Introduction to acoustic wave sensors

Acoustic wave sensors are extremely versatile devices that are just beginning to realize their commercial potential. They are competitively priced, inherently rugged, very sensitive, and intrinsically reliable, and can be interrogated passively and wirelessly. Sensors that require no operating power are highly desirable for remote monitoring of chemical vapors, moisture, and temperature. Surface acoustic wave (SAW) sensors have proved to be the most sensitive in general as a result of their larger energy density on the surface. For liquid sensing, a special class of shear-horizontal surface acoustic wave sensors called Love wave sensors proved to be the most sensitive. Much work is continuing in developing these sensors for future applications.

DESIGN CONSIDERATIONS FOR AN ACOUSTIC WAVE SENSOR:

Several design considerations must be satisfied when selecting and applying the chemically sorptive coating. Ideally, the coating is completely reversible, meaning that it will absorb and then completely desorb the vapor when purged with clean air. The rate at which the coating absorbs and desorbs should be fairly quick, for instance, less than 1 second.

<u>Some requirements for material coating:</u>

- robust enough to withstand corrosive vapors;
- selective, absorbing only very specific vapors while rejecting others;
- operate over a realistic temperature range;
- stable, reproducible, and sensitive;
- its thickness and uniformity are very important.

When several SAW sensors, each with a unique chemically specific coating, are configured as an array, each will have a different output when exposed to a given vapor. Pattern recognition software allows a diverse list of volatile organic compounds thus to be detected and identified, yielding a very powerful chemical analyzer. For instance, a simple handheld SAW chemical vapor analyzer can incorporate an array of four SAW sensors, each coated with a different polymer. By coating a SAW device with a chemically sorptive polymer, a chemical vapor sensor is made. Adding another SAW device minimizes the temperature drift and provides a manageable difference frequency.

ACOUSTIC WAVE SENSORS

Mass Sensor. It is thought that SAW sensors are the most sensitive to mass loads. This opens up several applications including particulate sensors and film thickness sensors. If the sensor is coated with an adhesive substance, it becomes a particulate sensor; any particle landing on the surface will remain there and perturb the wave propagation. Particulate sensors are used in cleanrooms, air quality monitors, and atmospheric monitors.

Thickness sensors operate on basically the same principle as particulate sensors, except that they are not coated. The measured frequency shift is proportional to the mass of the deposited film, so the sensor provides thickness data by measuring the film density and acoustic impedance. This method is accurate, provided that the film is thin (ideally no more than a few percent of the acoustic wavelength) [18]. Most commercially available thickness sensors are based on TSM resonators. Although not so sensitive as SAW sensors, these devices offer ease of use and adequate sensitivity.

Dew Point/Humidity Sensor. If a SAW sensor is temperature controlled and exposed to the ambient atmosphere, water will condense on it at the dew point temperature, making it an effective dew point sensor. Acoustic wave sensors with an elastic hygroscopic polymer coating make excellent humidity detectors. Three operational mechanisms contribute to the sensors' response: mass loading, acoustoelectric effects, and viscoelastic effects, each of which can be effectively controlled to yield an accurate, low-cost, humidity sensor. Also, a SAW sensor has been used as a remote water sensor, and a Love wave sensor has also been demonstrated as an ice sensor.

Vapor Chemical Sensor—Coated and Uncoated. Chemical vapor sensors based on SAW devices were first reported in 1979 [24]. Most of them rely on the mass sensitivity of the detector, in conjunction with a chemically selective coating that absorbs the vapors of interest and results in an increased mass loading of the device. As with the temperature-compensated pressure sensors, one SAW is used as a reference, effectively minimizing the effects of temperature variations. Thickness shear mode (TSM) resonators have also successfully been used for chemical vapor sensing, but they are significantly less sensitive than their SAW counterparts. In addition, SAW chemical vapor sensors have been made without coatings. This method uses a gas chromatograph column to separate the chemical vapor components, and a temperature-controlled SAW that condenses the vapor and measures the corresponding mass loading.

Biosensor. Similar to chemical vapor sensors, biosensors detect chemicals, but in liquids rather than vapors. Biosensors have been fabricated using the TSM resonator, SH-APM, and SH-SAW sensors. Of all the known acoustic sensors for liquid sensing, the Love wave sensor, a special class of the shear-horizontal SAW, has the highest sensitivity. To make a Love wave sensor, a waveguide coating is placed on a SH-SAW device such that the energy of the shear horizontal waves is focused in that coating. A biorecognition coating is then placed on the waveguide coating, forming the complete biosensor.

