

Characterization of Thin Film MEMS Using Photo-acoustic Microscopy

Carmen Hernandez

Todd Murray

Sridhar Krishnaswamy

Department of Mechanical Engineering

Northwestern University

Evanston, IL60208-3020

Tel: 847-491-4006

Email: s-krishnaswamy@northwestern.edu

talk outline

- Introduction
- Photo-acoustic microscope
- Guided waves in thin films
 - general dispersion curve
 - asymptotic expressions for dispersion relations
- Thin film fabrication
- Results
 - experimental dispersion curve
 - material property extraction
- Conclusion

Photo-acoustic Materials Characterization

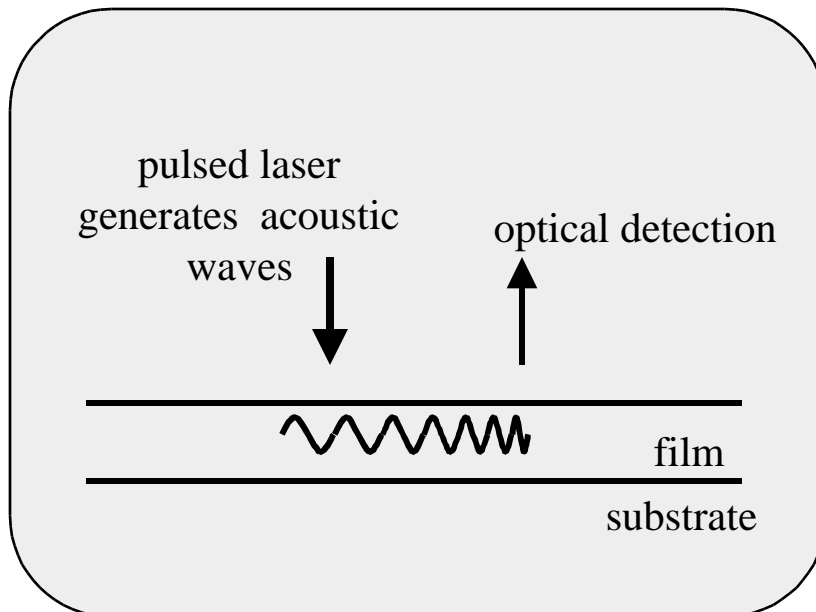
- Idea:
 - Use high frequency ultrasonic waves in solids to measure:
 - Material stiffness
 - Material attenuation
 - Film / coating thickness
- Techniques:
 - Conventional ultrasonics / acoustic microscopy
 - Surface Brillouin scattering
 - Photo-acoustics (laser ultrasonics)

Photo-acoustic techniques:

- provide **non-contact, non-destructive** measurement
- have **small footprint & high spatial resolution**
- can be applied on **complex geometries** (non-planar)
- can be used in **hostile environments**

