SH wave velocity in a ZnO piezoelectric semiconductor layered structure under initial stress

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1. INTRODUCTION & OBJECTIVE

Piezoelectric materials, including ceramics, crystals, and polymers, serve as vital components in electromechanical transducers, facilitating the conversion of mechanical energy to electrical energy (direct piezoelectric effect) and vice versa (inverse piezoelectric effect)[1, 2, 3, 4]. Piezoelectric materials are commonly regarded as dielectrics, despite some being semiconductors. In piezoelectric crystals, acoustic wave propagation involves an accompanying electric field, stemming from the material's intrinsic piezoelectric properties. On the other hand, in piezoelectric semiconductors, acoustic waves prompt both electric fields and concentration fields of charge carriers [5]. The interaction between the electric field and the charge carriers produces an electric current, leading to acoustic dispersion and attenuation [6]. In recent times, there has been a continuous effort to enhance the performance of PS materials using various artificial techniques, aiming to expand their applications in smart devices and composite structures [7]. These applications are intricately linked to the characteristics of elastic wave propagation within these PS materials. Therefore, investigating the propagation properties of elastic waves in PS materials holds significant theoretical importance.

Zinc oxide is an important piezoelectric material widely used in signal processing, telecommunications, microelectromechanical systems (MEMS), nanoelectromechanical systems (NEMS), and sensor technologies. Piezoelectric zinc oxide (ZnO) films have been deposited onto a range of substrates and films, amongst which diamond has the highest Young's modulus, leading to the highest acoustic velocities [8]. When a piezoelectric semiconductor (PSC) thin film of zinc oxide (ZnO) is deposited on a diamond half-space, it produces high-velocity surface acoustic waves (SAW), making it attractive for future ultra-high frequency SAW devices.

The previous research shows a noticeable need for more theoretical findings related to surface wave propagation characteristics in structures composed of piezoelectric semiconductors. This work examines the shear horizontal (SH) surface wave propagation in a PSC thin film that is perfectly bonded over an elastic dielectric half-space. Exponential variation is assumed along the thickness, for both material parameters and initial stresses. Consequently, we derived the governing equations for the considered shear surface wave within a graded PSC plate under initial stress. Further, the governing equations are analytically solved using the traction-free

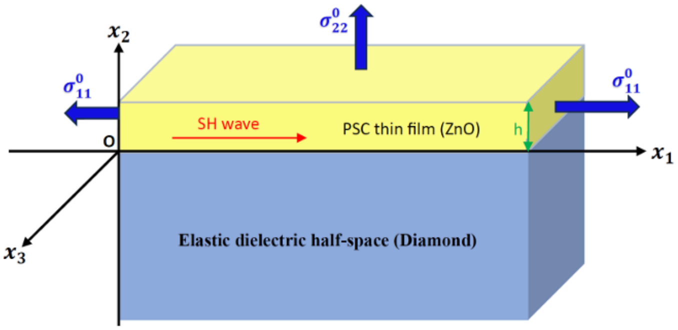

Figure 1: Schematic Diagram of the Problem.

boundary conditions, leading to the complex dispersion equation. Through numerical examples and graphical illustrations, we examined the influence of initial stresses, semiconductivity, rigid base, and gradient index on phase velocity and attenuation.

In the current study, the propagation behavior of SH waves is studied on a PSC layered structure. The structure consists of a pre stressed, exponentially graded p-type PSC plate of thickness h over an elastic dielectric half-space as shown in Fig1. Tensile initial stresses act on PSC film both horizontally and vertically. The interface between the film and the half-space is considered to be perfectly bonded. A regular cartesian coordinate system is employed, with the x_1 axis aligned in the direction of wave propagation with particle displacement along x_3 axis while the positive x_2 axis is oriented upwards. The origin lies at the interface of the PSC plate and the elastic dielectric half-space. The elastic half-space is assumed to be isotropic, while the PSC film displays transverse isotropy with its poling orientation along the x_3 axis. The material coefficients of the PSC film and initial stresses acting on it exhibits consistent exponential variations along the depth. For surface acoustic wave devices, the substrate's thickness is significantly greater than the layer's thickness, allowing the structure to be treated as a layered elastic dielectric half-space problem. Thus, the initial stress in the substrate can be neglected and we only assume the initial stresses to be acting on the layer [9] [10]. The initial stress values are taken from Sottos et al. [11].

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

This study presents a theoretical analysis of the effects of steady-state carrier density, functional gradient index, initial stress, biasing electric field, PSC film thickness, and substrate rigidity on the phase velocity and attenuation of SH waves in a PSC film. The PSC film is considered to be pre-stressed and perfectly bonded to an elastic dielectric halfspace. The material properties of PSC film and the initial stresses follow exponential variation along the depth. The results obtained in the study are validated by reproducing previously established work.

The significant findings of the considered model are summarised as follows:

1. Increasing the steady-state carrier density slows down the SH wave in the layer but preserves most of its original strength. This is advantageous in applications where maintaining signal clarity is crucial.

2. Incorporating functional grading into the PSC enhances its performance by increasing wave speed and reducing attenuation, thereby improving wave transmission and efficiency.

3. A higher biasing electric field causes more damping of the SH waves.

4. Vertical tensile initial stress has almost no impact on the wave transmission characteristics.

5. Reducing the thickness of the PSC film allows for faster signal transmission and reduced

signal loss over a distance. This means that sensors made with thinner PSC film can perform just as well, or even better, than those with thicker film. This is an important finding for producing more cost-effective sensors.

6. Rigidity of the half-space directly influences the phase velocity of SH waves. This makes it a crucial factor to consider when selecting a backing for PSC thin films.

This theoretical investigation into the complexities of smart materials is done to improve our understanding of wavepropagation in piezoelectric semiconductor thin films.

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