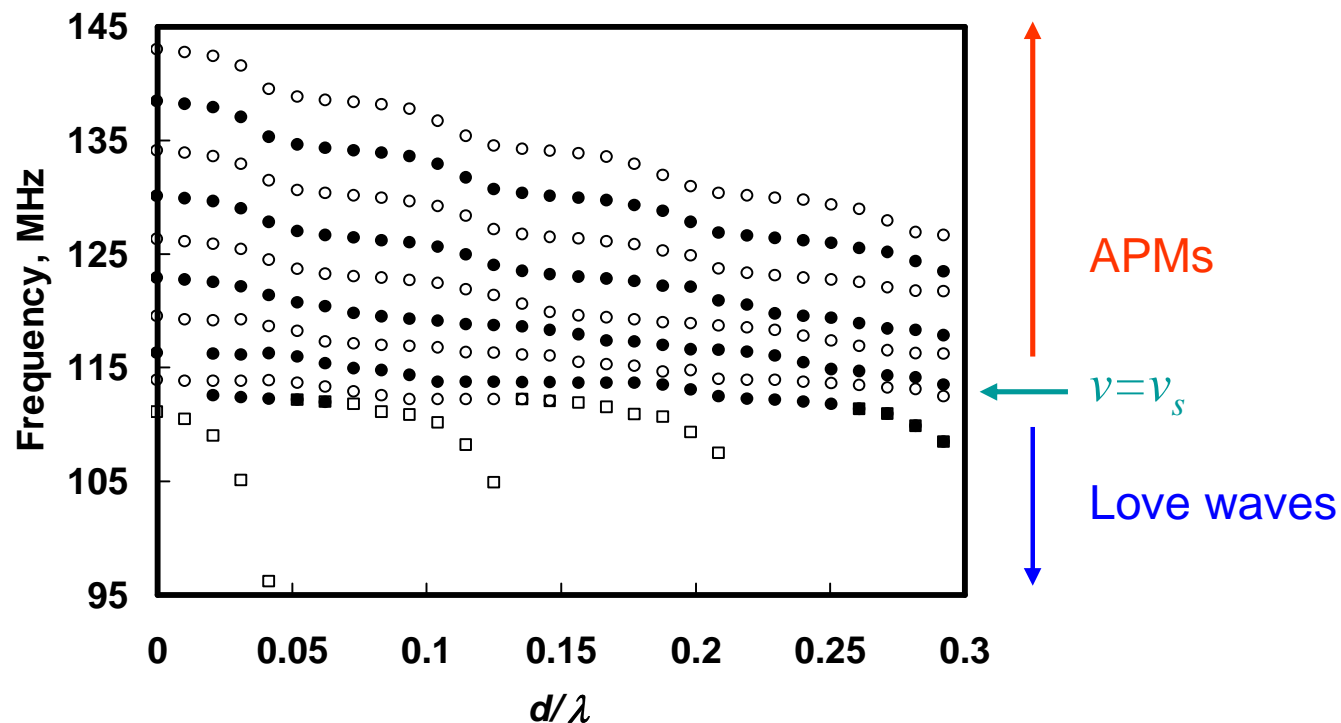
# Preliminary Experimental Data for SH-APM

- **Layer-Guided SH-APM Modes**

Prop. Orthog. to  $x$ -axis of thinned ( $200\ \mu\text{m}$ ) ST-Q substrate  
110 MHz surface skimming bulk wave (SSBW)

SSBW  $\rightarrow$  Love wave by a spin-coated photoresist layer

Old mask so insertion loss high (axis is  $d/\lambda$  with  $\lambda$ =IDT period)



