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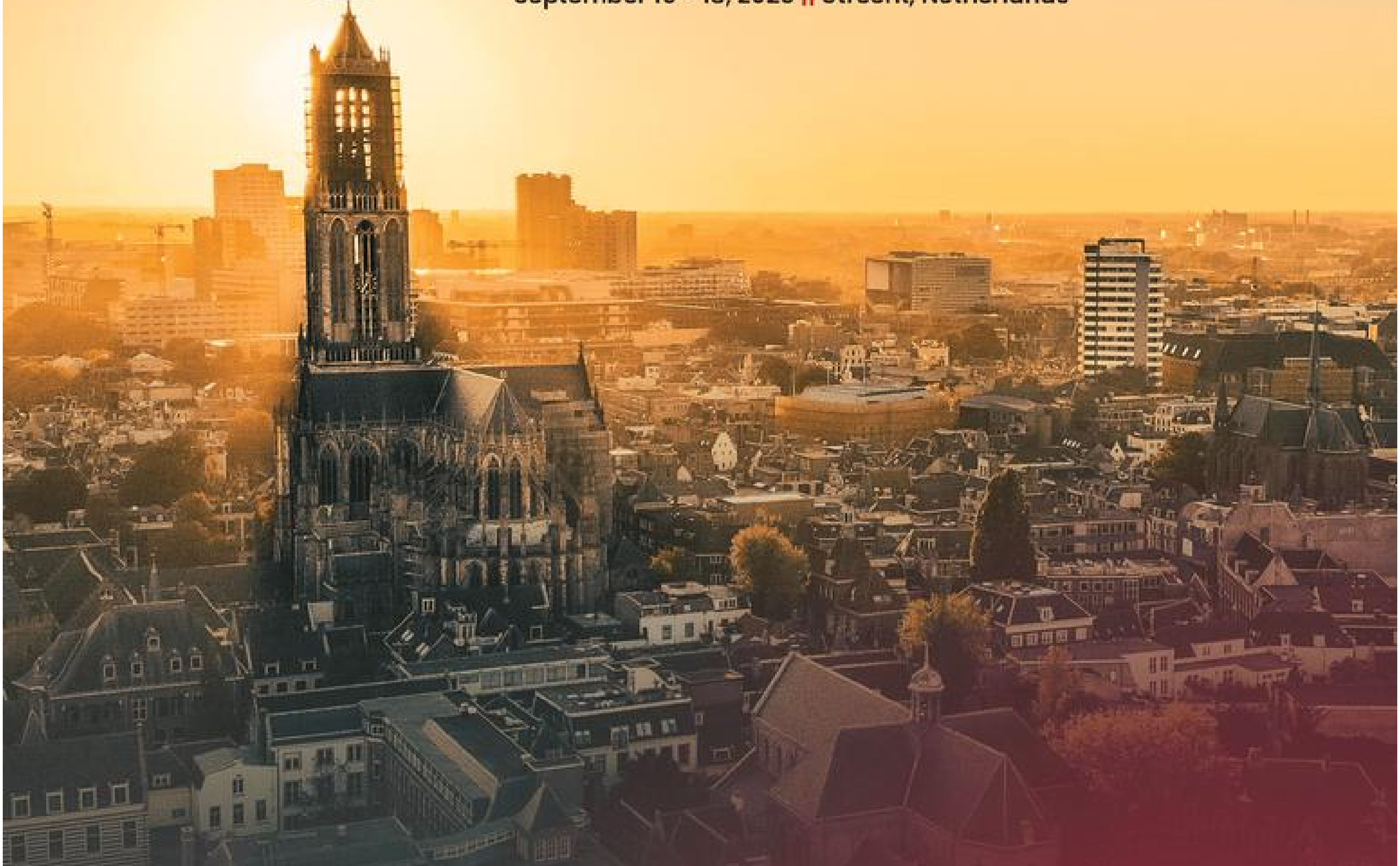

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Recent Discovery of a New Class of Surface Elastic Waves Enabling Breaking the Diffraction Limit, Superresolution and Sensors with Giant Sensitivity

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Background, Motivation and Objective

The goal of this work is to present (discovered by the author) a new type of ultrasonic surface waves with an extraordinary properties, i.e., 1) ability to break the diffraction limit, 2) ability to amplify evanescent waves, 3) super-resolution and 4) giant mass sensitivity.
Such amazing properties can be achieved by using elastic metamaterials with negative elastic compliance $s_{44}(\omega) < 0$. The layered waveguide, where the newly discovered wave propagates comprises of a conventional elastic surface layer deposited on a metamaterial elastic substrate with negative $s_{44}(\omega) < 0$, see Fig. a. The discovered new (Love-like) SH surface wave has only one SH component of the mechanical displacement, which reaches 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., 100 times greater than the classical Love waves, which have the highest mass sensitivity to date (of the order of $1000\ m^2/kg$). 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 mass sensitivity of the group velocity $S_\sigma^{v_{gr}}$, see Eq.2, the dispersion equation, see Eq.1 and Fig. b, and group velocity v_{gr} of the new (Love-like) SH surface elastic wave.

Results/Discussion

The author developed the analytical formula for the dispersion equation of the new surface wave, (Eq.1): Subsequently, the author has established the analytical expression for the mass sensitivity of the group velocity, see Eq.2: velocity, see Eq.2:

$$\boxed{tanh(n1\cdot h)\cdot\left\{\left(c_{44}^{(1)}\cdot n1\right)^2-(\sigma\cdot\omega^2)\cdot\left(c_{44}^{(2)}\cdot b\right)\right\}+\left(c_{44}^{(1)}\cdot n1\right)\cdot\left\{\left(c_{44}^{(2)}\cdot b\right)-(\sigma\cdot\omega^2)\right\}=F(k,\omega,\sigma)=0} \quad (1)$$

$$\boxed{S_\sigma^{v_{gr}}=\frac{1}{v_{gr}}\left(\frac{dv_{gr}}{d\sigma}\right)=\frac{1}{\frac{d\omega}{dk}}\cdot\frac{d}{d\sigma}\left(\frac{d\omega}{dk}\right)=\frac{1}{\frac{d\omega}{dk}}\cdot\left\{\frac{\partial^2F/\partial k\partial\sigma\cdot\partial F/\partial\omega-\partial F/\partial k\cdot\partial^2F/\partial\omega\partial\sigma}{\partial^2F/\partial k\partial\omega\cdot\partial F/\partial\omega-\partial F/\partial k\cdot\partial^2F/\partial\omega^2}\right\}} \quad (2)$$

Using Eqs.1-2, we plotted $S_\sigma^{v_{gr}}$ versus the thickness h, see Fig c. Numerical calculations were performed for a structure based on a PMMA surface layer and a Quartz substrate with built-in local oscillators. The maximum mass sensitivity $S_\sigma^{v_{gr}}$ reaches $241\ 000\ m^2/kg$, see Fig. c. This extremely large mass sensitivity will enable the detection of objects as small as a single hydrogen atom (H). We have shown that the use of metamaterials 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. a) b) c)