Photo-acoustic Characterization of Thin Films

Guided-wave Techniques



Bulk-wave Techniques

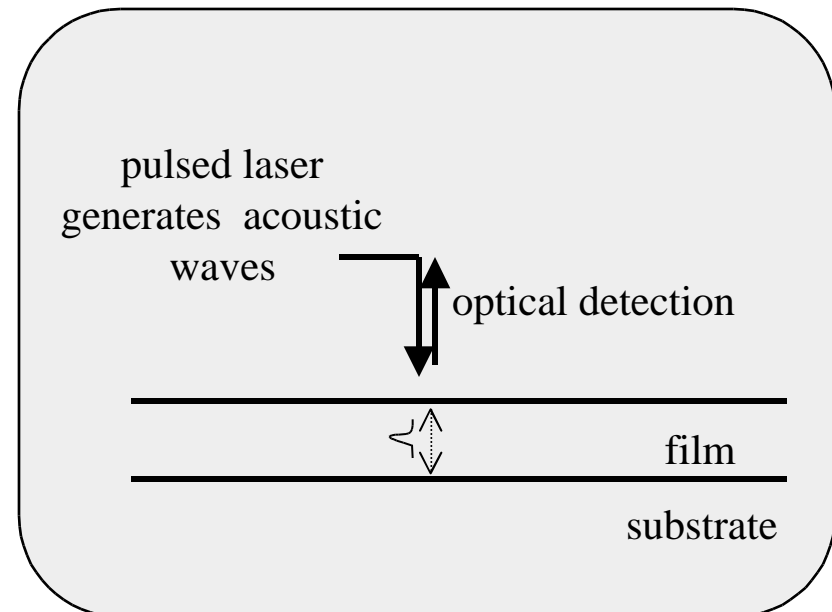


Photo-acoustic Characterization of Thin Films

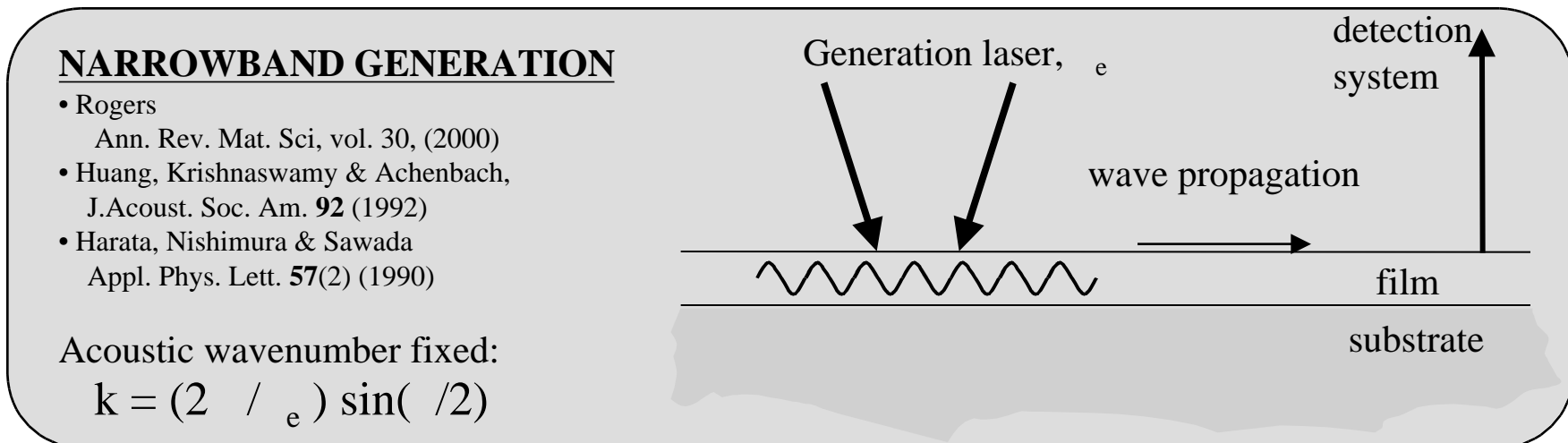
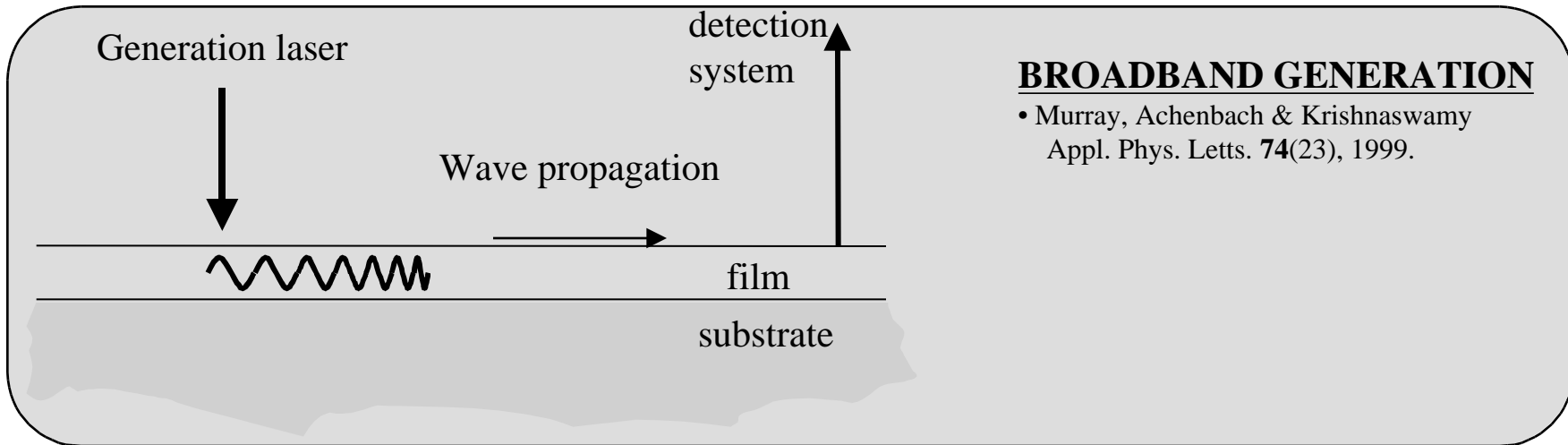
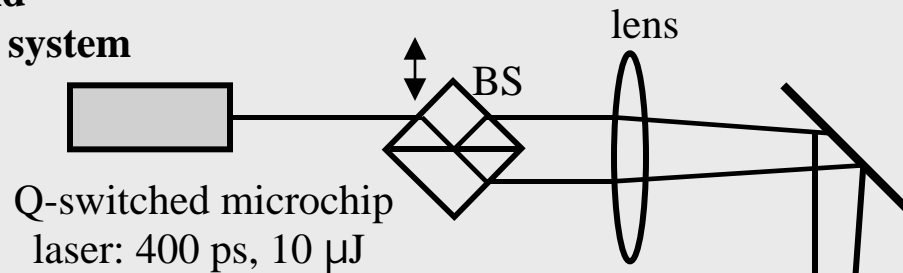


