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Semiclassical diffractive scattering for transport through open rectangular microstructure

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Abstract. We study the transport through weakly open rectangular billiards by a new semiclassical approach within the framework of the Fraunhofer diffraction. Based on a Dyson equation for the semiclassical Green's function, the transmission amplitude can be expressed as the sum over all classical trajectories connecting the entrance and the exit leads. We find that the peak positions of the transmission power spectrum not only correspond to classical trajectories but associate with a lot of nonclassical trajectories and the contributions to the power spectrum of the transmission amplitude for the first mode are largely depending on the classical trajectories with small incident angles showing a good agreement with the diffracted angular distribution within the framework of the diffractive scattering effect at the lead openings.

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Key words: Semiclassical approach, Fraunhofer diffraction, transmission amplitude.

1 Introduction

During the recent few decades, mesoscopic physics has evolved into a greatly progressing and fascinating field of physics [1, 2]. Remarkable advances in the fabrication of submicron semiconductor microstructures have made it possible to produce the mesoscopic devices in the experiment. Mesoscopic devices, whose dimensions are intermediate between microscopic and macroscopic systems, exhibit both classical and quantum signatures [3]. Two-dimensional open quantum billiards has extensively served as model systems to study the ballistic transport through the mesoscopic microstructures [4].

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Semiclassical theory is widely used to describe and analyze the quantum transport property in mesoscopic systems. Several semiclassical methods [5-11] to quantum transport have been proposed, which provide a link between the classical dynamics of the electron motion in the billiards and quantum transport. Semiclassical approximations provide a way to handle quantum mechanics problems by a simplified path integral formalism to bridge the gap between quantum mechanics and its classical limit in a very direct way: each classical trajectory carries an amplitude reflecting its geometric stability and a phase which contains the classical action and accounts for quantum interference effect [12-15]. Due to the fact that the width of the leads is comparable to de Broglie wavelength, several semiclassical approximations were presented on the basis of Kirchhoff diffraction [12], Fraunhofer diffraction [13-15], geometric theory of diffraction and uniform theory of diffraction [16-18].

In this paper, we use a semiclassical approximation within the framework of the Fraunhofer diffraction to study the transport through a weakly open rectangular microstructure as depicted in Fig. 1 (a). Starting from a Dyson equation for the semiclassical Green's function, we formulate the transmission amplitude between the two leads of the rectangular quantum billiards as for Fig. 1 (b). We investigate the correspondence between the peak positions of the transmission power spectrum and the classical trajectories according to classical dynamics, and we find that the transmission probability not only associate with classical trajectories but contain prominent contributions from a series of nonclassical trajectories due to the diffractive scatterings at the lead openings.

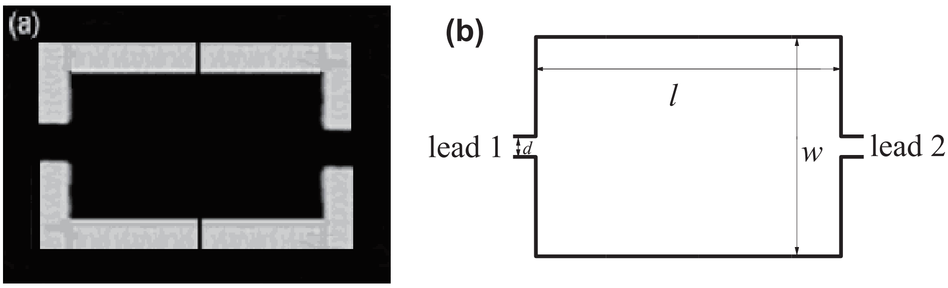

Figure 1: (a) Scanning electron micrograph of a rectangular device [19]. (b) Rectangular quantum billiards as the schematic of the rectangular device with length l=3.5, width w=2.0, and the width of the leads d=0.25. All dimensions are in μm.

The structure of this paper is arranged as follows. In Section 2 we introduce the theoretical approach in detail. In Section 3 we use the stationary-phase condition to calculate the classical trajectories according to the classical dynamics of the electron motion in the billiards. Numerical results and discussions are given in Section 4, followed by a short conclusion in the last section.