International Institute of Zakharenko Waves

STUDYING SUBJECTS

- Love type waves
- Dispersive Bleustein-Gulyaev waves
- Dispersive Rayleigh waves
- Lamb type waves
- Interfacial Maerfeld-Tournois waves
- Interfacial Stoneley waves
- Leaky Sezawa waves
- Bulk acoustic waves

APPLICATIONS

- Filters
- Sensors
- Dispersive delay lines
- Non-destructive testing
- Structural health monitoring
- CMUTs-MEMS
- NEMS
- Magnetoelectric devices
- Optical devices

International Institute of Zakharenko Waves

RECENT DISCOVERIES

- Ultrasonic interfacial Zakharenko waves
- Ultrasonic surface Zakharenko waves
- First and second types of slow surface Zakharenko waves
- Non-dispersive Zakharenko waves
- Leaky Zakharenko waves

APPLICATIONS

- Filters
- Sensors
- Dispersive delay lines
- Non-destructive testing
- Structural health monitoring
- CMUTs-MEMS
- NEMS
- Magnetoelectric devices
- Optical devices
- Quantum devices

OTHER DISCOVERIES AND POSSIBILITIES

- New non-dispersive supersonic surface acoustic waves (SAWs) with the in-plane polarization and the phase velocity V_{ph} about V_L
- Dispersive and non-dispersive supersonic SAW latent solutions with the in-plane polarization and the phase velocity V_{ph} about V_L
- Dispersive and non-dispersive surface-wave latent solutions with polarization perpendicular to the sagittal plane and the phase velocity V_{ph} below V_t
- Supersonic Love type waves
- Existence of dispersive Rayleigh type waves in the phase velocity range $V_{ph1} < V_{ph} < V_{ph2}$, where V_{ph1} and V_{ph2} are velocity equivalents appearing due to the crystal anisotropy
- The non-dispersive Zakharenko waves in the fundamental modes of Lamb type waves for crystals with the anisotropy term $C^2 < 0$
- Unusual behavior of some LTW7-modes for shorted surface

Materials for computer simulations

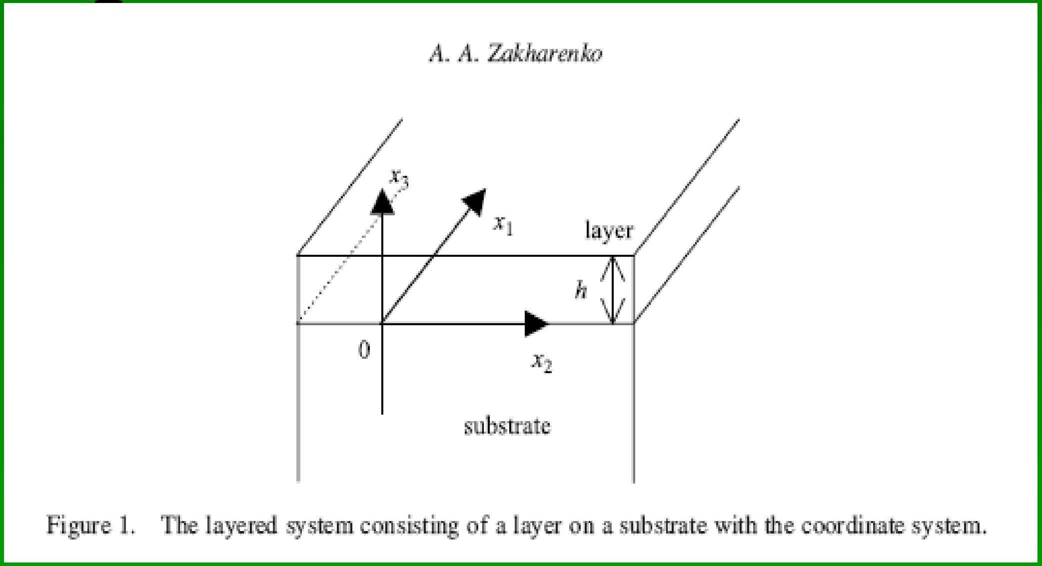
A. A. Zakharenko

Figure 1. The layered system consisting of a layer on a substrate with the coordinate system.

