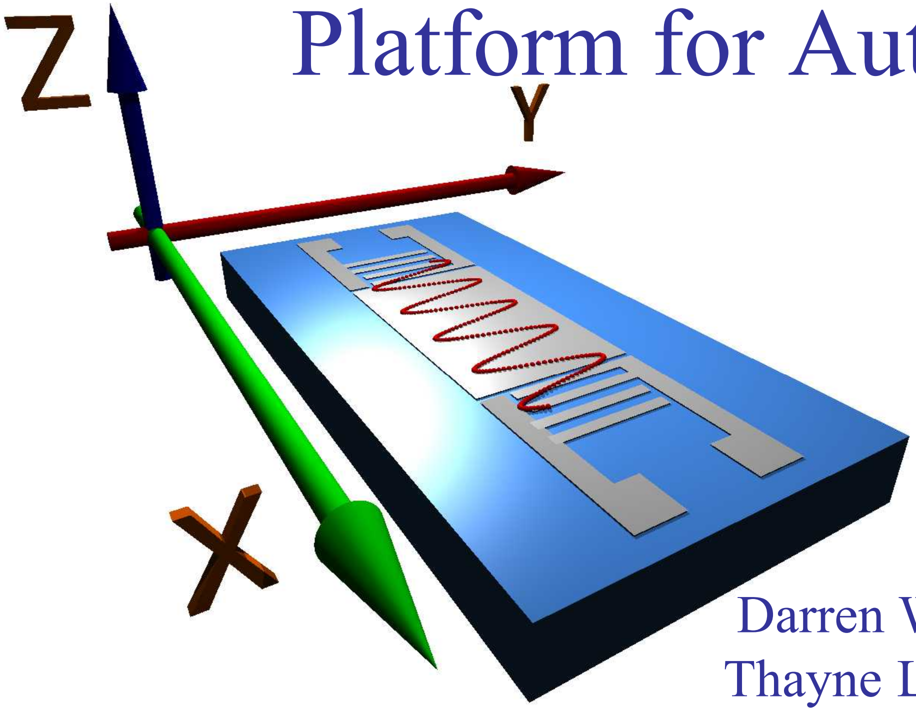
SAND2007-6957C

Love Wave Acoustic Array Biosensor Platform for Autonomous Detection



Darren W. Branch
Thayne L. Edwards

Sandia National Laboratories
Biosensors and Nanomaterials Department
PO Box 5800, MS-1425
Albuquerque, NM 87185
email: dwbranc@sandia.gov

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Outline

- Sensor System Approach
- Sensor IDT Design
- Waveguide
- Sensitivity and Temperature Analysis
- Detection System
- Sensitivity to Mass Density
- Multi-Analyte Biodetection
- Conclusions

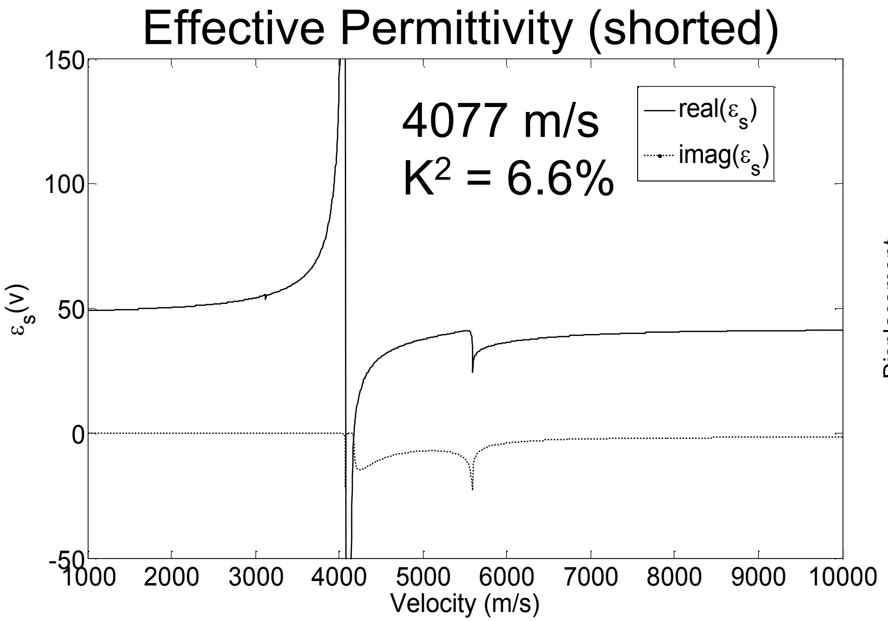
dwbranc@sandia.gov

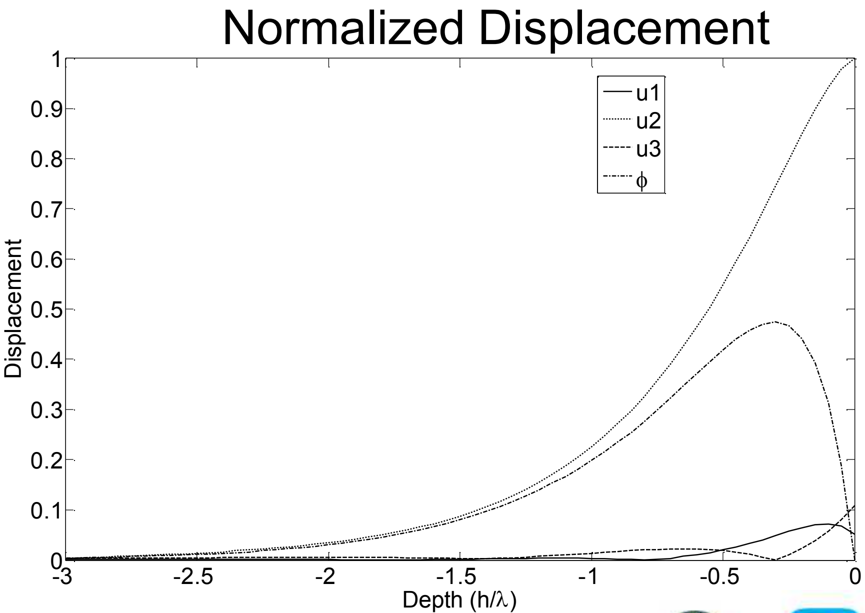
Sensor System Approach

- Design Criteria:
  - High frequency (> 300 MHz)
  - Good phase linearity
  - Low insertion loss
  - Large phase slope
  - Small footprint

