Layer Guided Acoustic Wave Sensors

Glen McHale, M. I. Newton and F. Martin

Department of Chemistry and Physics
The Nottingham Trent University
Nottingham NG11 8NS, UK

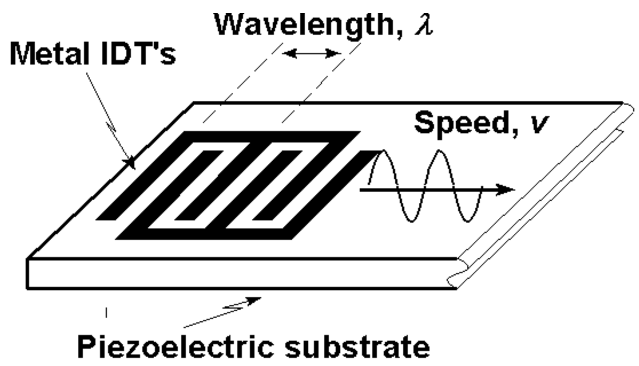
Acknowledgements

Dr Electra Gizeli and Dr Kathryn Melzak, Institute of Biotechnology, Cambridge University

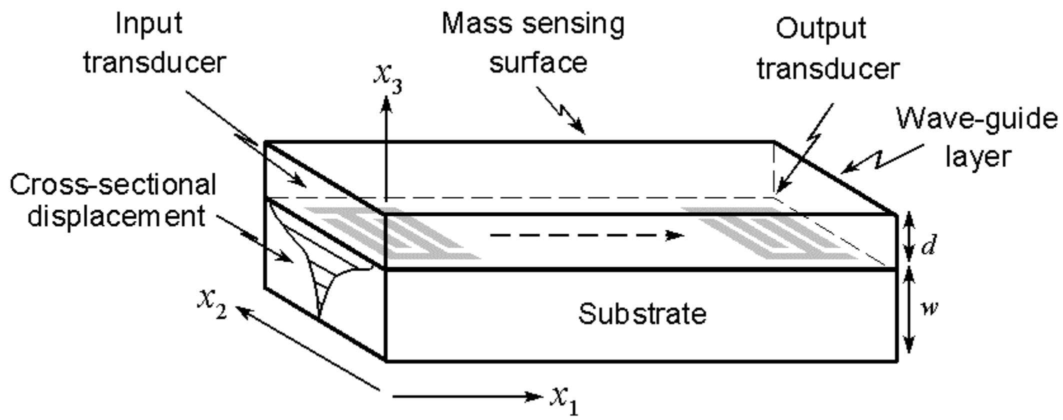
BBSRC (Grant 301/E11140)

Love Waves v SH-APMs

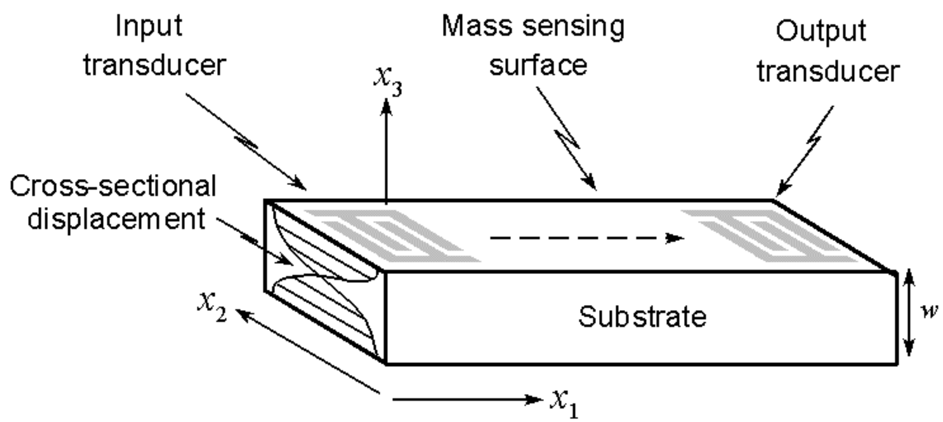
- Surface Acoustic Wave (SAW)