- Dielectrics
- Metals
- Piezoelectrics
- Piezomagnetics
- Complex systems such as layered and quantum systems
- Materials with complex structure: perovskites, spinel, etc.

Supersonic Love type waves

- Materials for the layer: Gold, Silver, Diamond
- Materials for the substrate: Biotite, Phlogopite, Muscovite

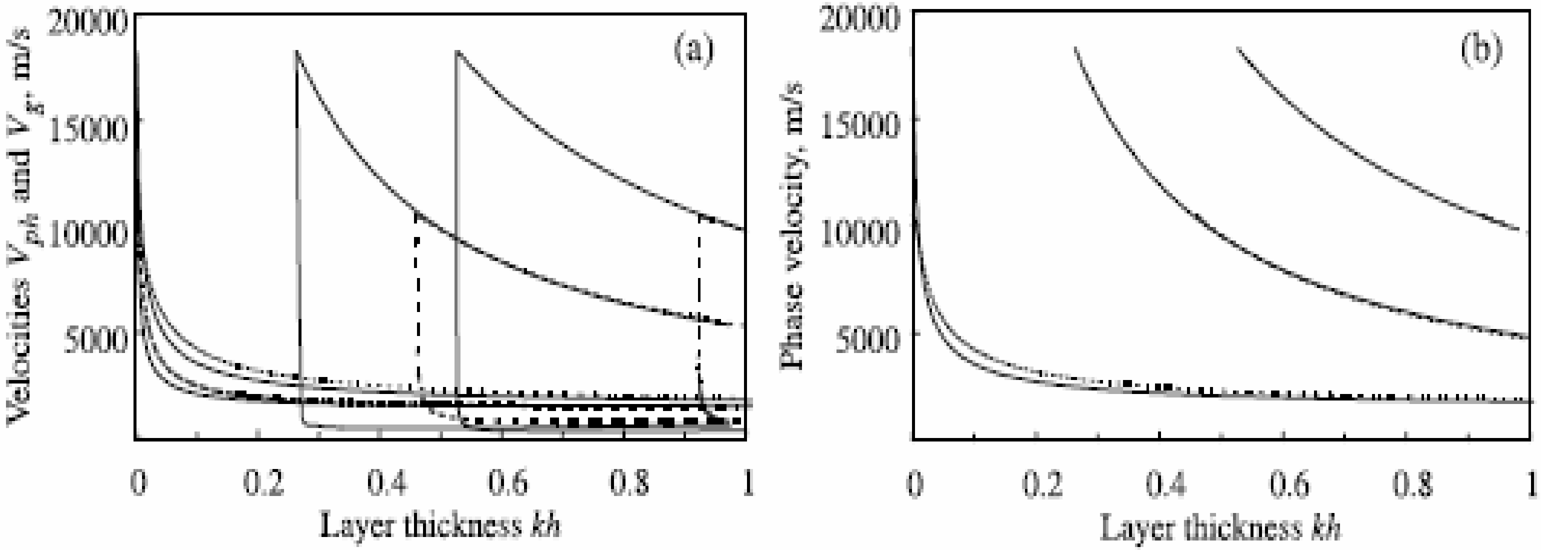

Figure 2. (a) The phase (normal lines) and group (bold) velocities for three modes of dispersive LTW3-waves for the layered systems: Au/Biotite (solid) and Au/Muscovite (dashed); (b) the phase velocity for three modes of dispersive non-surface waves for the layered systems: Au/Biotite (solid lines) and Au/Muscovite (dashed lines).

Supersonic Love type waves

A.A. Zakharenko, Non-destructive Testing and Evaluation, 2005.