Photo-acoustic Microscope

**Narrowband
Generation system
(source)**



Optical footprint

- source spot size: 20 μ m
- receiver spot size: 5 μ m
- source-receiver distance adjustable

**Balanced Michelson Interferometer
(receiver)**

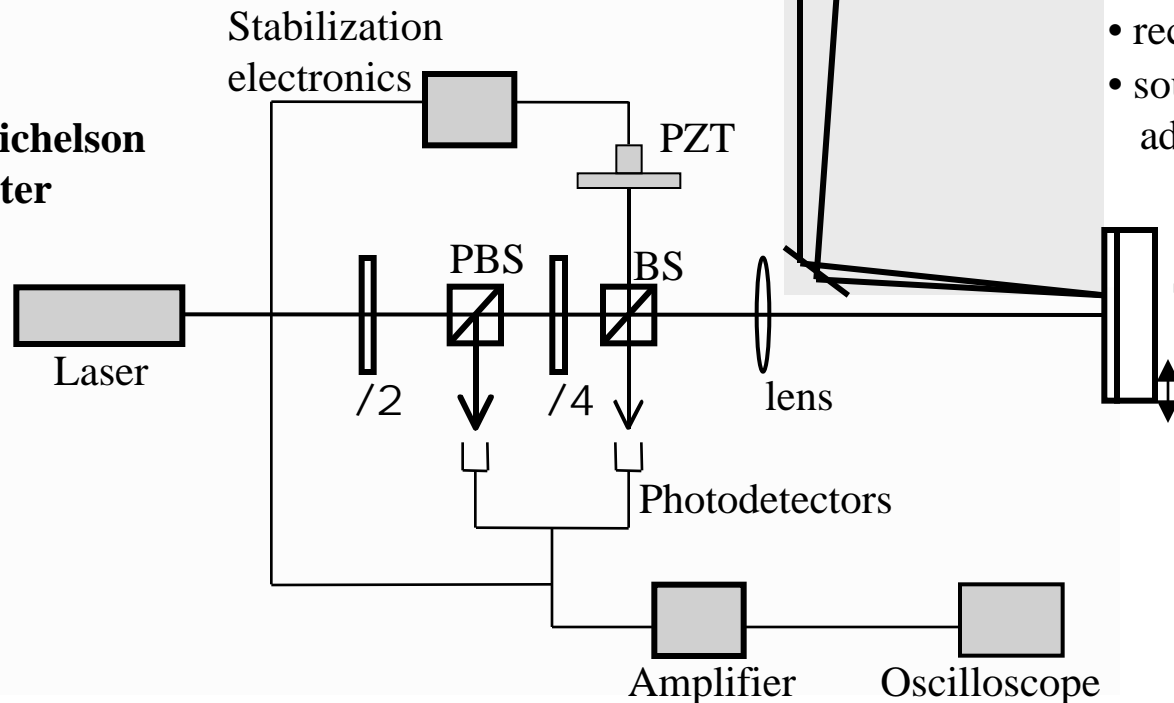
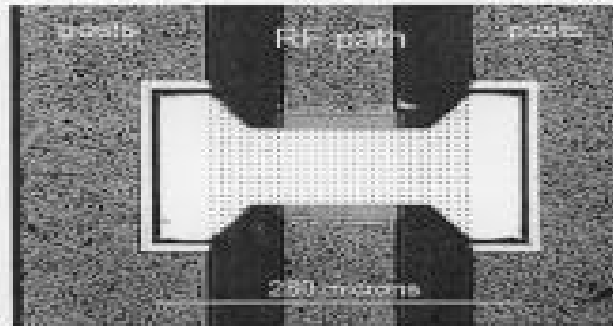
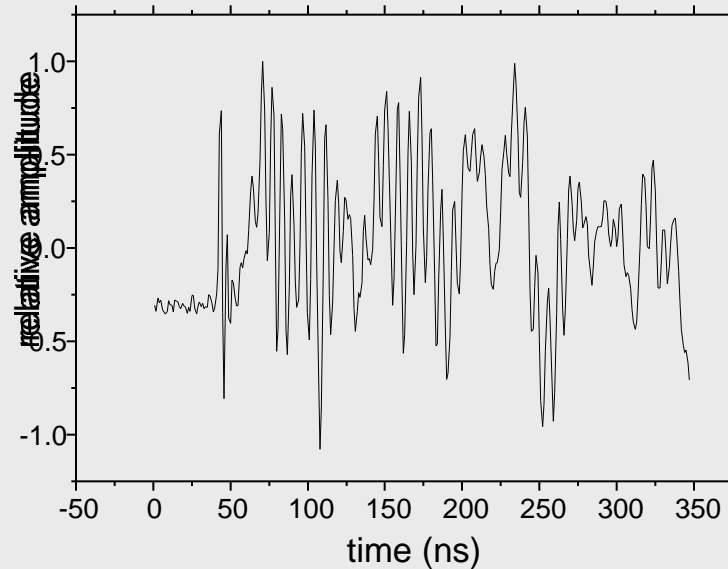