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



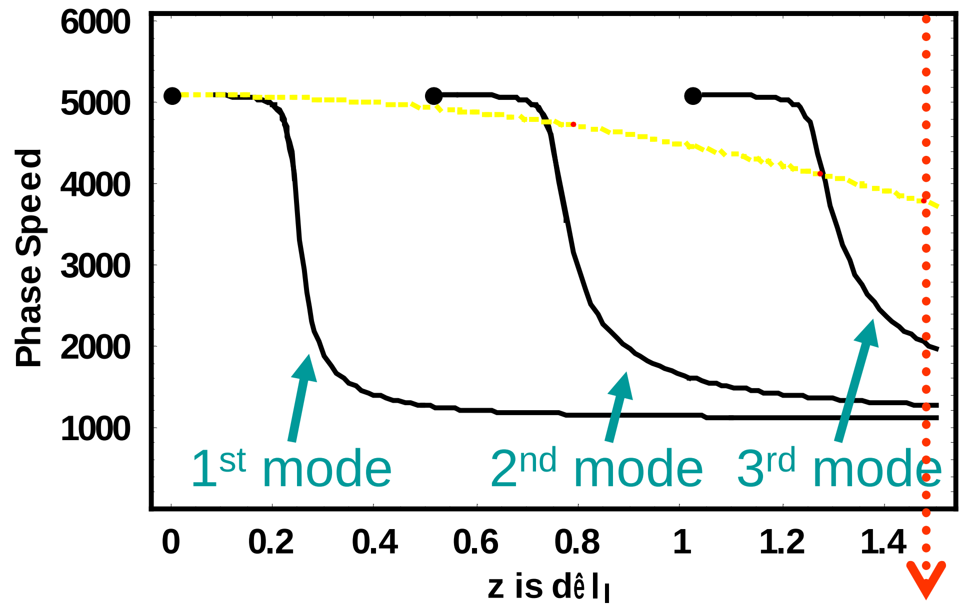
- SH-APM
  Substrate resonance



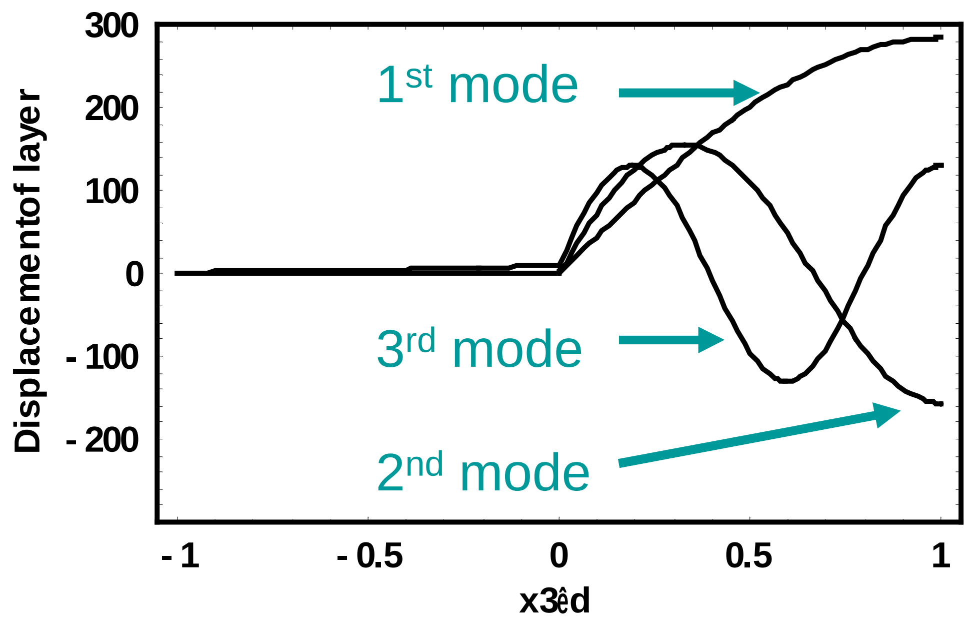
Love Waves

- Theoretical dispersion curve

(Insertion loss is unchanged by an elastic guiding layer)



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



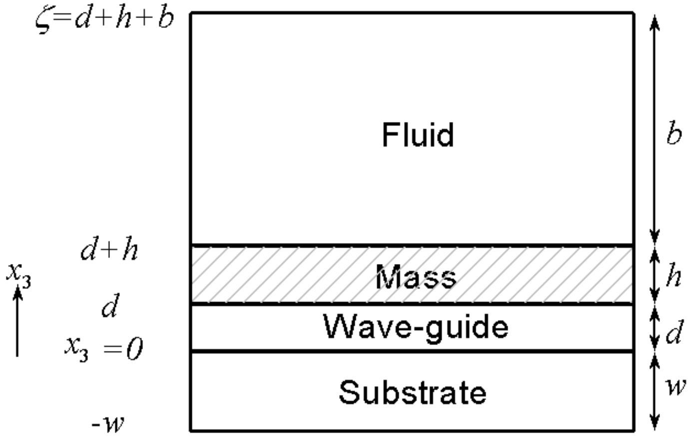
Layer Guided SH-APMs

- Generalized Dispersion Equation[1]