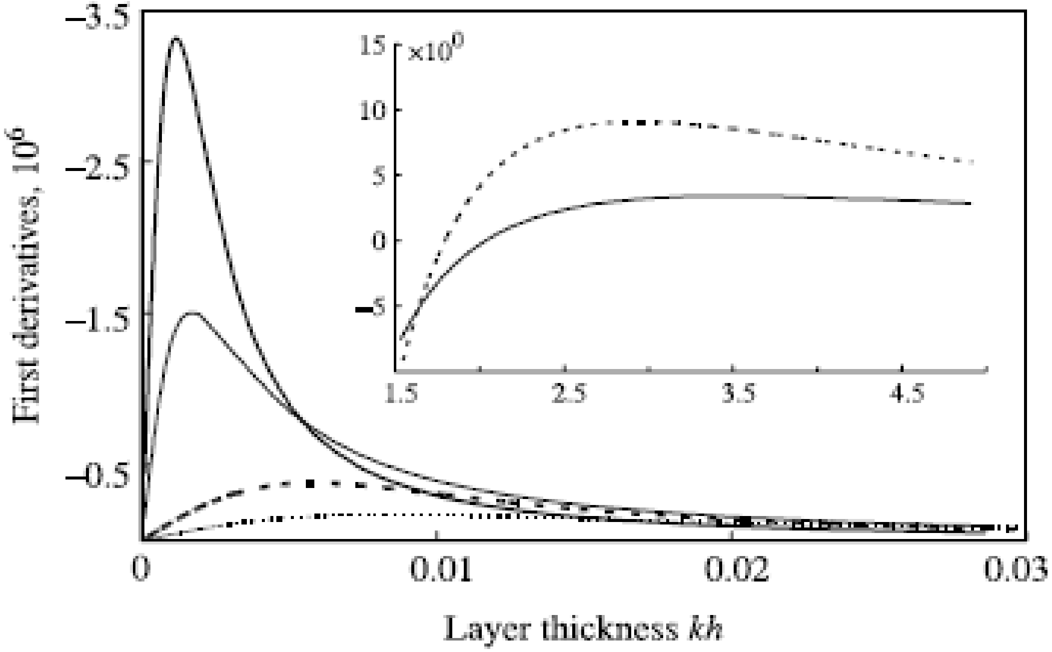

Figure 6. The first-order derivatives of both the phase (normal lines) and group (bold) velocities for the first mode of dispersive LTW3-waves for the structures: Au/Biotite (solid) and Au/Muscovite (dashed). The insertion shows the group velocity derivatives.

Supersonic Love type waves

A.A. Zakharenko, Non-destructive Testing and Evaluation, 2005.

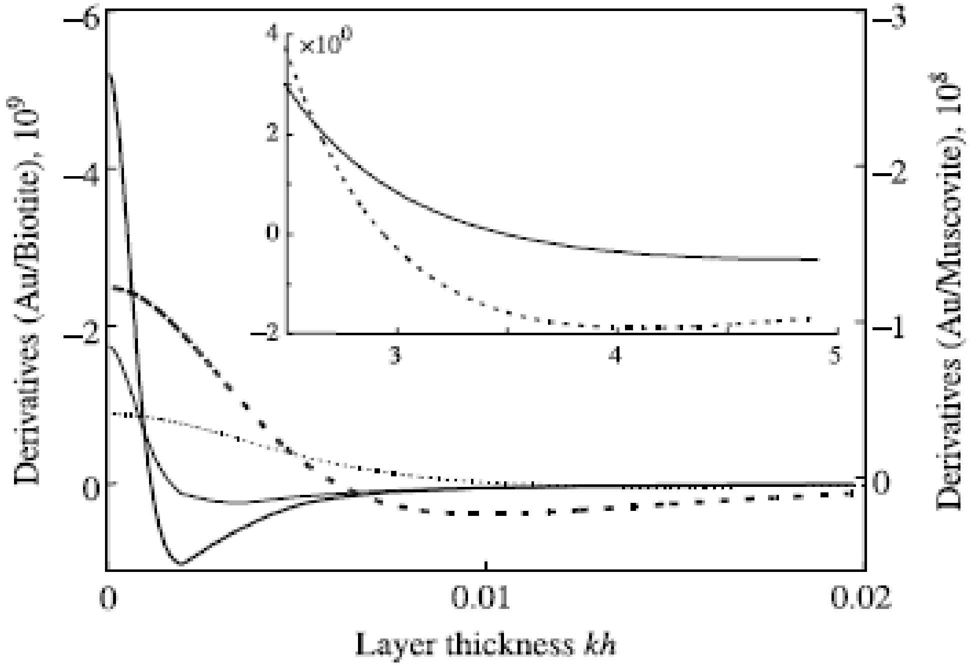

Figure 7. The second-order derivatives of both the phase (normal lines) and group (bold) velocities for the first mode of dispersive LTW3-waves for the structures: Au/Biotite (solid) and Au/Muscovite (dashed). The insertion shows the group velocity derivatives.