# Dispersion and Group Velocity

- Guiding Layer Induces Dispersion<sup>1</sup>

Phase velocity

$$v = f\lambda \quad \text{or} \quad v = \omega/k$$

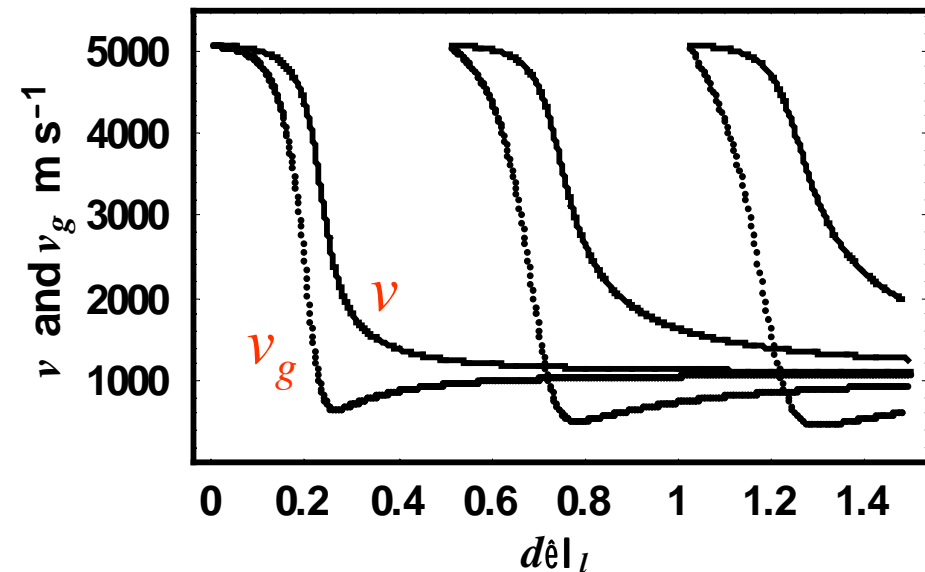
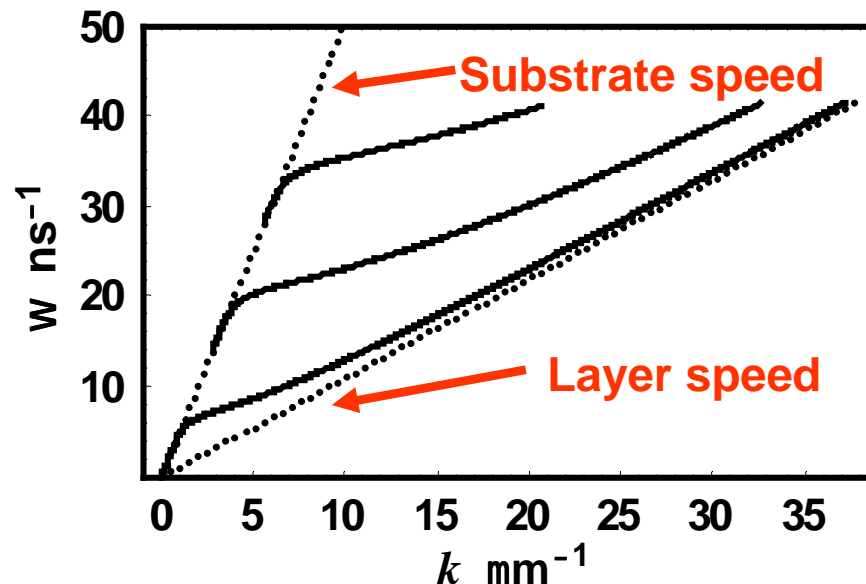
Group velocity

$$v_g = d\omega/dk$$

Group velocity is slope of the  $(\omega, k)$  dispersion curve

Example

0.25  $\mu\text{m}$  polymer guiding layer on Quartz with  $w \rightarrow \infty$



<sup>1</sup>McHale et al, "Sensitivity from group and phase ....", Accepted by J. Appl.Phys. (2002)