Photo-acoustic Characterization of MEMS

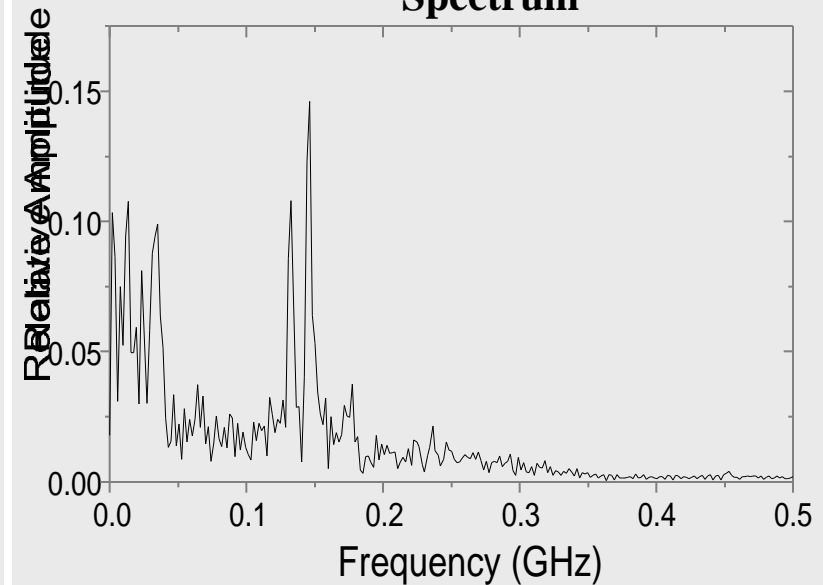
- proof of concept -



Time-trace

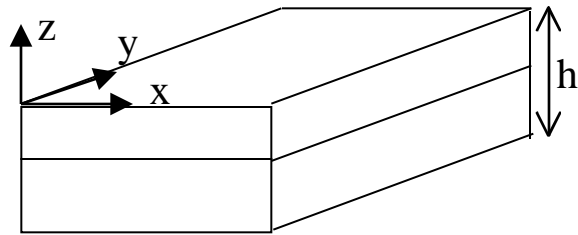


Spectrum

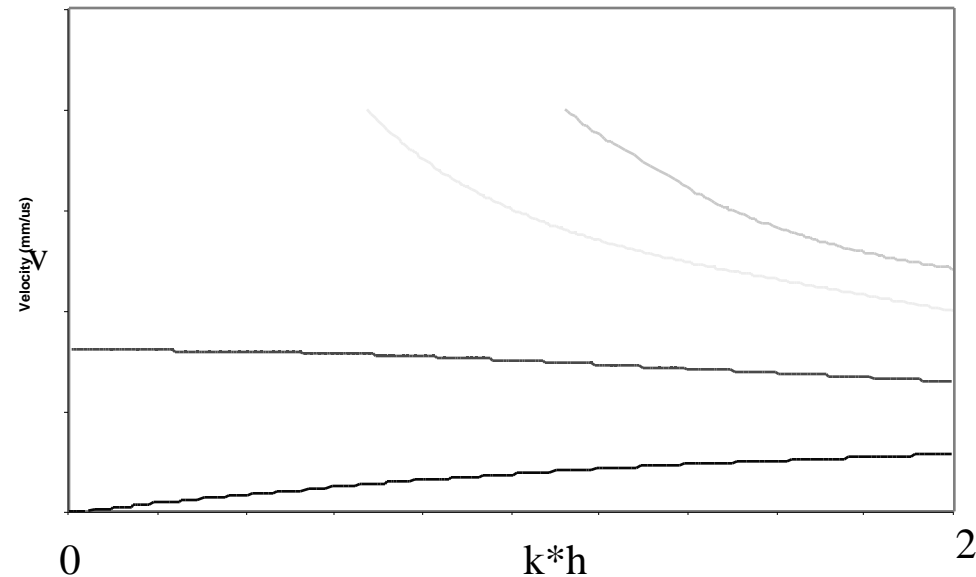


- Two closely spaced modes of same wavelength but different frequencies are observed.

