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Metamaterial Inspired New Class of Ultrasonic Shear Horizontal (SH) Surface Wave Sensors with Extremely Large Mass Sensitivity

Background, Motivation and Objective

The goal of this work was to search for an ultrasonic sensor with the highest possible mass sensitivity S_σ^v. So far, ultrasonic sensors that use classical surface acoustic Love waves have the highest mass sensitivity. The search for ultrasonic sensors with the highest possible mass sensitivity led the author to the discovery of a new type of shear horizontal (SH) Love-like elastic surface waves that propagate in a layered waveguide composed of an elastic surface layer deposited on a metamaterial elastic substrate with special properties, i.e., with negative shear elastic compliance $s_{44}(\omega) < 0$, (see Fig. a). The practical realization of negative compliance $s_{44}(\omega) < 0$ which follows the Drude model is presented in the paper (Sensors, 2023, 23, 9878, doi.org/10.3390/s23249879).
The discovered new (Love-like) SH surface waves have only one transverse component of the mechanical displacement, which attains its maximum at the interface between the surface layer and the metamaterial substrate (see Fig. a). The amazing property of the newly discovered (Love-like) SH waves is that they have an extremely high mass sensitivity, e.g., 10 times greater than the classical Love waves, which have the highest mass sensitivity to date. Also, the phase and group velocity of the new wave tend to zero as the frequency ω runs to the cut-off frequency ω_{sp}. A key property of the newly discovered SH surface ultrasonic waves is their ability to break the diffraction limit, which allows acoustic energy to be concentrated in a region near the surface smaller than the wavelength (e.g., of the order of $\lambda/10$).

Statement of Contribution/Methods

Employing the equations of motion, constitutive equations and appropriate boundary conditions on the waveguide surface and at the interface of the surface layer with the metamaterial substrate, we developed analytical formulas for the dispersion relation, phase velocity v_p and group velocity v_{gr} of the new (Love-like) SH surface elastic wave, propagating in the metamaterial waveguide. The optimum surface layer thickness h giving the highest mass sensitivity S_σ^v was evaluated and will be presented at the IUS.

Results/Discussion

We have shown that the newly discovered (SH) surface acoustic waves can propagate on the surface of an elastic layer deposited on an elastic metamaterial substrate which has negative shear elastic compliance $s_{44}(\omega) < 0$. As a consequence, the discovered new (Love-like) surface acoustic waves can exhibit extremely large sensitivity to the mass load σ of the guiding surface. The dispersion relation (see Fig. b), phase and group velocity and mass sensitivity, as a function of frequency ω, were calculated and will be presented at the Symposium. Numerical calculations were performed for an exemplary waveguide structure based on a PMMA surface layer deposited on a Quartz substrate with built-in local oscillators. The wave frequency ranges from a few kHz to several MHz. We have shown that the use of metama-terials to fabricate ultrasonic waveguides opens new exciting possibilities for the design and optimization of a new class of SH ultrasonic sensors, biosensors and chemosensors with extremely large mass sensitivity S_σ^v and extraordinary applications.