# Group Velocity Mass Sensitivity

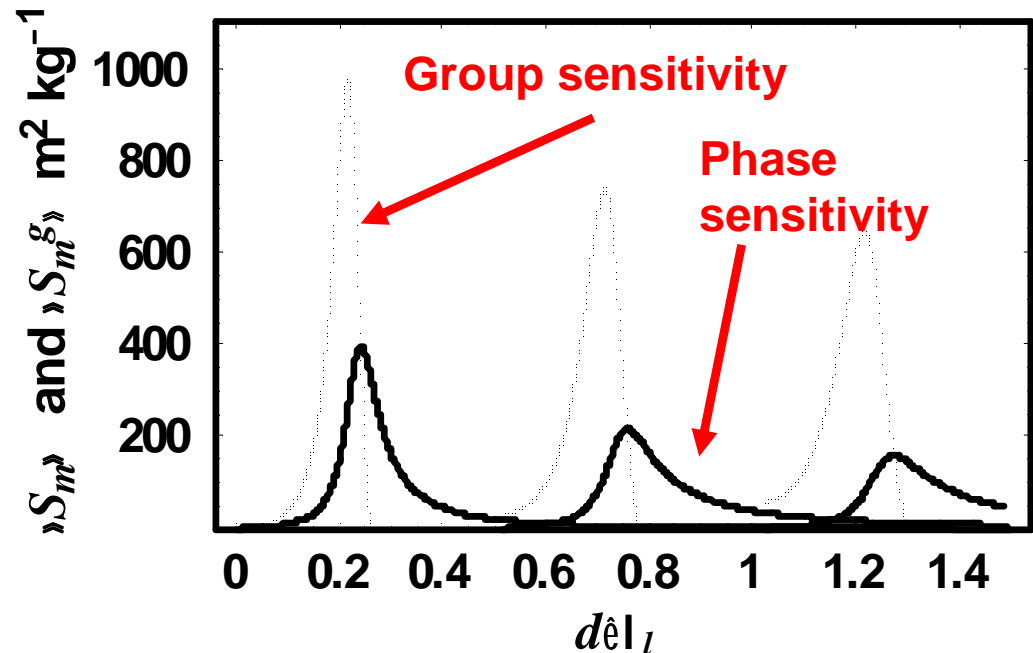
## "Rigid" mass

Mass sensitivity is fractional deviation of the phase velocity from the group velocity divided by mass per unit area due to the guiding layer

$$S_m \approx \frac{1}{\rho_l d} \left( 1 - \frac{v}{v_g} \right) = \frac{1}{\rho_l d} \frac{(v_g - v)}{v_g}$$

- Define a Group Velocity Sensitivity

$$S_m^g = \frac{f_0}{\rho_l v_l} \left( \frac{d \log_e v_g}{dz} \right)_{z=z_0}$$



# Love Waves and Higher Frequency

- Established QCM Sensor Principle

Mass sensitivity  $\propto$  Fundamental frequency  
Higher frequency  $\Rightarrow$  Higher mass sensitivity

- Love Waves on a (Semi-) Infinite Substrate

Controlling dimensionless variable is  $z = d/\lambda_l = df/v_l$

$$S_m = \lim_{\Delta m \rightarrow 0} \frac{1}{\Delta m} \left( \frac{\Delta \nu}{\nu_o} \right) \approx \frac{f_o}{\rho_l v_l} \left( \frac{d \log_e \nu}{dz} \right)_{z_0}$$

Mass Sensitivity  $\propto$  Frequency  $\times$  Function of  $z_0$   
Normalized thickness at operating point  $z_0 \propto d \times f$

# Higher Frequency Operation<sup>1,2</sup>

## Routes

1. Increase fundamental frequency
2. Hop the frequency to a harmonic

## Issues

1. Change of Love wave mode?
2. Const. guiding layer thickness?

- Frequency Increase at Constant  $z_0$

Reduce  $d$  as  $1/f$   $\Rightarrow$   
 $\Rightarrow$

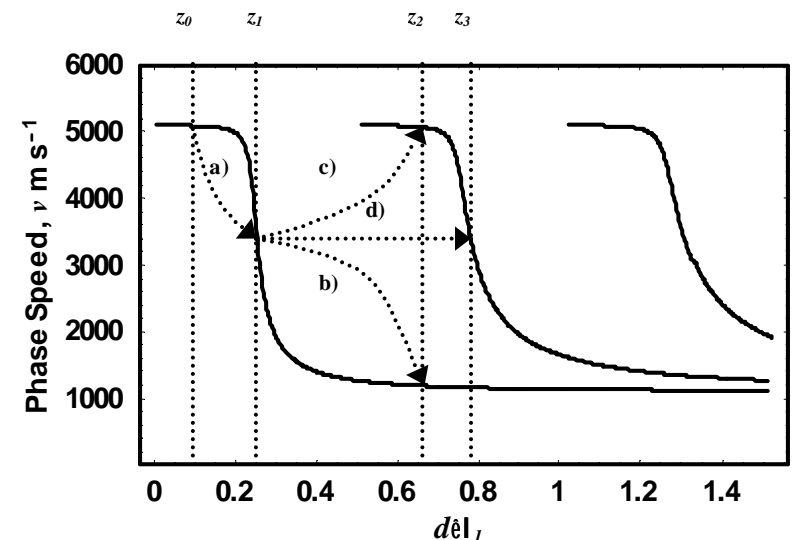
No change on dispersion curve  
Mass sensitivity scales with  $f$