→ IDT design is highly critical

- Challenges for 36° YX Lithium Tantalate x(0,-54°,0) substrate

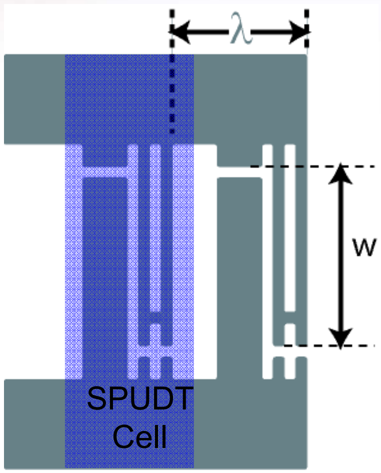


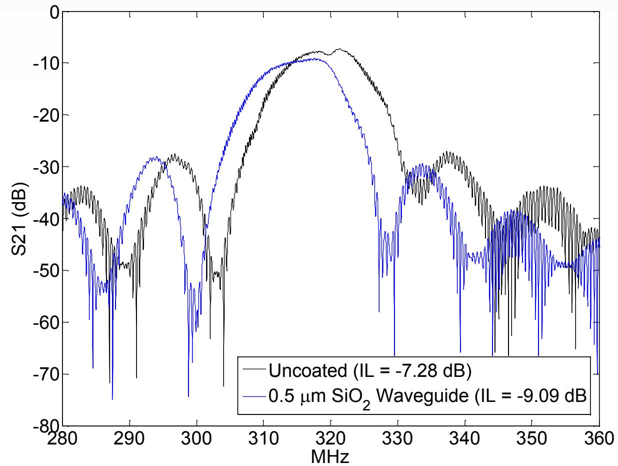


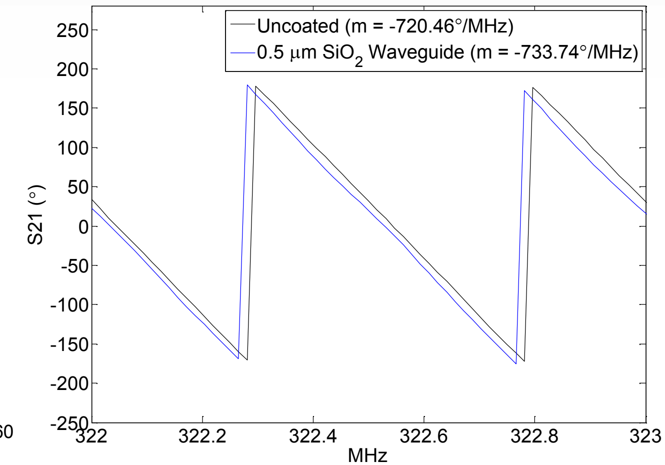
dwbranc@sandia.gov

Sensor IDT Design

1)

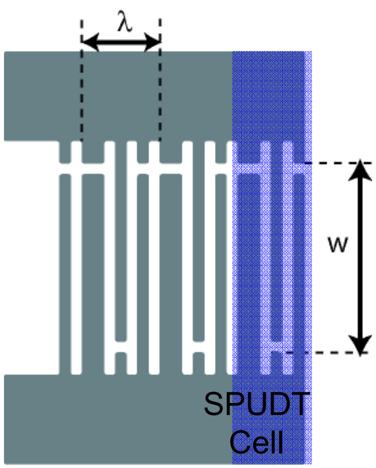


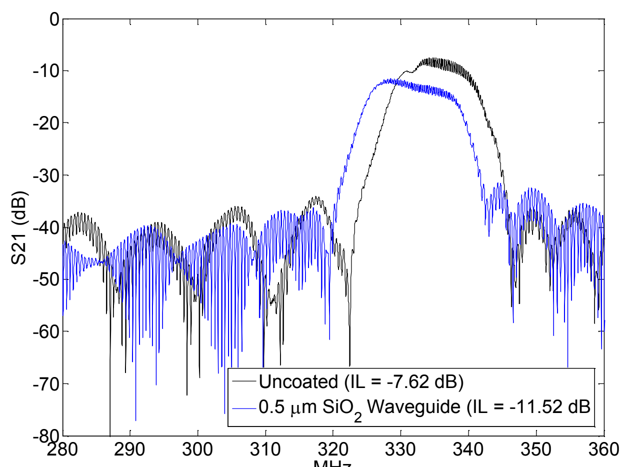


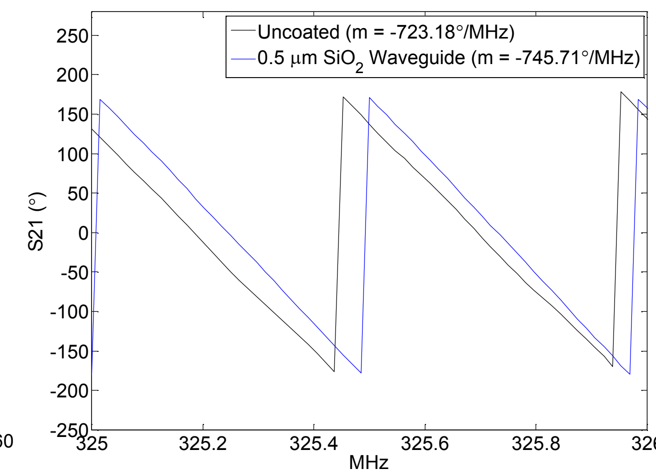


Based on Hartmann, C. S. and B. P. Abbott (1989).