Guided Acoustic Waves in Layered Films



Dispersion curve for Al/Si₃N₄



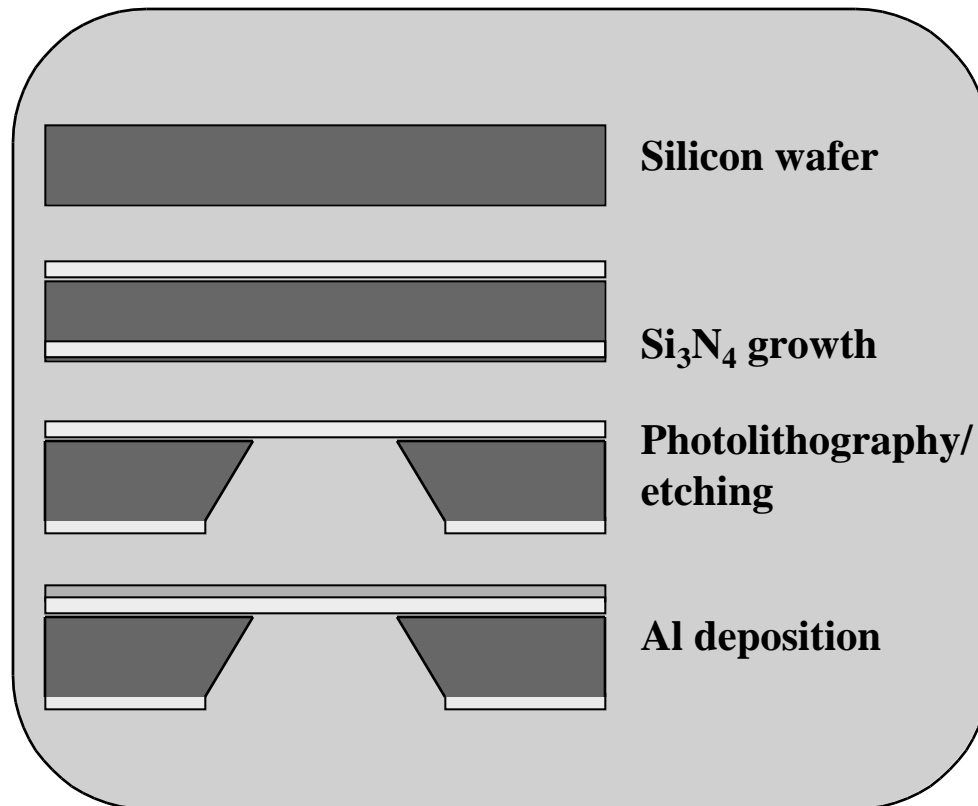
Asymptotically as $kh \sim 0$, the phase velocity for the two lowest order modes become:

$$v_{so} = \frac{\omega}{k} = \sqrt{\frac{C^*}{\rho^*}}$$

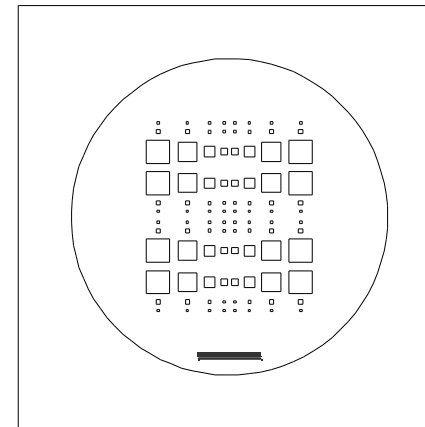
$$v_{ao} = \frac{\omega}{k} = \sqrt{\frac{D^*}{\rho^*} (kh)^2 + \frac{\sigma_x}{\rho^*}}$$

where C^* , D^* and ρ^* are the composite elastic stiffness, flexural rigidity and density respectively, and σ_x is the average residual stress in the film.

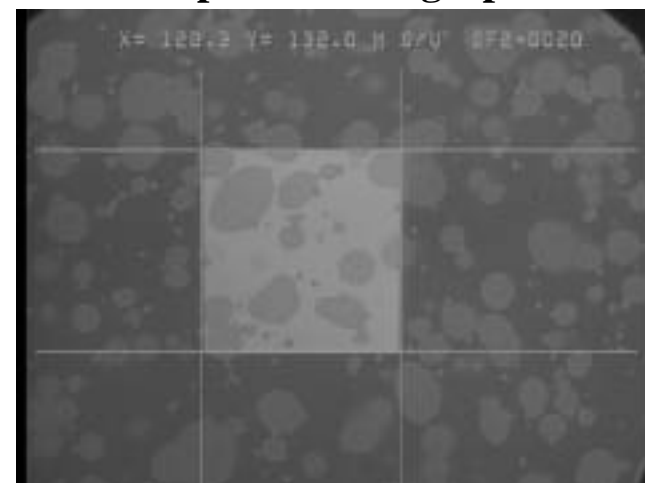
Microfabrication of two-layer thin films



