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# Implementation of guiding layers of surface acoustic wave devices: A review

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ABSTRACT

The purpose of overviewing research and development status of dependable, efficient, and portable and miniaturized surface acoustic wave (SAW) is to propose practical devices for biosensing and medical diagnosis. SAW Love-mode sensors fortunately have a great deal of attention during last two decades. Several periodic structure models of SAW devices were reviewed, especially interdigital transducers (IDTs), wave guiding layers, patterned-ZnO. SAW devices based on such periodic wave guiding layers and patterned-ZnO were demonstrated with superior performance, much better than conventional SAW devices. Both 2D and 3D models of phononic-crystal-based SAW devices can be respectively fabricated by an array of periodic cylindrical holes and pillars, which allowed SAW devices to have both higher *Q*-factor and GHz-level frequency. Ring waveguide and spherical SAW devices would have potential applications and implementation in biosensing. ZnO is one of attractive guiding-layer materials. Its nanostructures, such as nanowires, nanorods and nanofibers provided with excellent properties, will make nanoscaled SAW devices contribute to be much more sensitive in biosensors. A range of applications based on SAW and ZnO guiding-layer would be therefore expected among of immunochemical analysis, in-situ virus or bacteria determination, microfluidic automation, and cell manipulation.

## 1. Introduction

Acoustic-wave study began with earthquake waves through geological stratigraphic layers. A famous phenomenon was discovered by Love (1911). Since then, acoustic-wave technology and devices have attracted a great deal of attention in scientific community. Earthquake waves were divided into transverse and longitudinal, while acoustic waves seem to be differentiated into bulk acoustic wave (BAW) and surface acoustic wave (SAW). Sauerbrey (1959) first put forward a BAW device. White and Voltmer (1965) then reported a SAW device using interdigital transducers (IDTs) to generate SAW. Extensive investigations of SAW sensors were demonstrated afterwards. It is worth mentioning two milestone achievements. SAW sensors were utilized for a wide range of applications (Vellekoop, 1998) such as in viscosity, density, chemical and biochemical sensing. Especially, SAW Love-mode sensors with high sensitivity were used for detection of various analytes in liquid (Rocha-Gaso et al., 2009).

### *1.1. Principle of SAW sensor*

Both input and output IDTs of a SAW sensor are constructed by a metal thin film. A delay line is in the middle of both IDTs. Guiding layers are normally deposited on top of SAW substrate. SAW can be divided into Rayleigh and Love waves by propagation and vibration, as shown in Fig. 1. Input IDTS are responsible for generating a resonant frequency. If SAW propagation was perturbed, both changes of resonant frequency and attenuation are due to mass applied on delay-line surface, which are distinguishable at output IDTs. Acoustic energy is confined on Love's surface, due to a thin guiding layer at approximately one wavelength (Kabir et al., 2016). Love's sensor therefore has the higher resonant frequency, leading to much higher sensitivity (Rocha-Gaso et al., 2009).

### *1.2. Modelling and simulation*

There are still some theoretical issues to be further investigated and clarified to simplify complicated SAW models. Simulation has played a very valuable role in studying principle and methodology, especially biosensing applications. Piezoelectric, wave, and dispersion equations are important modelling and simulation means to analyze propagation properties of SAWs in substrates or overlaid structures. The investigation of operation frequency, mass sensitivity, phase velocity, electromechanical coupling of SAW devices requires simplified assumptions or numerical simulation methods (Powell et al., 2004). Finite element

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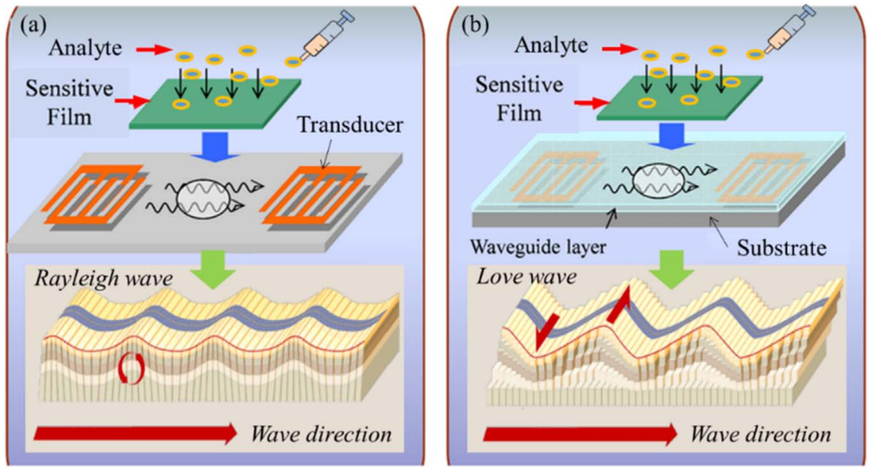


**Fig. 1.** SAW propagation: (a) Schematic of Rayleigh wave, having both surface-normal and surface-parallel components with respect to propagation direction (Thompson and Stone, 1997). (b) Schematic of shear-horizontal (SH) Love wave, an added guiding layer keeps most of SH vibration close to surface.

method (FEM) simulation can be therefore very essential and convenient for evaluation and fabrication of proposed SAW devices.