2)



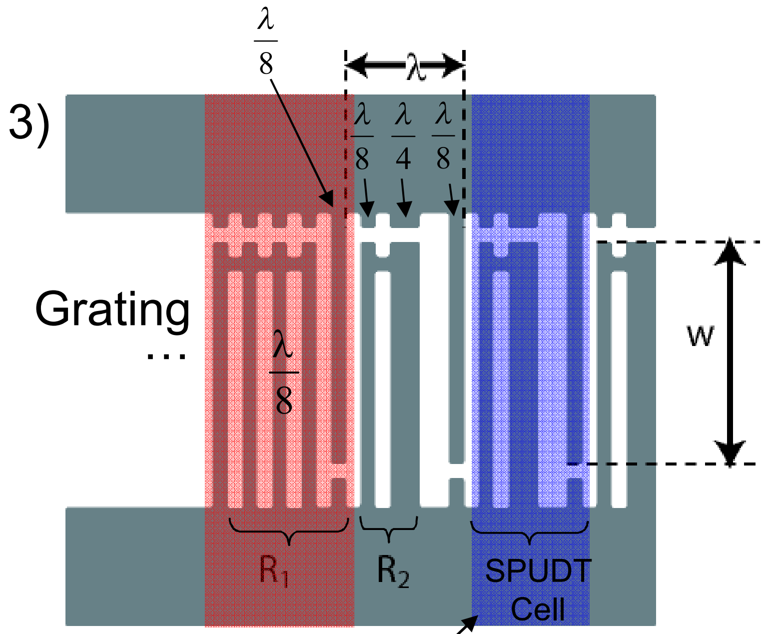




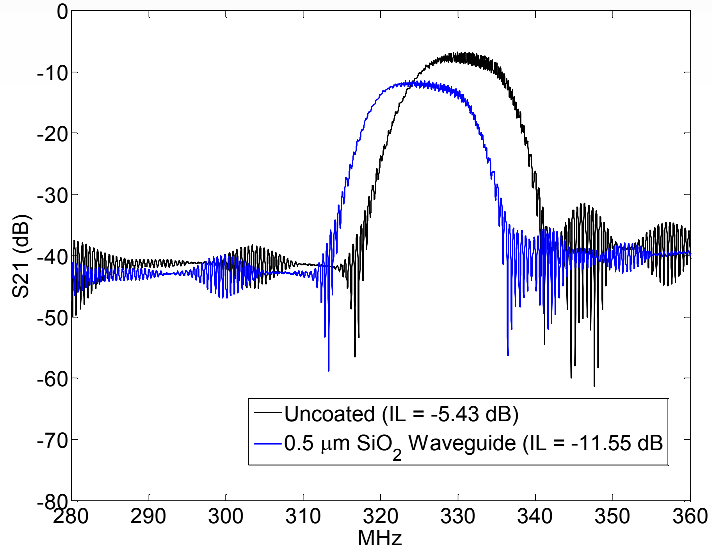
Hartmann, C. S. and B. P. Abbott (1989).
Nakagomi, S., H. Asano, et al. (2003).

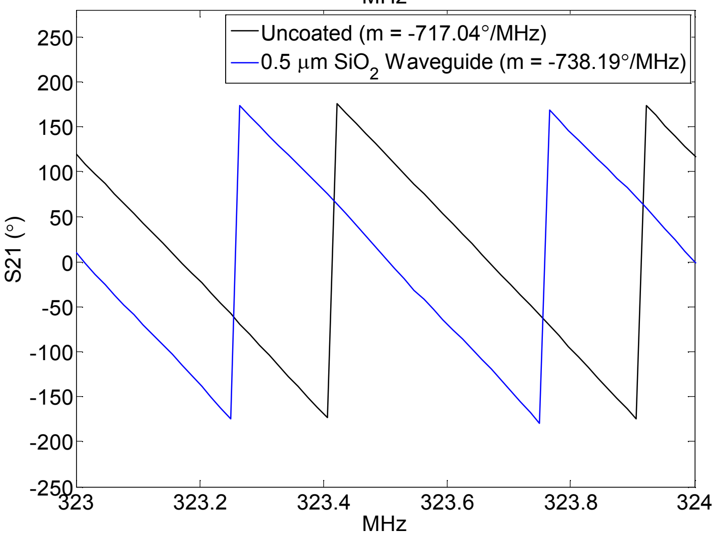
Sensor IDT Design

Grating plus one SPUDT cell type:



Experimentally tuned SPUDT cell for best response

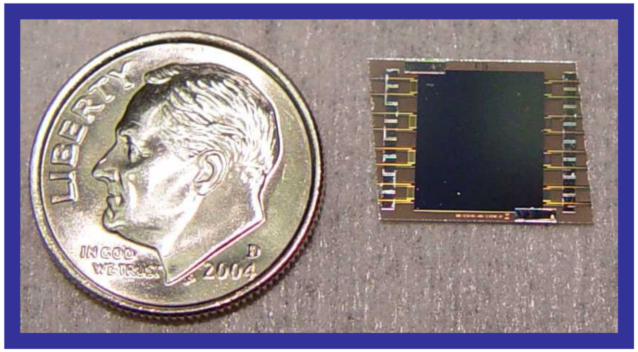




dwbranc@sandia.gov

Four Channel Love Wave Array

Four Channels per Die



Each Channel:
8.1 mm x 0.75 mm

$$\delta = \sqrt{\frac{\eta}{\pi \rho \nu}}$$

Wave penetration depth (δ):
31 nm @ 330 MHz in water
(η = 1cP, ρ = 1 g/cm^3)