Photomask

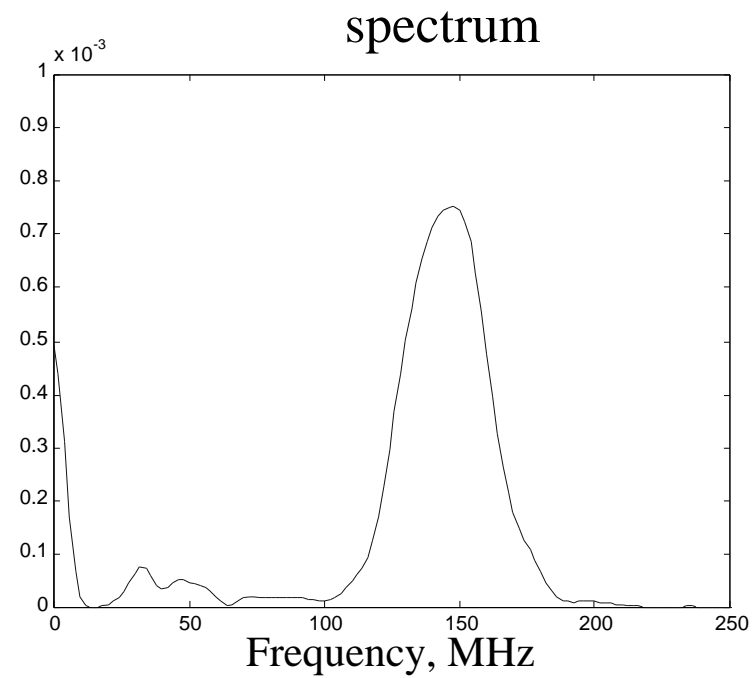
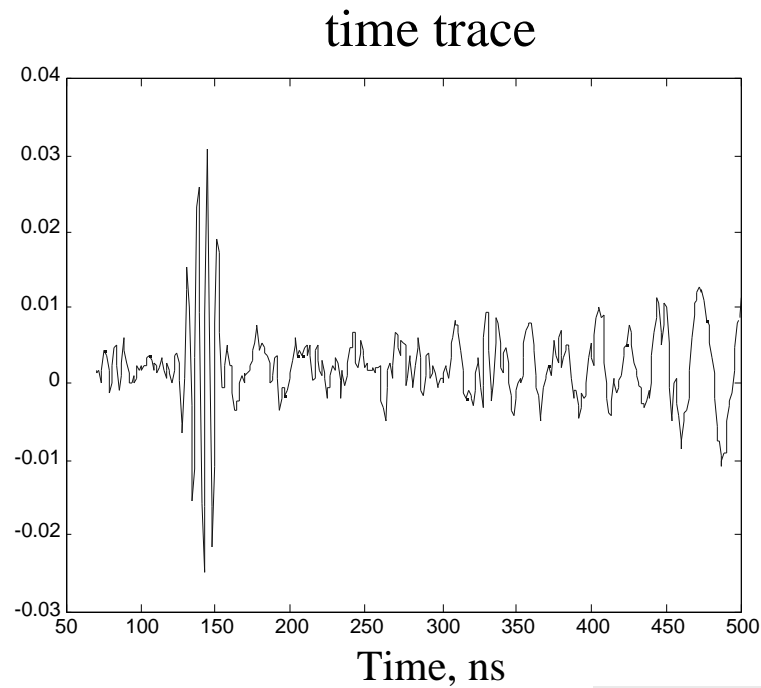


Optical Micrograph



S_o - mode on aluminum / silicon-nitride

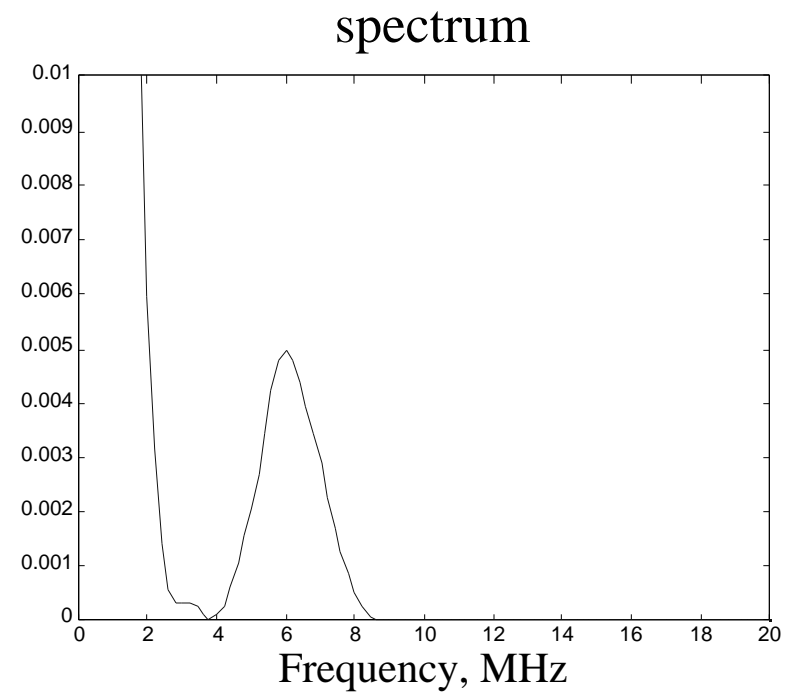
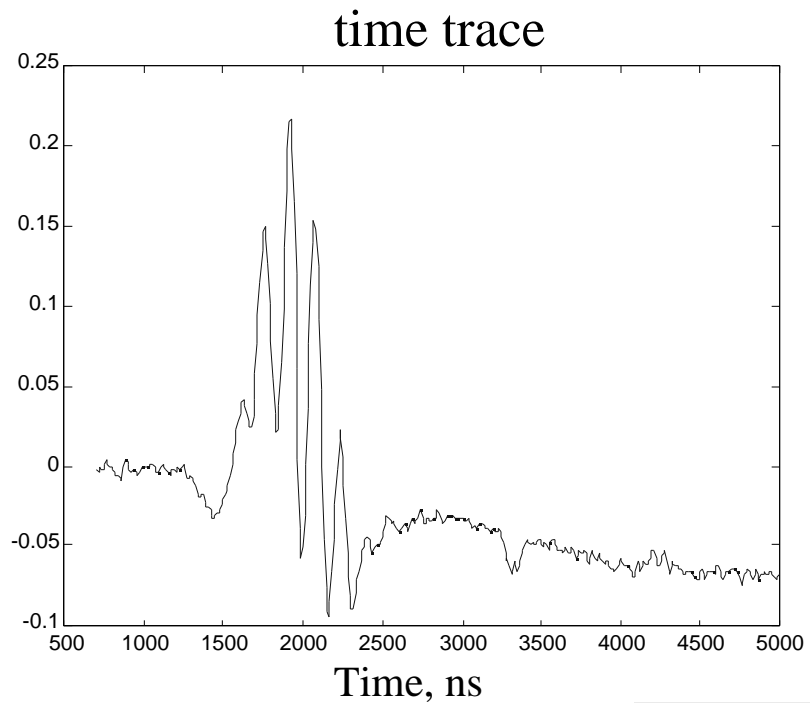
Specimen: 420nm-Al/236nm-silicon nitride



