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# Interface phonon-polaritons in quantum well wire systems of polar ternary mixed crystals

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ABSTRACT

The interface phonon–polaritons in quasi-one-dimensional rectangular quantum well wire systems consisting of polar ternary mixed crystals have been investigated with the modified random-element-isodisplacement model and the Born–Huang approximation, combined the Maxwell's equations and the boundary condition of electromagnetic field. The numerical results of the frequencies of interface phonon–polaritons as functions of the wave-vector, geometric structures, as well as composition $x$ for the quantum well wire systems $GaAs/Al_xGa_{1-x}As$ and $Zn_xCd_{1-x}Se/ZnSe$ are gained and discussed. It is shown that there are six branches of interface phonon–polariton modes in quantum well wire systems. The effects of "one mode" and "two mode" behaviors of the ternary mixed crystals on the interface modes are also shown in the dispersion curves.



## 1. Introduction

Surface and interface phonon–polaritons are composite modes arising from the coupling of infrared photons with transverse optical phonons near the surfaces or interfaces of different dielectric medium. The characteristics of surface and interface phonon–polaritons have been investigated experimentally and theoretically due to their applications in many fields, such as thermo-photovoltaic energy conversion system, optical sensor, near field microscopy, high density optical data storage, and near field surface enhancement [1–7]. Low-dimensional semiconductor nanostructures, such as quantum wells,

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quantum wires, and quantum dots have attracted extensive attention due to their numerous potential applications in electric and photoelectric devices [8–10]. Knowledge on surface and interface phonon–polaritons is significant to understand the optical properties of low-dimensional structures.

Recently, ternary mixed crystals (TMCs) have drawn considerable interest in view of their unique properties, which can be utilized for various important applications such as light emitting diodes, laser diodes, and other optoelectronics devices [11–13]. At present, the properties of surface and interface phonon–polaritons in quasi-two-dimensional systems of binary semiconductors and TMCs have been extensively investigated experimentally and theoretically [14–19]. The methods of Raman scattering and attenuated total reflection are two conventional techniques to detect the characteristics of surface and interface phonon–polaritons. Lately, Hussein et al. [14] have studied the surface phonon–polaritons of the three mode $Zn_xBe_{1-x}Se$ alloy by near-forward Raman scattering. Using *p*-polarized infrared attenuated total reflection spectroscopy, Lee et al. [15] investigated the surface and interface phonon–polariton characteristics of a wurzite ZnO thin film grown on a wurzite 6H–SiC substrate, and observed two surface and interface phonon–polariton modes.

Mills and Maradudin [16] theoretically studied the properties of surface phonon–polaritons in a GaAs film by employing classical electromagnetic approach firstly. Nakayama et al. [17] used the same method to research the surface and interface phonon–polaritons in a GaAs/AlAs heterostructure, and obtained one surface mode and four interface modes in this system. Subsequently, the polariton theory was extended to the case of quantum wells [18] and superlattices [19]. Recently, Lee and his collaborators [20] have studied the dispersion of surface and interface phonon–polaritons in wurtzite semiconductor multilayer system.

However, the characteristics of surface and interface phonon–polaritons in quasi-one-dimensional quantum well wire systems of TMCs have rarely been reported. The surface and interface phonon–polaritons in low-dimensional semiconductor nanostructures of TMCs will show more intricate properties than that in systems of binary crystals [21,22]. More recently, Bao and Liang have extended the research of phonon–polaritons from quasi-two-dimensional systems to quasi-one-dimensional systems, and reported the surface phonon–polaritons in free-standing rectangular quantum wires of polar TMCs [23]. In this work, we have investigated theoretically the interface phonon–polaritons in quantum well wires (QWWs) of polar TMCs by using the modified random-element-isodisplacement (MREI) model [22] and Born–Huang approximation [24], combining Maxwell's equations and boundary conditions of the electromagnetic field. It is necessary to study the characteristics of phonon–polaritons in low-dimensional heterostructures constituted by two different polar materials, because the low-dimensional systems are possessed by many uncovering new physical properties and applications to new photo-electronic devices.

The dispersion relations of the interface phonon–polaritons are deduced, and the numerical results for the dispersive frequencies of the interface phonon–polaritons in several III–V and II–VI systems are calculated and discussed in detail.

## 2. Formulation

A QWW system consisting of TMC with material "1" for $|x| \leqslant L_x$ and $|y| \leqslant L_y$ and material "2" for $|x| > L_x$ and $|y| > L_y$ is considered in this study, and the system is of infinite in the *z* direction, the geometry for the QWW system investigated is given in Fig. 1.

Interface phonon–polaritons are traveling along the *z* direction with the wave vector $k_z$, and the electric field $\boldsymbol{E}$ lies in the $x-z$ ($y-z$) plane, and the magnetic field $\boldsymbol{H}$ is along the $y-(x-)$ axis. Since the system is translationally invariant in the *z* direction, the electric field can be expressed as

$$\vec{E}(\vec{r}) = \vec{E}(x, y)\exp(ik_z z - i\omega t) \tag{1}$$

Combine the Maxwell's equations, we get the following equation

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} - \kappa_i^2\right)\vec{E}(x, y) = 0, \tag{2}$$