  Layer and substrate displacements

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

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



  Eqns of motion ⇒ T_l's and T_s

  Boundary conditions ⇒ dispersion eqn

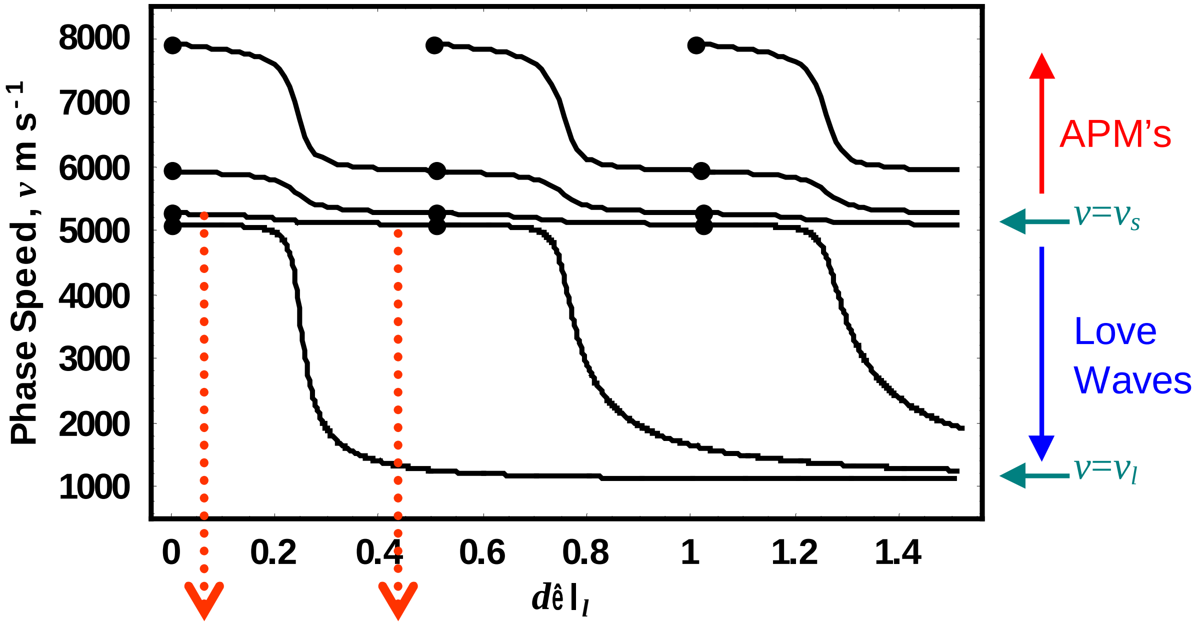
- Substrate + Layer Solutions

T_s real	⇒	$v<v_s$	⇒	"Love" Waves
$T_s=jk_s$ with k_s real	⇒	$v>v_s$	⇒	"Layer guided SH-APMs"

[1]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).