$$v_{so}^{(m)}(k) = \frac{\omega(k)}{k}$$

A_o - mode on aluminum / silicon-nitride

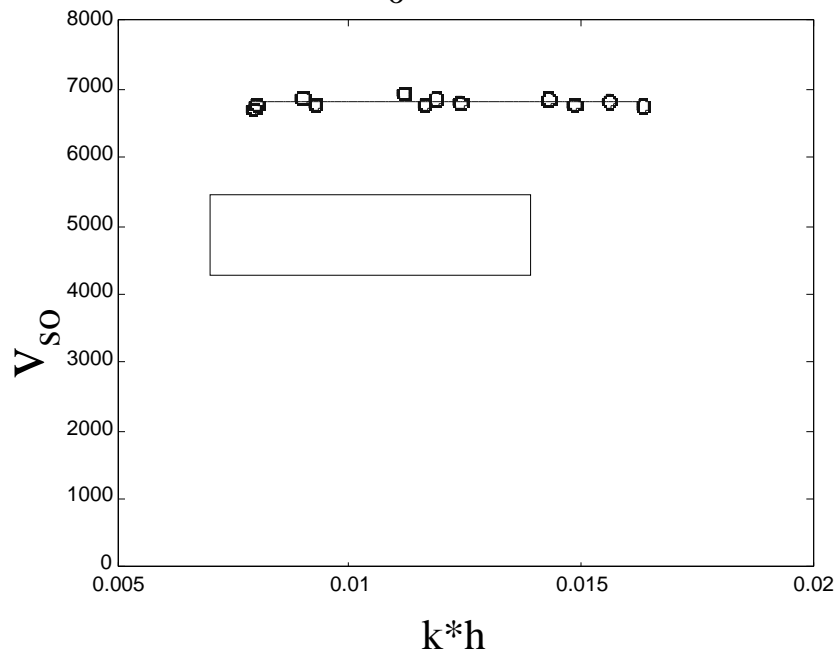
Specimen: 420nm-Al/236nm-silicon nitride



$$v_{ao}^{(m)}(k) = \frac{\omega(k)}{k}$$

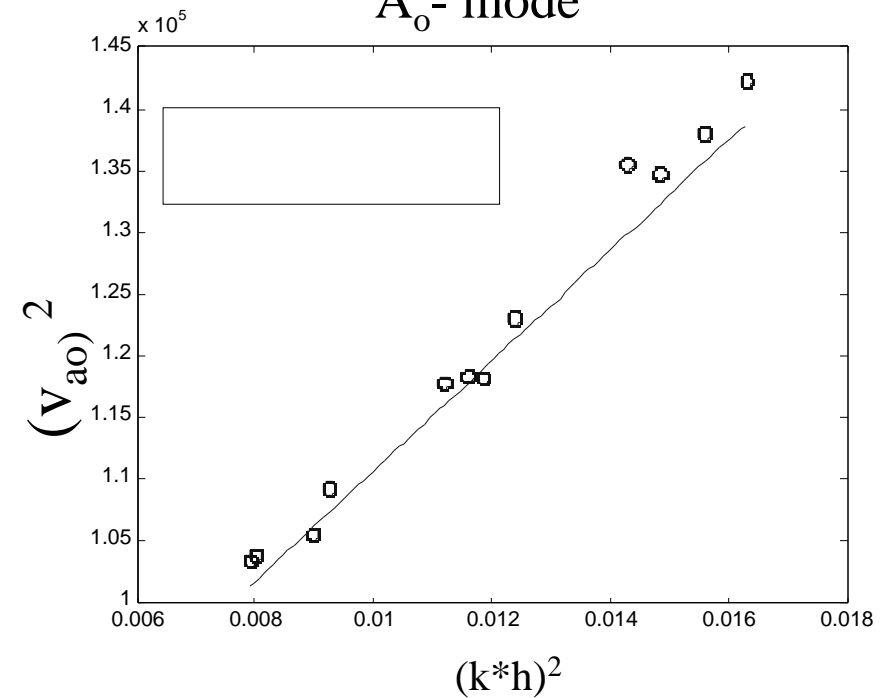
Dispersion curves for aluminum / silicon-nitride

