

Finite element modeling, design and characterisation of SAW transducers for acoustofluidic systems

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Summary:

The aim of our work is to design an interdigital electrode that generates standing waves on a Lithium niobate substrate and enables particle separation in a fluidic channel in the particle range below 4 μm . Before manufacturing the actual fluidic device, the frequency dependence of the designed electrode and the position of the nodes and anti-nodes created by the standing waves excited on the surface were tested FEM simulation using COMSOL code.

Keywords: microfluidic system, particle separation, standing acoustic wave, lithium niobate, FEM simulation

Acoustic waves in microfluidic applications

Among the active separation methods applicable to microfluidic particle separation, acoustophoresis is considered, in which migration can be induced by acoustic pressure waves, without affecting the viability of the applied cells. Surface acoustic waves are more common in microfluidic applications to manipulate flows and the suspended particles, generating droplets [1], enhancing reagent mixing, or managing cell focusing, separation, sorting or target concentration [2], respectively. Moreover, the SAW technology enable sensitive biological or chemical molecule detection.

The generated SAWs (such as Rayleigh waves, Leaky SAW, Love waves, Bleustein–Gulyaev waves) can be used for size dependent separation even in a submicron range [3]. G. Destgeer et al. [4] were able to separate polystyrene beads with a size resolution of only 200 nm (beads with a diameter of 3 μm and 3.2 μm). Shupeng Ning et al. [5] even performed standing surface acoustic waves (SSAWs) in a serpentine microfluidic channels, and separated *E. coli* bacteria from human RBCs achieving 92.7% purity besides high flow rate.

The advantages of the method are its label-free and contact-free characteristics, and the cells can be focused in physiological solutions without dilution. In terms of reliability and robustness, the method is not extremely sensitive to the composition of the medium, and the vulnerability of living cells is not critical either, since the

negligible deflection is performed using acoustic pressure waves.

The method can be widely used for particle capture, but the primary objective is the separation of bacteria from urine from a fairly large sample volume (500 μl). In this case not only the different sizes of the variously shaped elements of urine pose a challenge (60 μm - 1 μm), but also the tight time frame in which the filtration and separation must be performed.

Generation acoustic waves

The acoustic wave theory can describe the formation of bulk (BAW) and surface acoustic waves (SAW) in piezoelectric materials. The SAW waves travel in the surface region, while the BAW waves propagate vertically in the bulk material. The BAW devices are typically used in the higher frequency range over 2 GHz, although for formation surface acoustic waves, the moderated (10 MHz - 1 GHz) frequencies are applicable.

The piezoelectric materials most popularly used in SAW devices include quartz, lithium tantalate (LT, LiTaO_3) and lithium niobate (LN, LiNbO_3). Also preferred choices are gallium arsenide (GaAs), cadmium sulfide (CdS), zinc oxide (ZnO), lithium tetraborate ($\text{Li}_2\text{B}_4\text{O}_7$), and langasite ($\text{La}_3\text{Ga}_5\text{SiO}_{12}$). SAW devices today not just only utilise the waves propagated along the symmetric crystal, but rather different rotated cuts were discovered and gained popularity in various applications. The SAW related microfluidics application majority use 128° YX LN [6].

For wave generation primarily interdigital transducers (IDT) are used, which are mounted on a piezoelectric substrate. The design of the IDT is quite critical regarding the applications and the adequate propagation of travelling waves (SAW) or the development the required standing wave pattern in the microfluidic chamber.

In this work the design, fabrication and characterisation of an IDT structure are highlighted, considering its further integration in a microfluidic system. Finite element modelling was applied to define the frequency dependence of the designed electrode system for supporting the microfluidic design and integration.

Design considerations and modelling

An acoustic wavelength was selected considering the 40 μm periodicity of the interdigitated electrode system, having electrode widths and gaps of 10 μm , respectively, and a metal thickness of 200 nm. Considering the SAW phase velocity of LiNbO_3 ($v_{\text{SAW}}=3990$ m/s), the expected resonance frequency can be estimated as (1):

$$f = \frac{v_{\text{SAW}}}{\lambda} \quad (1)$$

where $\lambda = 40$ μm and $f \approx 99.75$ MHz.

A single-unit-cell IDT geometry was implemented in COMSOL Multiphysics to evaluate the eigenfrequency spectrum of the device. The piezoelectric response was modelled coupling Solid Mechanics with Electrostatics. A rotated coordinate system was introduced to represent the crystallographic orientation of the 128° YX-cut LiNbO_3 substrate. Periodic boundary conditions were applied on the lateral boundaries of the unit cell, while a perfectly matched layer (PML) was introduced at the bottom boundary to suppress artificial wave reflections. The IDT electrodes were driven with an applied potential of 1 V. The material properties of LiNbO_3 were assigned according to literature values.

Results

Based on the numerical simulation two surface-localized SAW mode candidates were identified at 97.284 MHz and 98.314 MHz, corresponding to a symmetric and an antisymmetric mode shape, respectively (see Fig. 1).

The IDT systems of the SAW devices is fabricated on LiNbO_3 crystal using aluminium electrode materials, and the eigen frequencies are to be characterised by integrated detectors.

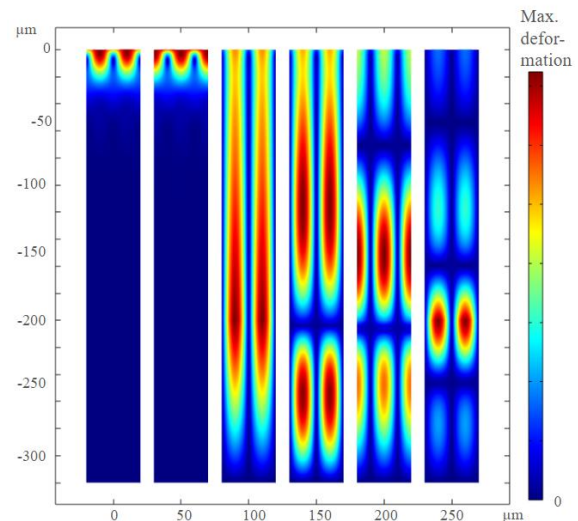


Fig. 1. Calculated eigenmodes visualized at different displacement scales. The first two modes correspond to the identified SAW candidates: the symmetric mode at 97.284 MHz and the antisymmetric mode at 98.314 MHz. The remaining modes are bulk acoustic modes with different nodal distributions, appearing at 101.90 MHz, 102.15 MHz, 102.67 MHz, and 103.38 MHz.

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