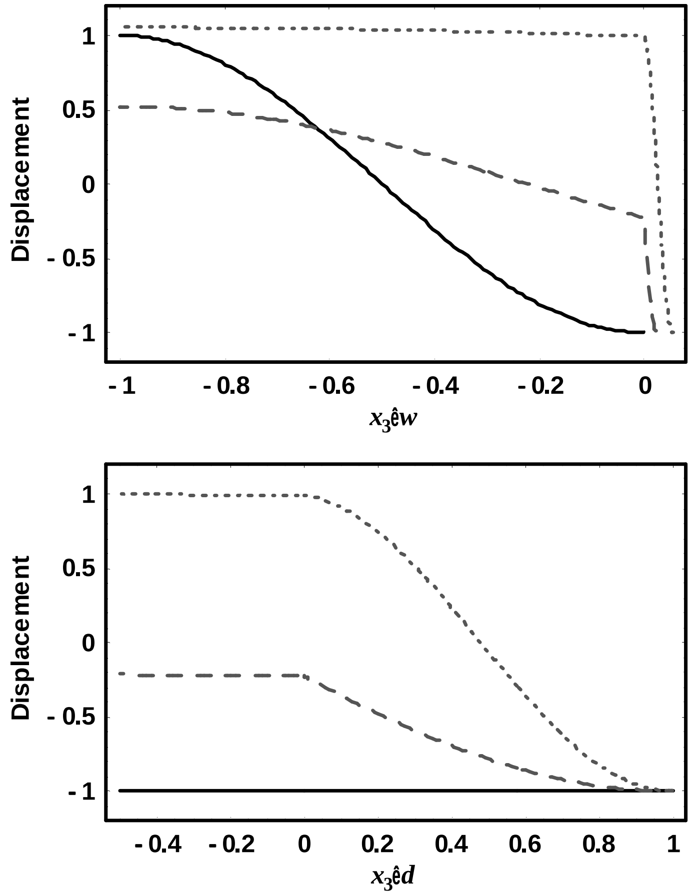
Substrate + Guiding Layer

Dispersion Curve



Points = Anti-node moving from substrate to layer

Evolution of 1st SH-APM



Solid → dashed

with increasing guiding

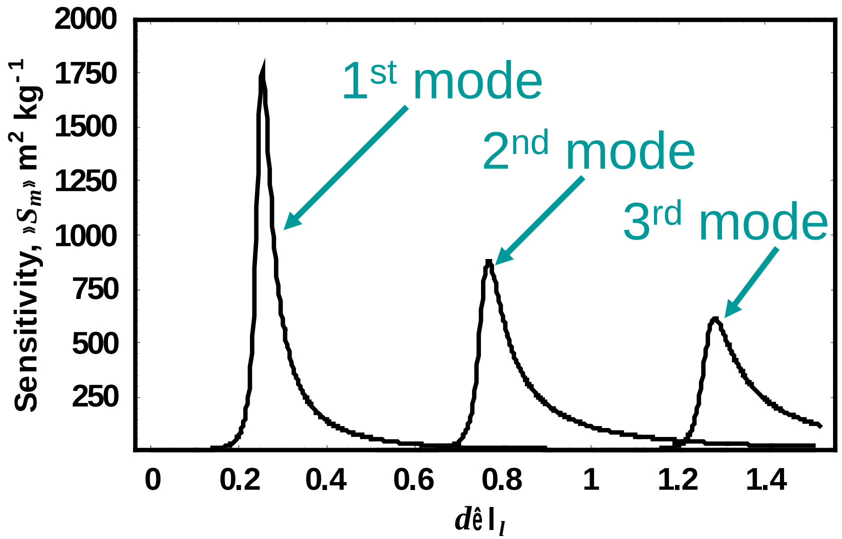
Phase Speed Mass Sensitivity

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

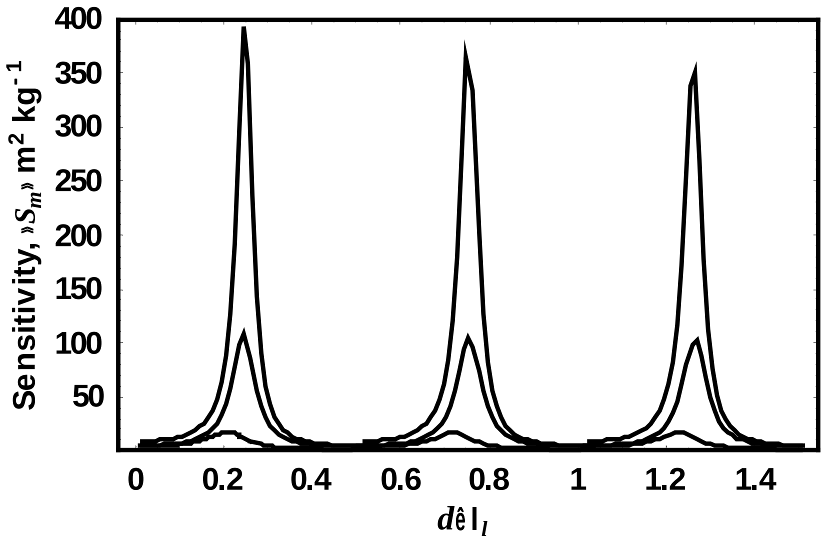
Δm is mass per unit area being sensed, $z=df/v_l$ is the normalized thickness

"Rigid" mass $\Rightarrow$ Mass sensitivity is slope of dispersion curve[1]

Love Waves



Layer-Guided SH-APMs

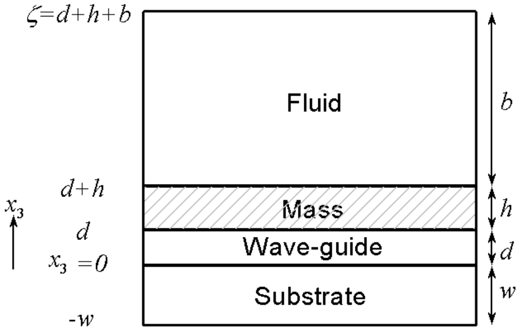


[1]McHale *et al*, J. Appl. Phys. (2002) 91, 9701-9710.

