

Abstract

Piezoelectric semiconductors (PSs) are functional materials with both piezoelectric and semiconductor properties. The core property of PSs is the multi-field coupling effect of mechanical-electro-carrier, and its multiple properties are adapting to the needs of the rapid development of electronic devices. In recent years, the research on multi-field coupling behaviors and waves modulation of PSs has become one of the hot topics. By integrating multiferroic materials with PSs, new magnetically regulated composite devices such as magnetically induced piezoelectric potential transistors, magnetically driven nanogenerators, and LED photovoltaic devices can be obtained, which have great potential applications. In this thesis, several fundamental surface acoustic wave (SAW) problems in multiferroic composite semiconductors (MCSs) are systematically studied. The propagation characteristic and regulation mechanism of coupled waves in composite structures are explained, and the electromechanical (ME) coupling responses with multi-physical fields are analyzed, which is of guiding significance for the design of magnetically related SAW devices and piezotronic devices. The main studies include:

(1) Based on the magneto-mechanical-electro-carrier coupling theory, the propagation characteristics of SH-type surface waves in piezomagnetic (PM) and PS layered half-space are studied. Two models of PS/PM layered half-space and PM/PS layered half-space are constructed. In the first model, based on the obtained dispersion equations in the complex domain, the effects of initial carrier concentration, overlay thickness and material properties on the dispersion and attenuation of SH waves are numerically calculated, and the distributions of the real and imaginary parts of electromechanical fields through the thickness are deeply analyzed. The results show that semiconductor properties have a great influence on the mechanical and electrical physical quantities, but a little influence on the magnetic related quantities. In the PM/PS layered half-space, the first three modes of Love waves are obtained for open and short circuits, and for different combinations of materials, respectively, where the wave speed and attenuation in open case are correspondingly smaller than those in short. The analysis shows that the propagation of Love waves depend on the overlay thickness, and the wave speed decreases significantly with the increase of

thickness. PM constant has obvious influence on the first two modes of wave speed, while the carrier concentration and piezoelectric (PE) constant have a small negligible effect.

(2) Considering the PM/PE/semiconductor three-layer composite structure, the effects of the overlay thickness, the initial carrier concentration, PM constant, and the four different material combinations on the Love waves and Rayleigh waves are obtained. The results show that both Love and Rayleigh waves only undergo dispersion without attenuation. Except for the first mode of the Rayleigh waves that starts at the Rayleigh wave velocity at substrate, the remaining modes of the Rayleigh waves and all modes of the Love waves start at the shear wave velocity of substrate. The wave speeds of the first three modes of both Love and Rayleigh waves decrease significantly with the thickness of PM layer, but do not vary with the initial carrier concentration. The influence of material on Rayleigh waves is greater than that on Love waves.

(3) The propagation of SH waves in a PS plate and PM/PS bilayer composite plate under initial stress is investigated, and the influence of initial stress on SH waves under multi-field coupling is analyzed. Numerical results show that the wave velocity of SH waves in PS plate becomes smaller and the attenuation is enhanced with constant initial stress. 100 MPa can be regarded as the inflection point where the phase velocity decreases sharply with increasing initial stress. In addition, both the wave speed and attenuation in short circuit are correspondingly smaller than those in the open case. In the PM/PS composite plate, the effects of carrier concentration, plate thickness, initial stress, and material properties on SH waves are similar to those in pure PS plate, indicating that the PM layer has a limited effect compared to the initial stress. Under the same initial stress, the phase velocity of CdSe/CoFe₂O₄ is much smaller than that of ZnO/CoFe₂O₄, and the attenuation is also much weaker.

(4) The SH waves regulation in PM/PS layered structure by rotation and biasing electric field is studied. The dispersion, attenuation characteristics and frequency drift of SH waves in the layered structure rotating around a fixed axis are obtained in the framework of coupled theory including Coriolis and centrifugal forces. The results show that the wave dispersion and attenuation are also caused by the rotation. With the increase of the angular velocity, the wave speed and attenuation decrease faster, the frequency drift and attenuation coefficient become larger. The rotational sensitivity is much greater at long waves than at short waves. The SH-wave gain can be obtained by applying a horizontal biasing electric field regardless of rotation. There exists a biasing electric field turning point for attenuation and gain, as well as an inflection point where the maximum gain is obtained. With the increase of the biasing electric field, the wave speed will first decrease to the minimum, and then increase rapidly until it levels off.

(5) The bending coupling of a PS bimorph and the electromechanical response of a PS/PM composite beam are studied, respectively. In the PS bimorph, coupled two-dimensional (2D) plate equations are obtained from three-dimensional (3D)

theory. Considering the uniform load in rectangular domain, the distributions of electromechanical fields such as deflection, potential, carriers are obtained by using plate theory series solution and finite element method, respectively. The results of the two methods are similar and the errors are small. Besides, locally self-balancing load induce the potential barriers/wells. The PS/PM composite beam exhibits a complex coupling of bending and extension, and the transverse magnetic field moves the mobile charges to the ends of the beam. All electromechanical fields increase and change significantly with the increase of magnetic field, but the mechanical fields are less sensitive to the change of initial carrier concentration than the electrical physical quantities.

Keywords: Piezoelectric semiconductor, Piezomagnetic, Layered structure, Propagation characteristic, Initial stress, Rotation, Coupling behavior