The number of degrees of freedom (DOF) would be extremely huge, when 2D and 3D models of FEM simulation were established for SAW devices. It is necessary to apply a simplified model, such as periodic boundary model (PBM), to reduce DOF and improve calculation efficiency. A complete and approximate model was used for simulation of a SAW device with guiding layers. The aim was to improve performance and optimize components structure. Exactly complete models depend on dispersion and micro perturbation theory, additionally to achieve accurate solution of Love wave. Such special and novel structures as periodic guiding layers (Qian et al., 2014), phononic crystals (PCs) (Pennec et al., 2010; Yankin et al., 2014) and nanostructures (Ozgur et al., 2010), were convenient to design and investigate by simulation platforms. However, it is difficult to fabricate these devices due to sophisticated experimental procedures.

SAW devices have played an important role in biochemical detection due to their high sensitivity and stability, especially Love-mode SAW devices immobilized various sensing elements for biosensing applications. Love-wave based biosensors will be promising for various applications in the future. Here, we briefly reviewed periodic theoretical models for SAW devices with different overlays and multiple elastic guiding layers, in Section 3. PCs models and complex structures were then introduced in Sections 4 and 5, respectively. Various guiding layers with sensing elements, such as ZnO nanostructures, graphene oxide (GO) and polymer, were summarized in Section 6. The preliminary applications for physical sensing, chemical sensing and biosensing were discussed in Section 7. Reviewing outline was illustrated in Fig. 2.

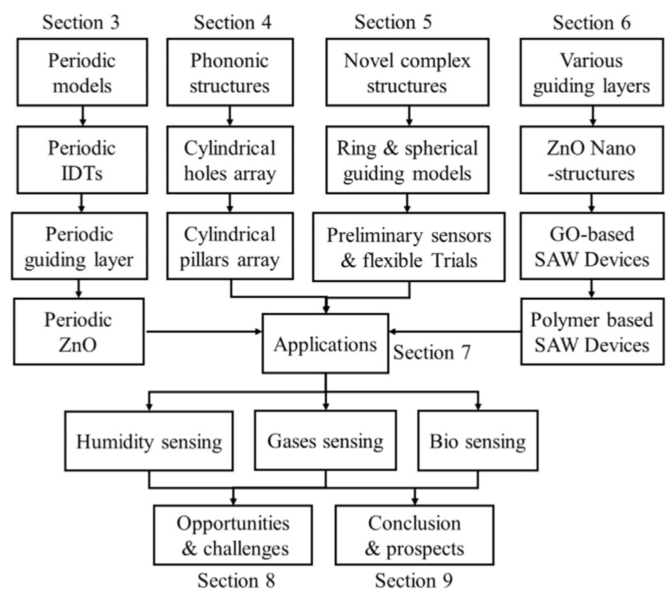


**Fig. 2.** Flow chart of reviewing outline.

## 2. Basic theory and performance parameters expression

SAW design based on IDTs and its properties were preferentially investigated by simulation. Common IDT model was an equivalent circuit model (Kino, 1987) as shown in Fig. 3(a) and coupling of mode (COM) (Chen and Haus, 1985). IDT equivalent circuit model was widely used for simulating SAW devices.

Major performance expressions of steady-state, frequency-domain and time-domain analysis are significant calculation methods implemented in scientific and commercial simulation software. Both ANSYS and COMSOL Multiphysics have been widely utilized to investigate proposed SAW devices. An aim for calculating parameters is to obtain mass sensitivity, electromechanical coupling coefficient (ECC, $K^2$), and *Q*-factor.

### 2.1. Mass sensitivity

Mass loading sensitivity can be defined as a relative change of oscillation frequency due to mass loading on SAW surface, as depicted in Eq. (1)

$$S_m = \frac{1}{f_0}\lim_{\Delta m\to 0}\frac{\Delta f}{\Delta m} \quad (1)$$

where $f_0$ is operational frequency without mass loading, $f$ is operational frequency with $\Delta m$, $\Delta f = f_0 - f$.

### 2.2. ECC

ECC is a measure and of the degree of SAW coupling with IDTs, obtained as followed:

$$K^2 = 2\frac{\Delta v}{v} = 2\frac{|v_s - v|}{v} \quad (2)$$

where $v$ is SAW phase velocity , $v_s$ is SAW phase velocity of electrical short, $\Delta v = v - v_s$.