Insertion Loss for Polymer Waveguide

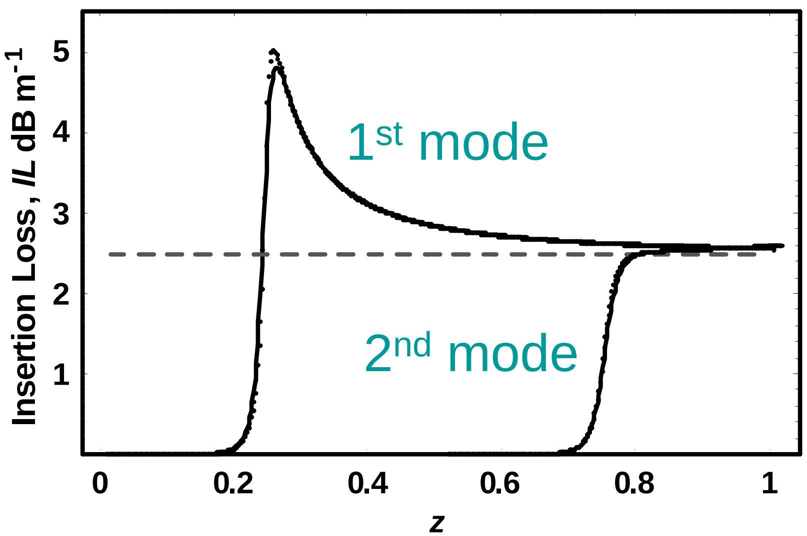
Cases considered

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)

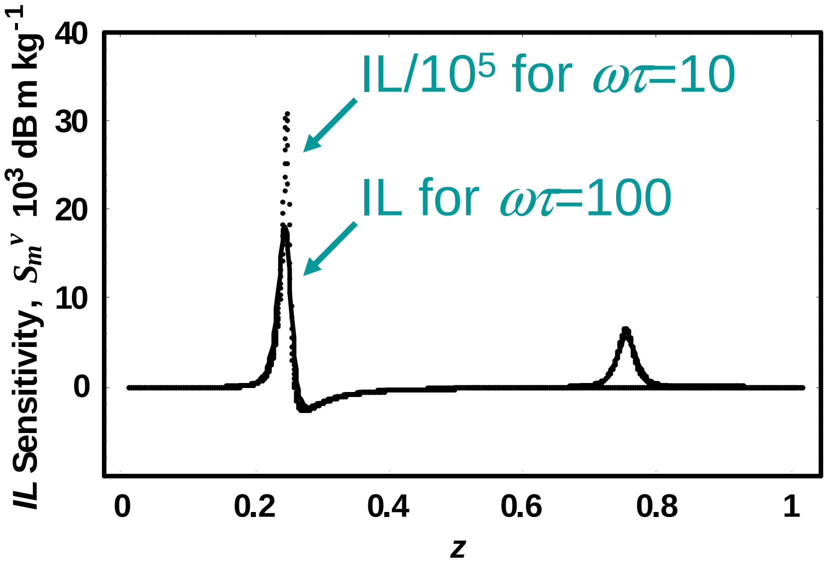


Mass/liquid sensitivity can be derived for phase velocity & insertion loss

Love Wave Insertion Loss



Love Wave IL Sensitivity



[1]McHale *et al*, *"Mass, liquid and polymer sensitivity …..",* Submitted to J. Appl. Phys. (2002).