SH-SAW Design Summary (no waveguide)

	(1)	(2)	(3)
Center Frequency	320 MHz	332MHz	330MHz
Insertion Loss	-7.28 dB	-7.62 dB	-5.43 dB
3 dB Bandwidth	9 MHz	10 MHz	7 MHz
Amplitude Ripple	0.8 dB P-P	3.9 dB P-P	2.5 dB P-P
Phase Ripple	2° P-P	4.4° P-P	2.8° P-P
Impedance near f_c	45.5 + j4.6 Ω	-	49 + j1.2 Ω
Cross Talk	38 dB	38 dB	39 dB
Phase Slope (uncoated)	-720.46°/MHz	-723.18°/MHz	-717.04°/MHz

dwbranc@sandia.gov

Waveguide

Piezoelectric Model:
Green's function method

$$\overline{kG(s)} = \begin{bmatrix} \overline{u_1^{(1)}} & \overline{u_1^{(2)}} & \overline{u_1^{(3)}} & \overline{u_1^{(4)}} \\ \overline{u_2^{(1)}} & \overline{u_2^{(2)}} & \overline{u_2^{(3)}} & \overline{u_2^{(4)}} \\ \overline{u_3^{(1)}} & \overline{u_3^{(2)}} & \overline{u_3^{(3)}} & \overline{u_3^{(4)}} \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \overline{T_{13}^{(1)}} & \overline{T_{13}^{(2)}} & \overline{T_{13}^{(3)}} & \overline{T_{13}^{(4)}} \\ \overline{T_{23}^{(1)}} & \overline{T_{23}^{(2)}} & \overline{T_{23}^{(3)}} & \overline{T_{23}^{(4)}} \\ \overline{T_{33}^{(1)}} & \overline{T_{33}^{(2)}} & \overline{T_{33}^{(3)}} & \overline{T_{33}^{(4)}} \\ \overline{D_3^{(1)\prime}} & \overline{D_3^{(2)\prime}} & \overline{D_3^{(3)\prime}} & \overline{D_3^{(4)\prime}} \end{bmatrix}^{-1}$$

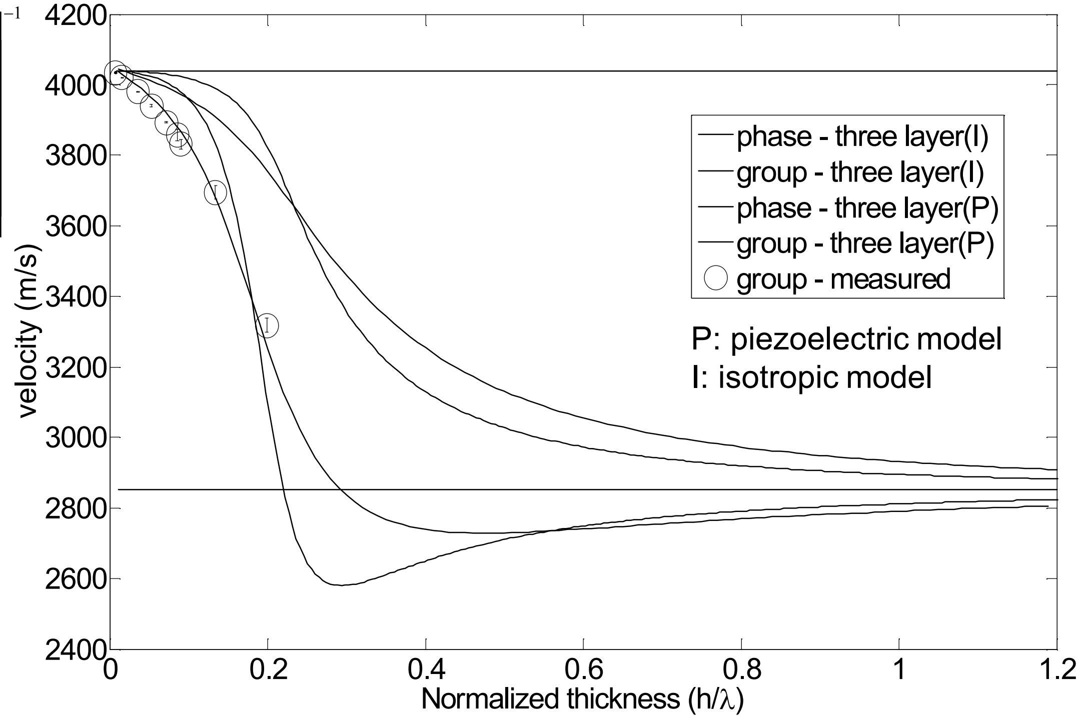
Qiao, D., W. Liu, et al. (1999)

