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Model of Impedance Delta-Inhomogeneities for Micro- and Nanostructures

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Abstract—A model of impedance δ-inhomegeneities for wave micro- and nanostructures of different nature has been proposed. This model combines the advantages of approaches based on δ-function and wave impedance. Analytic expressions were derived for single- and two-phase resonators and crystal-like structures. The characteristics of resonators based on finite width inhomogeneities and δ-inhomogeneities, and also the characteristics of single- and two-phase resonators were compared.

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INTRODUCTION

An approach based on δ-functions has been widely used in different fields of science and technology. In this case it is assumed that a physical object or physical quantity is concentrated to a point. For linear systems the input in the form of δ-function enables us to determine the characteristic-for-system response in the form of the Green function or pulse response (for linear circuits). The models make use of both single δ-functions and lattices of δ-functions in the case of multielement structures.

The potential δ-barriers and δ-wells in quantum mechanics are used for modeling of ideal crystals, defects in crystals, Tamm surface levels, and double-barrier structures with the resonance tunneling of electrons. In detail this model is considered in [1]. The model of δ-functions (δ-sources and δ-reflectors) played a key part in the development of applied acoustoelectronics, because it allows us to utilize the model of transversal filter for the synthesis and analysis of acoustoelectronic structure.

Wave micro- and nanostructures in the form of single wave inhomogeneities and lattices of inhomogeneities such as double-barrier and crystal-like structures (CS)—superlattices, the photon, electromagnetic and phonon crystals form the basis for signal processing devices of a new generation.

Wave propagation in CS is determined by a resonance passing in allowed bands and tunneling in forbidden bands. Due to these effects the specified structures possess the marginally possible range of wave control: from the complete transmission to practically complete suppression. Micro- and nanoinhomogeneities, and also CS ensure high localization of the field. The enhanced field localization corresponds to the enhanced selectivity and represents a fundamental task for signal processing devices.

The simulation of wave micro- and nanostructures involves the use of different approaches. Quantum-mechanical problems traditionally are solved by the matrix method employing "stitching" of solutions at the borders for obtaining the continuity of wave function and its derivative. The simulation of CS is reduced to solving the wave equation with periodic boundary conditions and is based on the Bloch theorem.

The wave properties of medium or structure are generally characterized by the wave impedance as a response to wave disturbance. The impedance concept for quantum-mechanical wave was proposed in [2, 3]. The impedance approach based on the wave impedance and the theory of transmission lines was developed in [4–7] for simulation of wave micro- and nanostructures. Hence, the quantum-mechanical structures and CS were discussed in [4] and [5], respectively, while analytic expressions for the proper values of barrier structures were obtained in [6, 7].

Within the framework of impedance approach the boundary conditions are ensured automatically. Due to this feature the simulation is considerably simplified; the band nature of CS and conditions for forbidden bands (FB) are obtained without the use of the Bloch theorem, and in many cases the solution can be