- Frequency Hopping at Constant  $d$

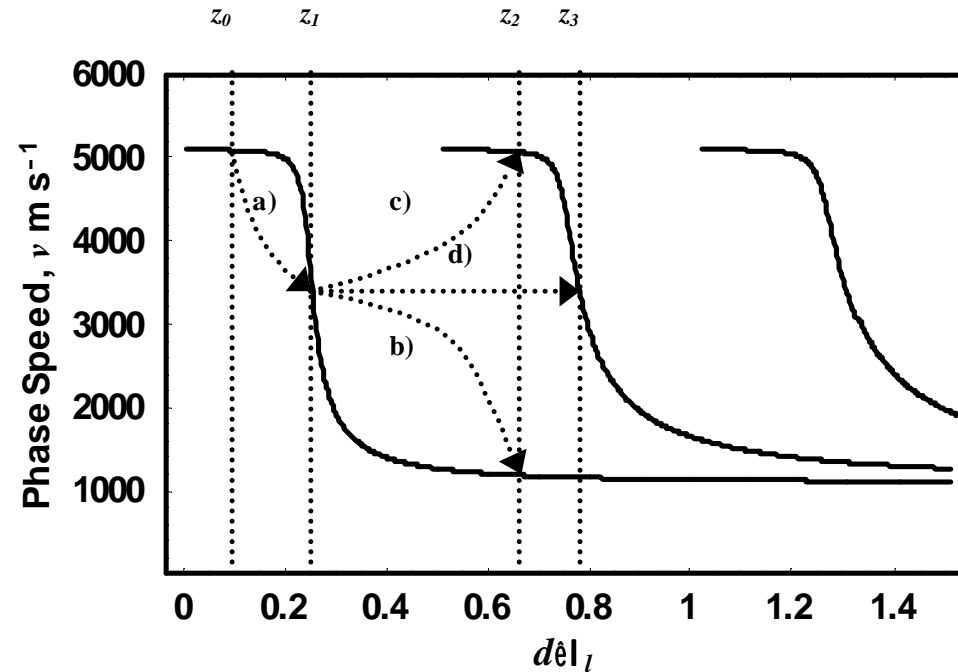
### Four example transitions

Same mode  $\Rightarrow$  lower/higher sensitivity

Change mode  $\Rightarrow$  lower/higher sensitivity



# Frequency Hopping Transitions



## No Mode Change

- Transition a)  $\Rightarrow$  Higher mass sensitivity
- Transition b)  $\Rightarrow$  Lower mass sensitivity

## Mode Change

- Transition c)  $\Rightarrow$  Lower mass sensitivity
- Transition d)  $\Rightarrow$  Higher mass sensitivity

## Maximum Increase in Mass Sensitivity

Ratio of frequencies  $\times$  ratio of max slopes of modes

i.e. scales by less than by the frequency ratio

# Summary

## Achievements

- **Unifying theory**  
Love wave and SH-APM's
- **New sensor**  
Layer-guided SH-APM's
- **Mass/liquid sensitivity predictions**  
Phase velocity and insertion loss  
Relation to group velocity
- **Love wave frequency response**  
Mode and non-mode changes

## Lessons

- **Higher order Love waves**  
from SH-APM's
- **Guiding layer on SH-APM's**  
significant increase in sensitivity
- **Higher frequency**  
Higher or lower sensitivity  
Frequency scaling of mode peak
- **Love waves  $\Rightarrow$  strong dispersion**  
Group and phase velocity differ

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**The End**

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