$$\varepsilon_s(s) = \frac{1}{\varepsilon_o G_{44}(s)}$$

Find all poles and create list of velocities as thickness increases

Isotropic Case:
Solve dispersion equation for three layered system

Dispersion Curves:
SiO_2 Waveguide on 36° YX LTO



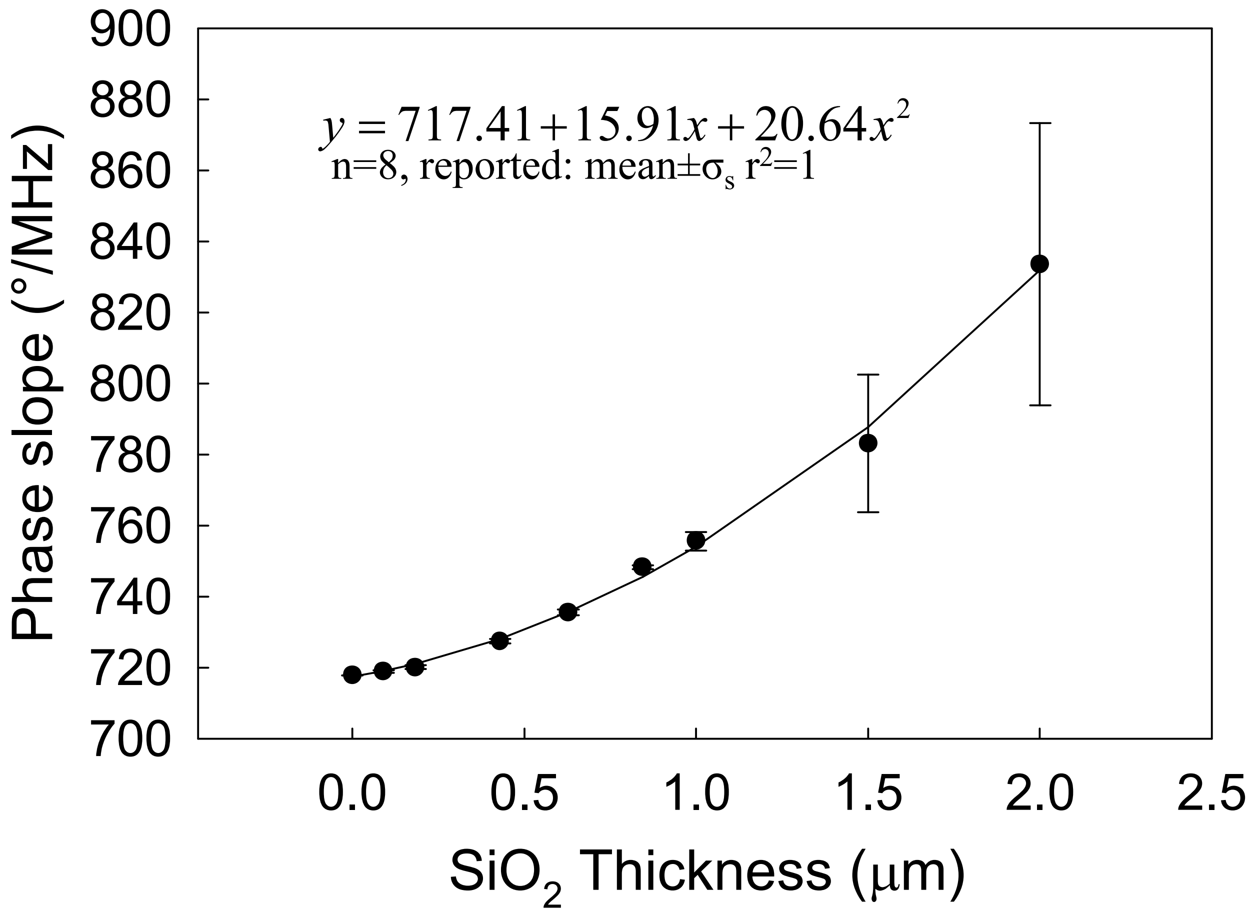
Dispersion for isotropic model differs significantly from the full piezoelectric model

dwbranc@sandia.gov

Waveguide, cont'd

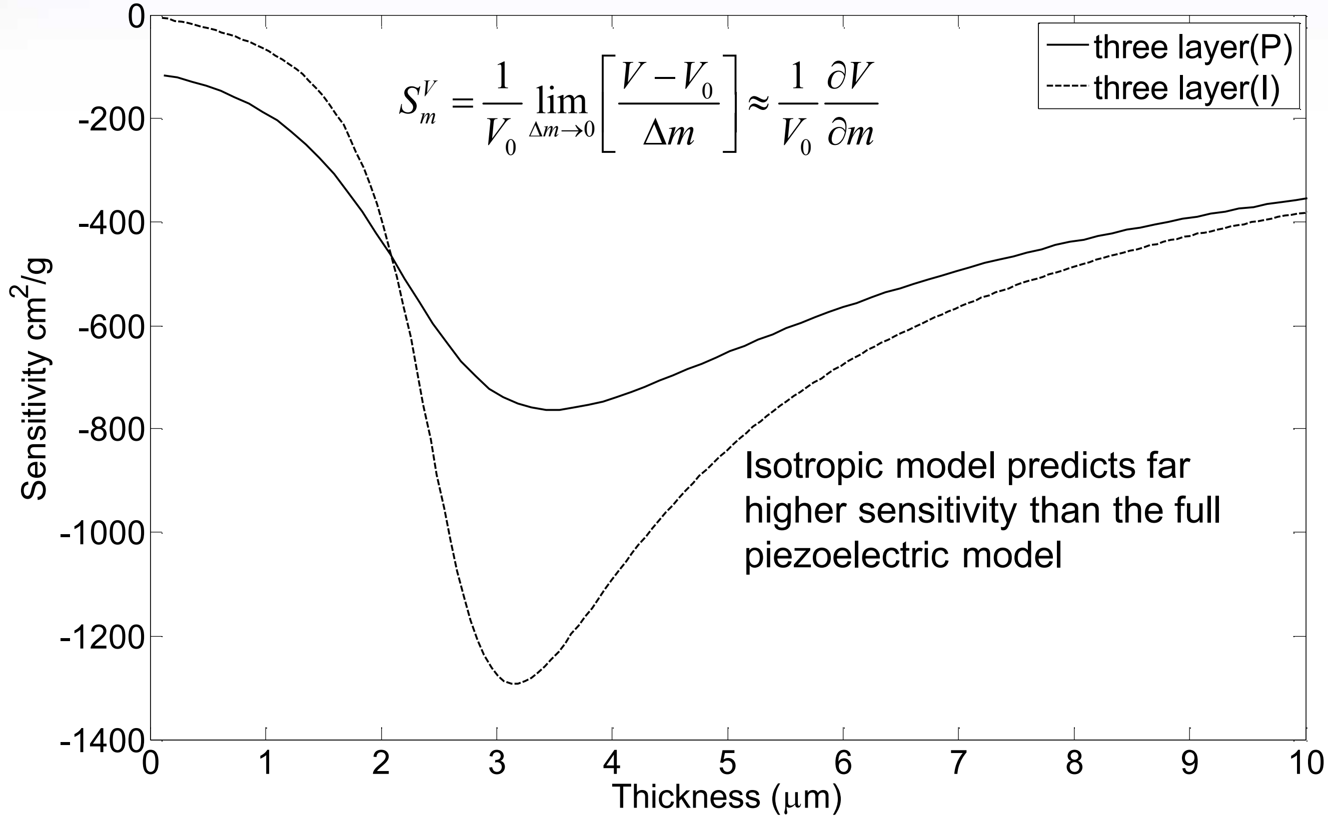
Nondestructive Analysis of Waveguide Sensitivity:

- Phase slope is an indicator of reproducibility for sensitivity
- Indirect measure of sensitivity without performing mass detection experiments



dwbranc@sandia.gov

Sensitivity Analysis



Model	Optimal Thickness		Optimal Frequency	Sensitivity	
	h/λ	h (μm)	f_{opt} (MHz)	$1/\rho_2\lambda$	cm^2/g
Plate mode	-	-	-	-	-1.22
Three layer(P)	0.290	3.55	285.01	-2.05	-761.97
Three layer(I)	0.260	3.19	287.53	-3.48	-1291.81

dwbranc@sandia.gov

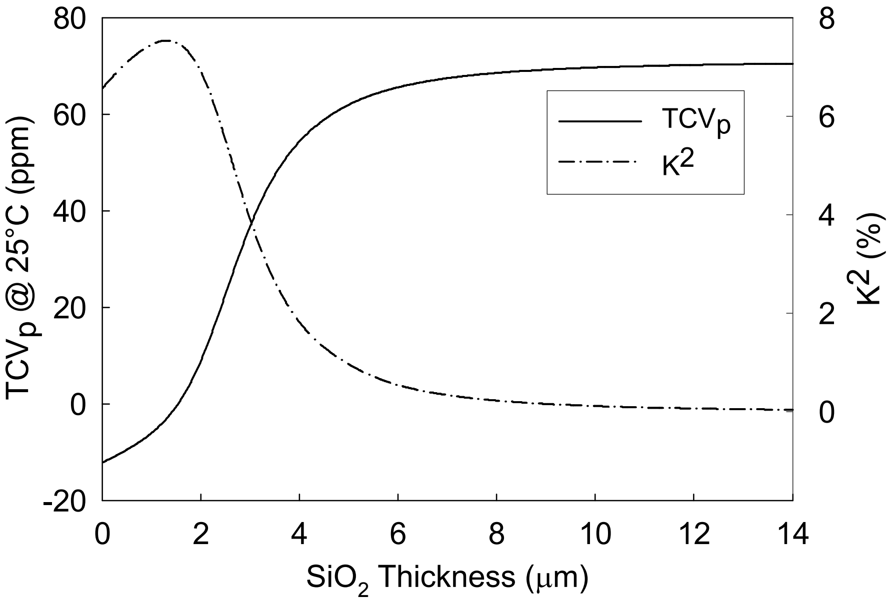
Temperature Compensation

TCF:
36° YX LTO = -35 ppm/°C
Silicon dioxide = +80 ppm/°C, α= +9ppm
α: Temperature expansion coefficient

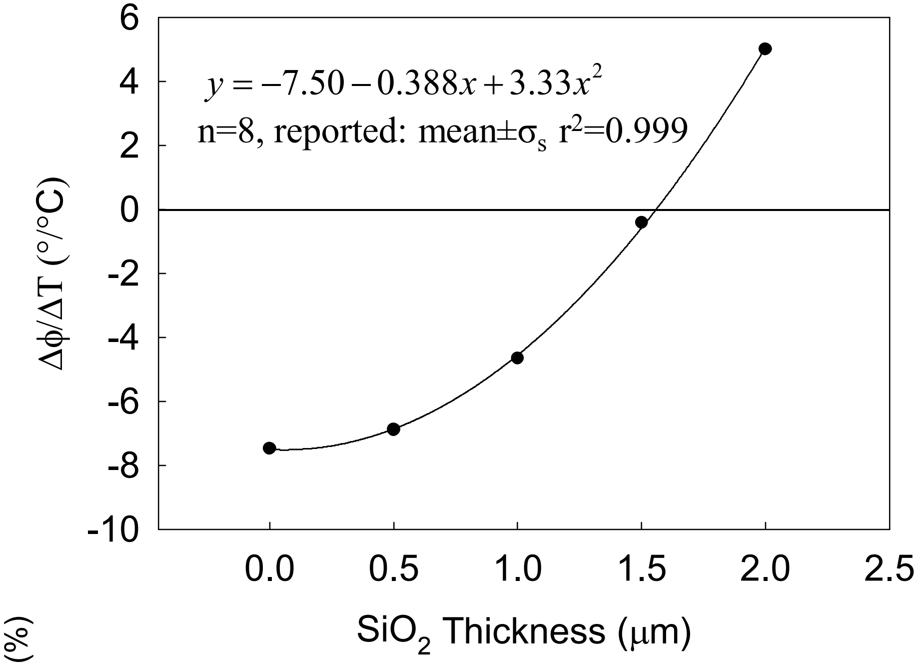
$$TCV_p = \alpha - TCF$$

$$TCV_p = \frac{1}{V(25^\circ C)}\frac{\partial V_p}{\partial T} \approx \frac{1}{V(25^\circ C)}\frac{V(35°C)-V(25°C)}{10°C}$$