Slow surface Zakharenko waves

A.A. Zakharenko, Non-destructive Testing and Evaluation, 2005.

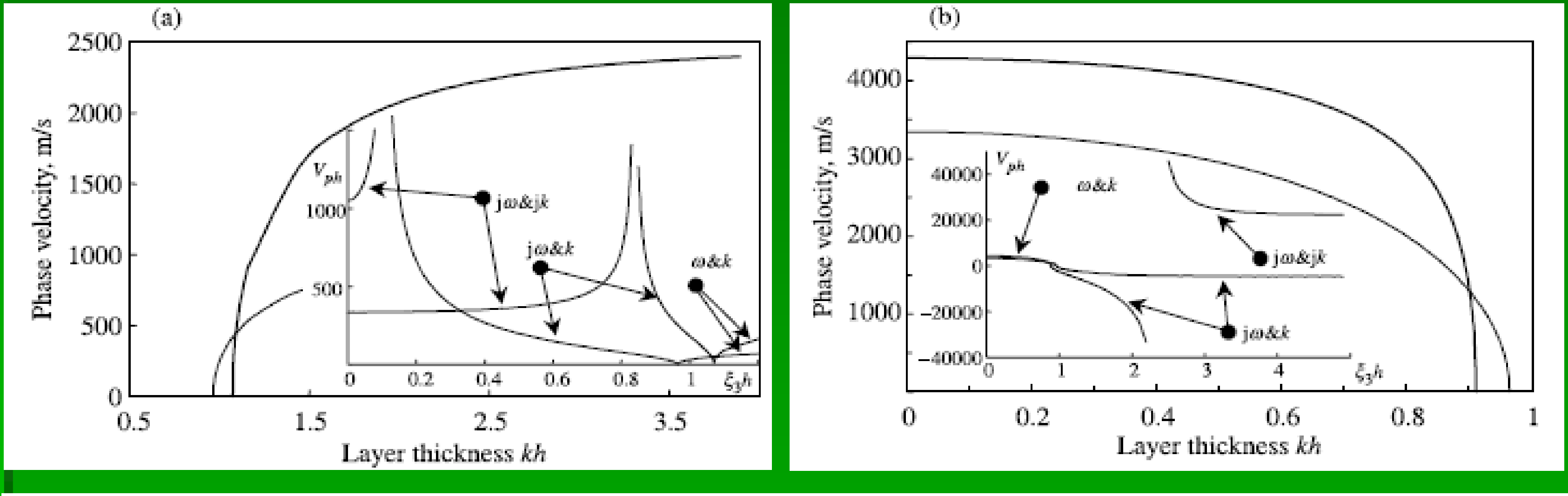

Figure 4. The phase velocity V_{ph} for the other solutions of dispersive waves for two possible cases: (a) equation (17) for the structures Au/Muscovite (normal line) and Cu/GaAs (bold line); (b) equation (19) for the structures Si/GaAs (normal line) and Si/Hedenbergite (bold line). The corresponding insertions show the dependencies $V_{\mathrm{ph}}(\xi_3 h)$.

SENSITIVITY OF SENSORS

The mass sensitivity *Sv* can be obtained from dispersion relations, i.e. from dependence of the phase velocity *Vp* on the non-dimensional value of *kh*, where *h* is the layer thickness, and *k* is the wavenumber; *ρ* is the material density.

$$S_v = \frac{1}{v_p}\frac{\mathrm{d}v_p}{\mathrm{d}(h_m\rho_m)}.$$

$$\lambda S_v = \frac{2\pi}{\rho_m v_p}\frac{\mathrm{d}v_p}{\mathrm{d}(kh_m)}.$$

FUTURE WORK

FURTHER RESEARCH

- Ultrasonic interfacial Zakharenko waves in cubic piezomagnetics
- Ultrasonic surface Zakharenko waves in cubic piezomagnetics
- First and second types of slow surface Zakharenko waves in piezoelectrics and piezomagnetics
- Non-dispersive Zakharenko waves
- Composites consisting of piezoelectric and piezomagnetic cubic materials for magnetoelectric devices
- Etc.
- Collaborative experimental investigations: developing new devices and using new materials