Preliminary Experimental Data for SH-APM

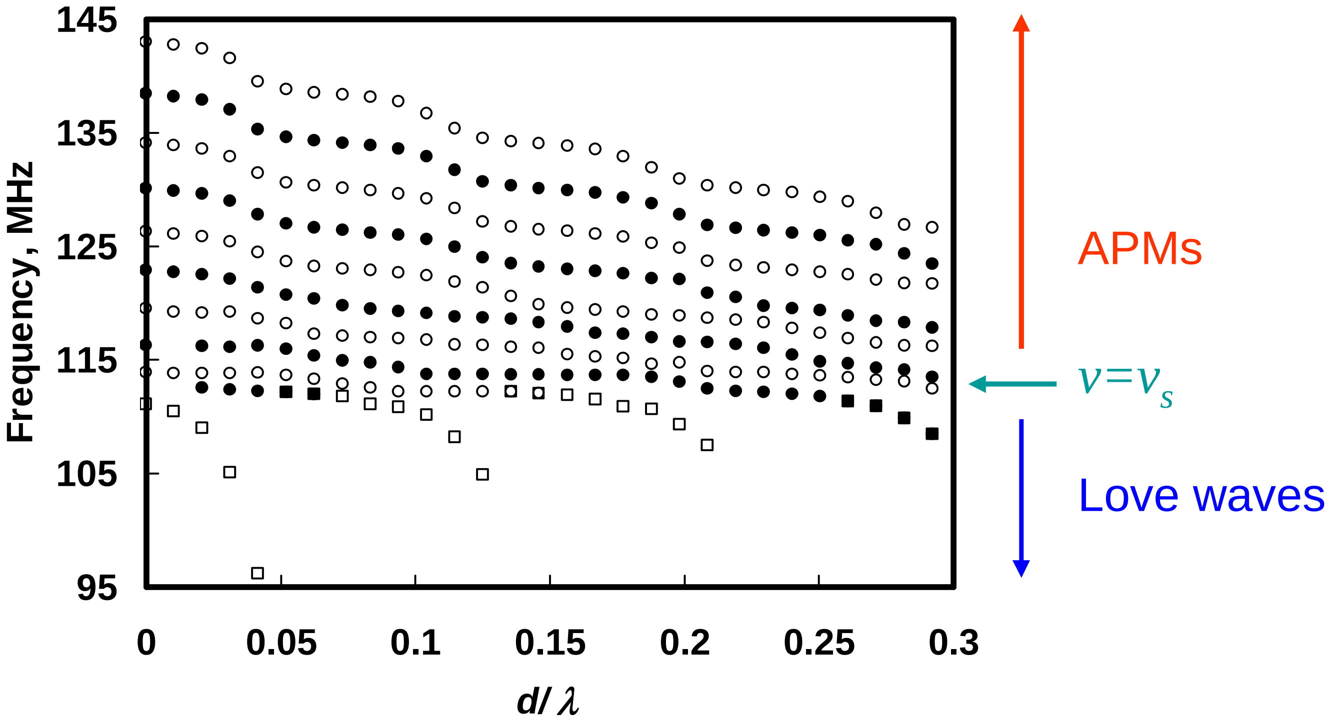
- Layer-Guided SH-APM Modes

  Prop. Orthog. to *x*-axis of thinned (200 μm) ST-Q substrate

  110 MHz surface skimming bulk wave (SSBW)

  SSBW → Love wave by a spin-coated photoresist layer

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



Dispersion and Group Velocity

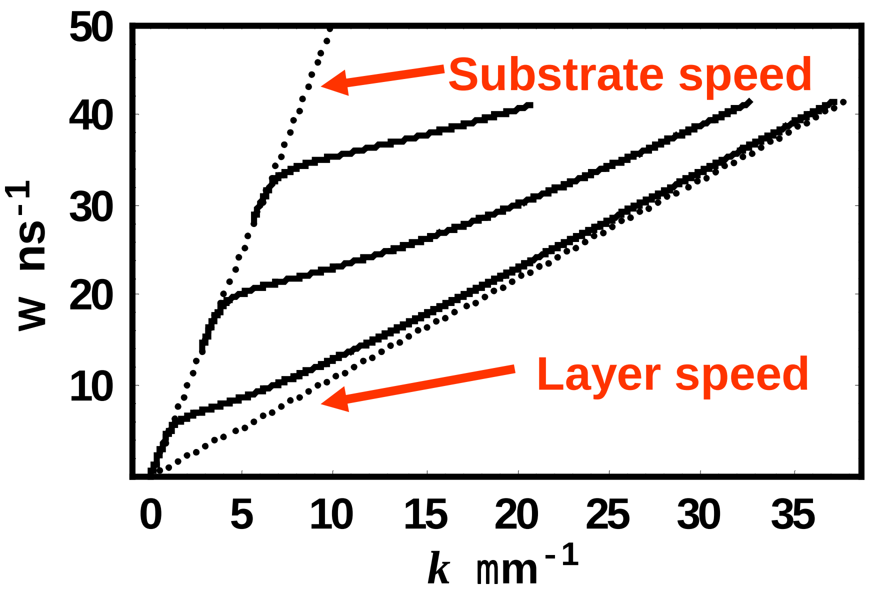
- Guiding Layer Induces Dispersion[1]