Calculated TCV_p vs. Waveguide Thickness



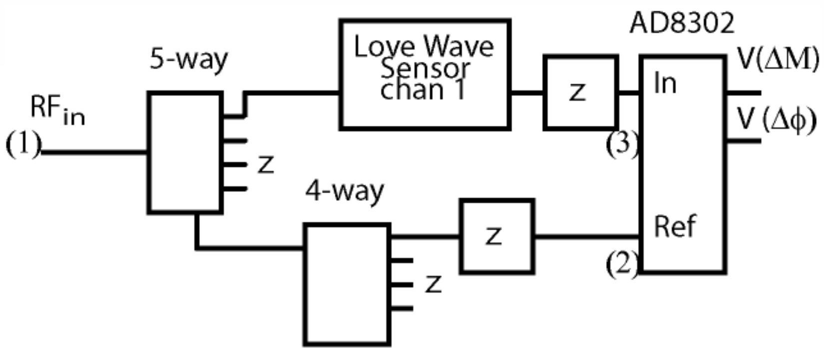
Measured Phase Shift/Temperature Shift vs. Waveguide Thickness

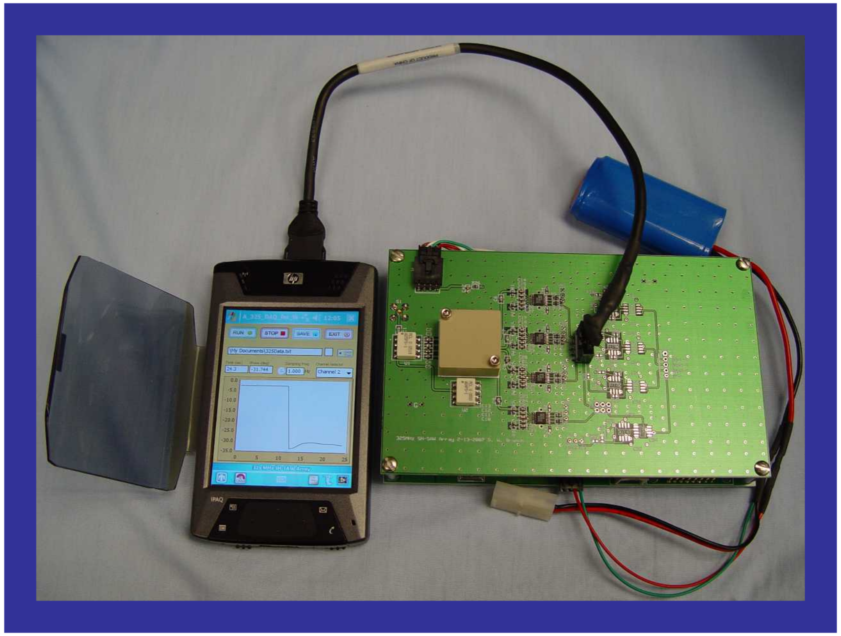


dwbranc@sandia.gov

Phase Based Detection System

- Tunable RF source (310-350 MHz)
  - Multiple frequency analysis
- Signals are split to drive 4 Love Wave sensors
- 5V DC, 20 hr operation
- AD8302
  - Phase difference
  - Magnitude difference
  - Φ resolution of 0.01°
- Labview software for DAQ and Analysis
- PDA or Laptop Readout
- Sample rate: 1k





dwbranc@sandia.gov

National Nuclear Security Administration

Sandia National Laboratories

Sensitivity to Mass Density

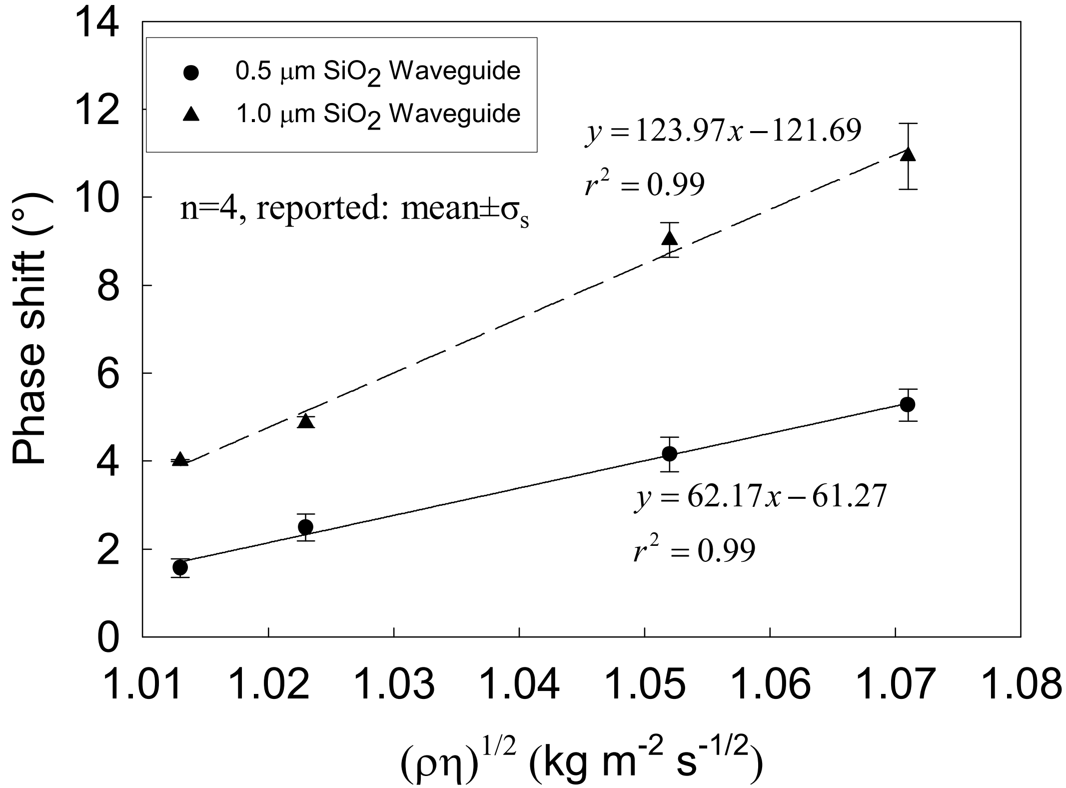
Sensitivity due to density/viscosity:

Method: Malavé, A., U. Schlecht, et al. (2006)

$$S_{\phi,\eta} = \sqrt{4\pi\nu}\left(\frac{\Delta\phi}{\sqrt{\rho\eta}}\right)$$

ν: frequency of Love Wave sensor
ρ: fluid density (g cm^{-3})
η: fluid viscosity (Pa s)
φ: phase shift (°)

Slope: $\frac{\Delta\phi}{\sqrt{\rho\eta}}$



0.5 μm Waveguide (ν = 328 MHz):

$$S_{\phi,\eta} = 4.31 \pm 0.33\ °\ \mathrm{mm}^2 / \mathrm{ng}$$

1.0 μm Waveguide (ν = 325 MHz):

$$S_{\phi,\eta} = 7.19 \pm 0.74\ °\ \mathrm{mm}^2 / \mathrm{ng}$$

Detection limit:
Noise (N): 0.01°, 5N
$= 6.71 \pm 0.40$ pg / mm^2

Conservative values

dwbranc@sandia.gov

Multi-Analyte Biodetection

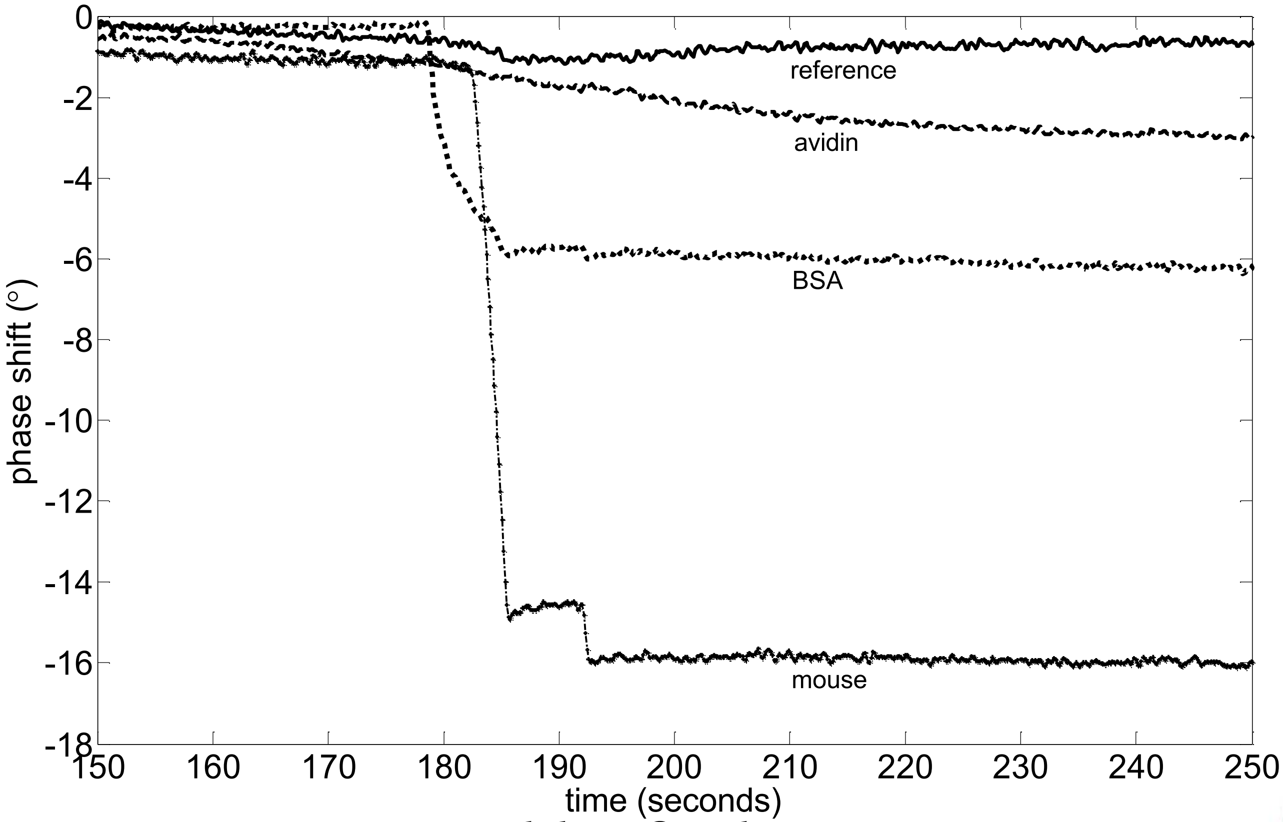
Multi-Analyte Detection:

1) IgG: Anti-avidin, antigen: avidin
2) 2) IgG: Anti-BSA (albumin), antigen: BSA
3) IgG: Anti-mouse, antigen: (mouse) anti-rabbit

- Antigens combined in a single fluid sample (50 μl) @ 100 ng/ml each

Flow cell: 4 μl

Flow rate: 10 μl/min, carrier buffer: 10 mM PBS



dwbranc@sandia.gov

Conclusions

- We have developed an IDT suitable for high frequency Love Wave sensors.
- The IDT design has an excellent S21 response, minimal bulk wave interferences, and excellent phase linearity.
- A Love wave array was fabricated with four detection channels.
- A phase detection system was developed to monitor four channels simultaneously.
- Sensitivity results indicate a detection limit of 6.71 ± 0.40 pg / mm^2 with $0.01°$ resolution at 5 times the noise level.
- Performed multi-analyte biodetection of a complex sample.