S_o - mode



$$v_{so}^{(c)} = \sqrt{\frac{C^*}{\rho^*}}$$

A_o - mode

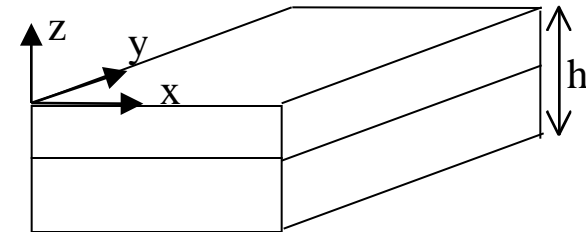


$$v_{ao}^{(c)} = \sqrt{\frac{D^*}{\rho^*} (kh)^2 + \frac{r_x}{\rho^*}}$$

Extraction of material properties from photoacoustic data

Error function:

$$\phi = \frac{\alpha}{M} \sqrt{\prod_{i=1}^M \left(1 - \frac{V_{ao}^{(m)}}{V_{ao}^{(c)}} \right)^2} + \frac{1-\alpha}{N} \sqrt{\prod_{i=1}^N \left(1 - \frac{V_{so}^{(m)}}{V_{so}^{(c)}} \right)^2}$$



Velocities:

$$v_{so}^{(c)} = \sqrt{\frac{C^*}{\rho^*}}$$

$$v_{ao}^{(c)} = \sqrt{\frac{D^*}{\rho^*} (kh)^2 + \frac{r_x}{\rho^*}}$$

Composite flexural rigidity:

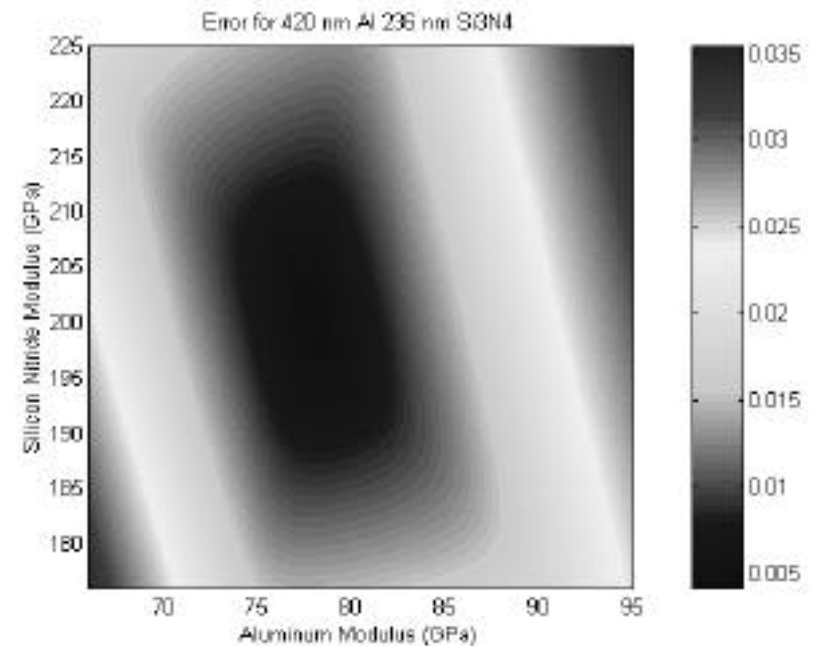
$$D^* = \frac{1}{h^3} \int_z \frac{E_k}{1 - \nu_k^2} z^2 dz$$

Composite reduced modulus:

$$C^* = \frac{1}{h} \int_z \frac{E_k}{1 - \nu_k^2} dz$$

Composite density:

$$\rho^* = \frac{1}{h} \int_z \rho dz$$



Extraction of material properties from photoacoustic data

MATERIAL	THICKNESS (nm)	MEASURED YOUNG'S MODULUS (MPa)	MEASURED RESIDUAL STRESS (MPa)
Aluminum Si ₃ N ₄	420 236	82 192	176
Aluminum Si ₃ N ₄	510 250	48 268	225
Aluminum Si ₃ N ₄	510 397	47 235	360

Conclusion

- **Photo-acoustic microscopy:**

- non-contact
- nondestructive
- small optical footprint
- film support conditions need not be known

- **Photo-acoustic data:**

- guided-wave dispersion curve
- S_0 - mode is non-dispersive and is independent of residual stress
- A_0 - mode is dispersive and depends on residual stress

- **Materials characterization:**

- Young's moduli
- residual stresses