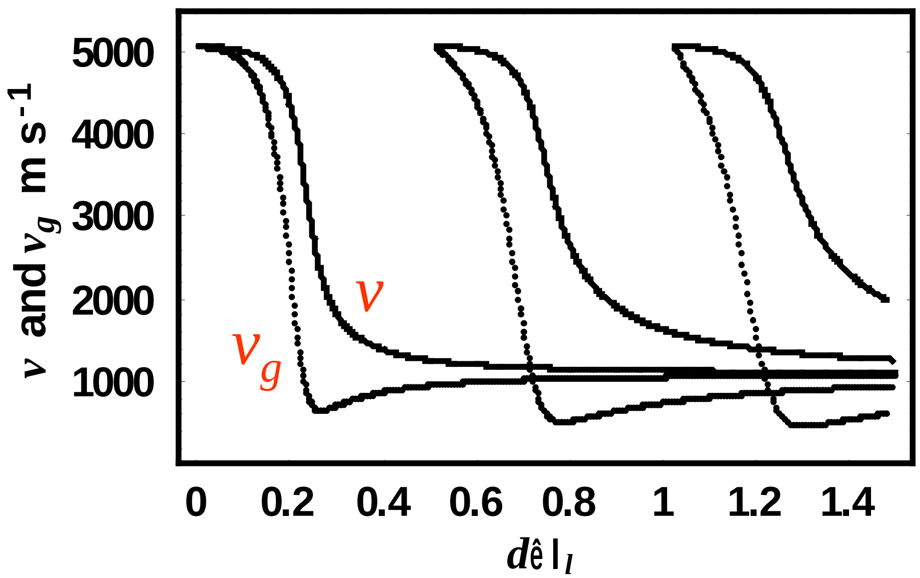
  Phase velocity $v = f\lambda$ or $v = \omega/k$

  Group velocity $v_g = \mathrm{d}\omega/\mathrm{d}k$

  Group velocity is slope of the (ω, k) dispersion curve

  Example 0.25 μm polymer guiding layer on Quartz with $w \to \infty$





[1]McHale *et al*, *"Sensitivity from group and phase …. "* , Accepted by J. Appl.Phys. (2002)

Group Velocity Mass Sensitivity

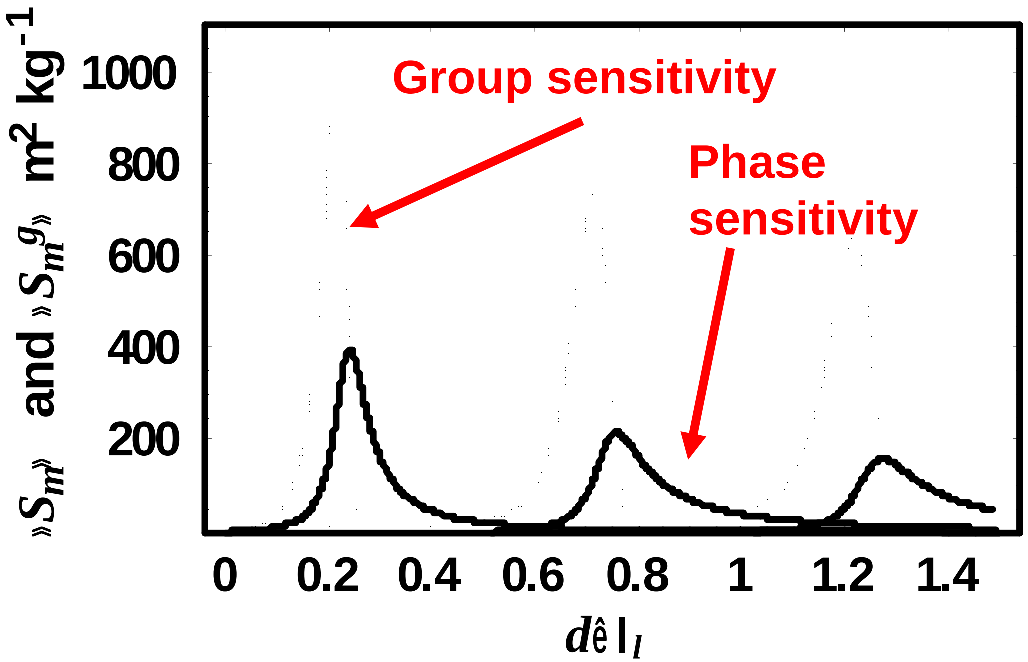
$$S_m \approx \frac{1}{\rho_l d}\left(1-\frac{v}{v_g}\right) = \frac{1}{\rho_l d}\frac{\left(v_g - v\right)}{v_g}$$

"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

- Define a Group Velocity Sensitivity

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



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 $z = d/\lambda_l = df/v_l$

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

  Mass Sensitivity $\propto$ Frequency $\times$ Function of z_o

  Normalized thickness at operating point $z_o \propto d \times f$

Higher Frequency Operation[1,2]

Routes	Issues
1. Increase fundamental frequency	1. Change of Love wave mode?
2. Hop the frequency to a harmonic	2. Const. guiding layer thickness?

