Photolithography-based realization of Frequency Steerable Acoustic Sensors on PVDF substrate

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Outline

- Guided-wave based directional sensing
- Frequency Steerable Acoustic Transducers (FSATs)
- FSAT fabrication
- Experiments
- Conclusions
Structural Health Monitoring (SHM)

Guided Waves (GW) vs. Ultrasonic scanning

- Long-distance inspection
- Fast
- Low cost
- Embedded applications
- Local inspection
- Time-consuming
- Expensive
- Offline inspection

Offside crack

Aluminum plate specimen with PWAS array
Directional inspection: phased arrays

- Many, individually controlled elements
- Associated circuitry (wiring, multiplexing,..)
- Signal processing

Li and Rose, IEEE TUFFC 48:3 (2001)


Yu and Giurgiutiu, Ultrasonics 48:2 (2008)

Silva et al., DAMAS 2011
Inherently directional devices

- Still several channels
- Bandwidth/angular resolution limitations

Salas and Cesnik, Sm. Mat. Str. 18 (2009)
Matt and L. di Scalea, Sm. Mat. Str. 16 (2007)
Frequency-steerable directivity

\[ \mathcal{D}[u(x, \omega)] = g(x, \omega) \]

- Differential operator
- Displacement field
- Load distribution

Harmonic GW propagation in a plate-like structure

\[ \hat{u}(k, \omega) = \hat{D}^{-1}(k, \omega) \hat{g}(k, \omega) \]

Solution in wavenumber domain

Maximization

\[ \hat{D}(k, \omega) = 0 \rightarrow \text{Dispersion relation of the medium} \]

\[ \max_{k,\omega} \hat{g}(k, \omega) \rightarrow \text{Maxima of the load distribution} \]

Maximum radiation/sensing conditions
Spiral-shaped load distribution

\[ \hat{D}(k, \omega) = 0 \]

Dispersion branch

\[ \omega' = 2\pi f' \iff k' \iff \theta' \]
Spiral-shaped load distribution

\[ \hat{D}(k, \omega) = 0 \]

\[ \omega'' = 2\pi f'' \iff k'' \iff \theta'' \]
Spiral FSAT design

[2] Senesi et al., to appear in JASA
Photolithography-based realization

- **Preparation**
  - PVDF
  - Carrier wafer

- **Resist coating**
  - Positive photoresist

Metal
Photolithography-based realization

Mask

Photolithography

Development & Wet etching
Photolithography-based realization

- Stripping
- Flip sensor & Repeat on the back electrode
- Transparent carrier wafer
PVDF prototype.

FSAT design including contact connections
Experimental setup
Pitch-catch imaging

FSAT signal

WFT

Warped signal

STFT

Warped spectrogram

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Cleanroom FSAT performance

Angular resolution better than 10° at 300mm from the sensor
Multi-sensor combination

Imaging of plate boundaries

- Mirror images (180° uncertainty)

Combined source imag.

- Full 360° capabilities
Conclusions

- FSAT geometry provides spatial filtering and hence directional sensing
- 2D imaging with a single FSAT signal
- Photolithography fabrication on PVDF
- Low hardware & software complexity enable in-situ and wireless SHM
Thank you for your attention!

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