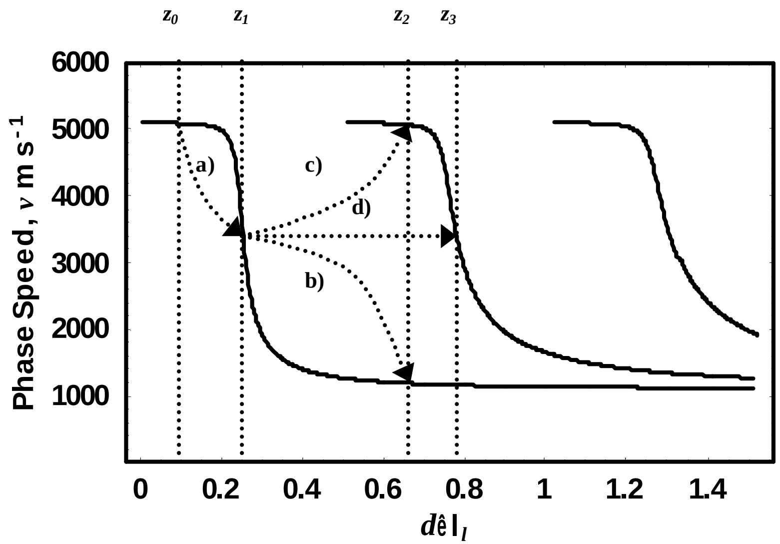
- Frequency Increase at Constant z_o

  Reduce d as $1/f$ ⇒ No change on dispersion curve
  ⇒ Mass sensitivity scales with f

- Frequency Hopping at Constant d

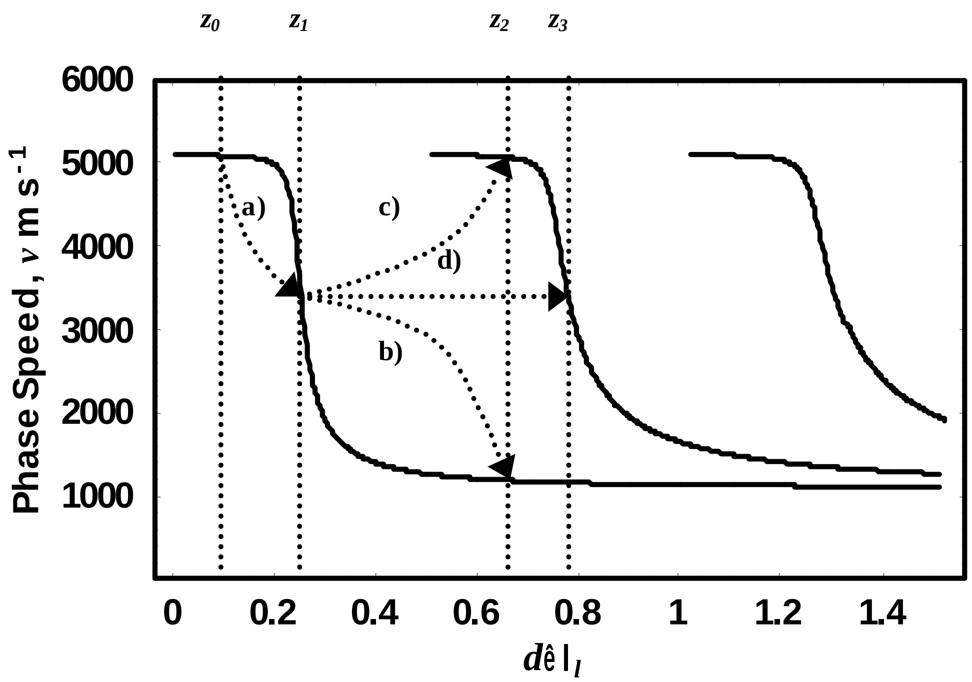
  Four example transitions

  Same mode ⇒ lower/higher sensitivity
  Change mode ⇒ lower/higher sensitivity



[1]M.I. Newton *et al*, Electron. Lett. (2001) 36, 340-341;[2]G. McHale *et al*, J. Appl. Phys. (2002), 91, 5735-5744

Frequency Hopping Transitions



No Mode Change

Transition a) ⇒ Higher mass sensitivity

Transition b) ⇒ Lower mass sensitivity

Mode Change

Transition c) ⇒ Lower mass sensitivity

Transition d) ⇒ Higher mass sensitivity

Maximum Increase in Mass Sensitivity

Ratio of frequencies × 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

The End