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Electron transmission through a periodically driven graphene magnetic barrier

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ABSTRACT

Electronic transport through graphene magnetic barriers is studied theoretically in presence of an external time harmonic scalar potential in the framework of non-perturbative Landau–Floquet Formalism. The oscillating field mostly suppresses the transmission for rectangular magnetic barrier structure and exhibits the Fano resonance for multiphoton processes due to the presence of bound state inside the barrier. While, for a pair of delta function barriers of larger separation, the oscillating potential suppresses the usual Fabry–Perot oscillations in the transmission and a new type of asymmetric Fano resonance is noted for smaller separation, occurring due to extended states between the barriers.

1. Introduction

Studies on the magneto-transport properties of a periodically driven graphene [1–3] microstructures is one of the most interesting research topic in current years, both theoretically and experimentally mainly because of their potential importance for the purpose of magnetic information storage devices as well as for the preparation of magnetic quantum dots to be used in the field of quantum computation. In particular, the current interest in the study of Giant Magneto Resistance (GMR) effect [4,5] modulated by magnetic barriers (e.g., magnetic vector potential) is one of the principal importances in this regards. The use of magnetic barriers [6–8] (instead of the electrostatic one [9,10]) in graphene is one of the efficient pathways to circumvent the severe limitation imposed on graphene (due to the Klein tunnelling effect [10,11]) for its fruitful exploitation in the field of digital electronics.

The kinetic transport in graphene under the action of an external uniform magnetic field exhibits an extraordinary property of unconventional half integer quantum Hall effect [12,13] that could be explained by the existence of relativistic Landau Levels formed by the charge carriers [14]. On the other hand, the use of an inhomogeneous magnetic field introduces the concept of graphene magnetic barrier [6] that totally reflects an incoming electron (thereby suppressing the Klein effect) with energy less than a threshold value related to the total magnetic flux through the barrier [6,8]. Now, when such graphene magnetic barrier is made to be driven by an external oscillating scalar or vector field, many exotic properties could stem from the nanoscale multiple field coupling [15–23]. To be more specific in the present context, one of the main motives is to suppress the transmission through graphene magnetic barrier in order to achieve the goal of the realisation of a better switching action that claims a high demand in designing electric field (A.C.) tuneable graphene based digital nano-devices. The application of an oscillating time dependent potential on a graphene magnetic barrier serves this purpose to a great extent by further suppressing the transmission through the system significantly. Thus in this perspective, the present work is supposed to be quite worth studying in view of device applications.

Further, such studies also bear fundamental importance since the underlying quantum physics deals with the interaction between the discrete and the continuum via the exchange of photons. Motivated by all these, the present study addresses the effect of the simultaneous interaction of the chiral Dirac fermions with an oscillating scalar potential and a static magnetic vector potential on the transmission profiles of the electron through graphene based tunnelling microstructures.

In a recent work [24], we studied the electron transmission through a single vector potential barrier (equivalent to two spatially separated δ function magnetic barriers [24–27] in opposite direction) in graphene based nanostructure in presence of an external laser field. This work is supposed to be the first attempt

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to study the electron tunnelling through a laser driven graphene magnetic barrier structure. However, the δ-function [24–27] type barriers to some extent arise in idealistic situations and are mainly adopted for mathematical simplicity while the realistic situation demands the use of finite width magnetic barriers. Apart from a pair of delta function magnetic barriers (DFMB), the present study also deals with a more realistic rectangular (finite width) magnetic barrier (RMB) in presence of an oscillating electric field (instead of laser [24] for the sake of mathematical simplicity). In fact, the problem of laser assisted transmission of the chiral Dirac fermion through a finite magnetic barrier is a bit difficult to solve theoretically, as the final solution becomes almost a formidable task. The effect of a sinusoidal time varying electrostatic potential on the tunnelling transport of a massive Dirac electron through a simultaneous electrostatic and magnetic barrier was also studied earlier [28]. Here special attention is also given to the Fabry Perot resonances [28–30], a widely discussed topic in optics, where a photon bounces back and forth between two coplanar semitransparent mirrors and the successive partially transmitted beams interfere coherently to produce the famous Fabry Perot interference pattern. The present study also aims at studying the effect of an oscillating potential (electrostatic) on the magnetic field induced quasi-bound states [6,8] in the framework of Floquet non-perturbative approach [31–33], supposed to be the most well known efficient technique for dealing with driven quantum systems.

The importance of the present work regarding the application of a time periodic potential with particular emphasis on photon assisted transport in graphene [34–39] was already emphasised [24]. In the case of a periodically driven quantum systems, the inelastic scattering channels open up due to the exchange of photons between the tunnelling electron and the oscillating potential. The Fano type resonances [40–44] are likely to appear in this context due to transitions between the Floquet sideband states and the bound states both for the δ-function as well as finite width graphene magnetic barriers.

Another aspect is to study the extended states inside a constant vector potential barrier in graphene that are responsible to produce a different kind of the Fano resonances, not reported in the literature so far. The present work for mass less Dirac fermion is the first attempt in this direction. The control or manipulation of these quantum states and the transmission profiles in graphene based tunnelling structures are inevitable not only from the theoretical point of view but also for their successful exploitations in device fabrications, e.g., in sensing and switching applications [45].

2. Theoretical model

The two band Dirac–Weyl Hamiltonian of a monolayer graphene in an external magnetic field described by a space dependent vector potential $\vec{A}(x)$ can be written as,

$$H_0 = v_F \vec{\sigma}.\left[\vec{p} - e\vec{A}(x)\right] \tag{1}$$

where v_F is the Fermi velocity $= c/300$, 'c' being the velocity of light; $\vec{\sigma} = (\sigma_x, \sigma_y)$ are the Pauli matrices representing pseudo-spin analogous to the original spin; $\vec{p} = -i\hbar(\partial_x, \partial_y)$ is the momentum operator in the graphene plane (x, y), 'e' being the electronic charge; the vector potential $\vec{A}(x)$ is uniform along the y-direction but varies along the x-direction. The magnetic field is chosen along the z-direction, perpendicular to the graphene plane.

For a rectangular magnetic barrier (RMB) of length L, the vector potential profile (Fig. 1(a)) polarised along the y-direction ($\hat{y}$) and the corresponding magnetic field profile (Fig. 1(b)) along the x-direction are respectively given by;

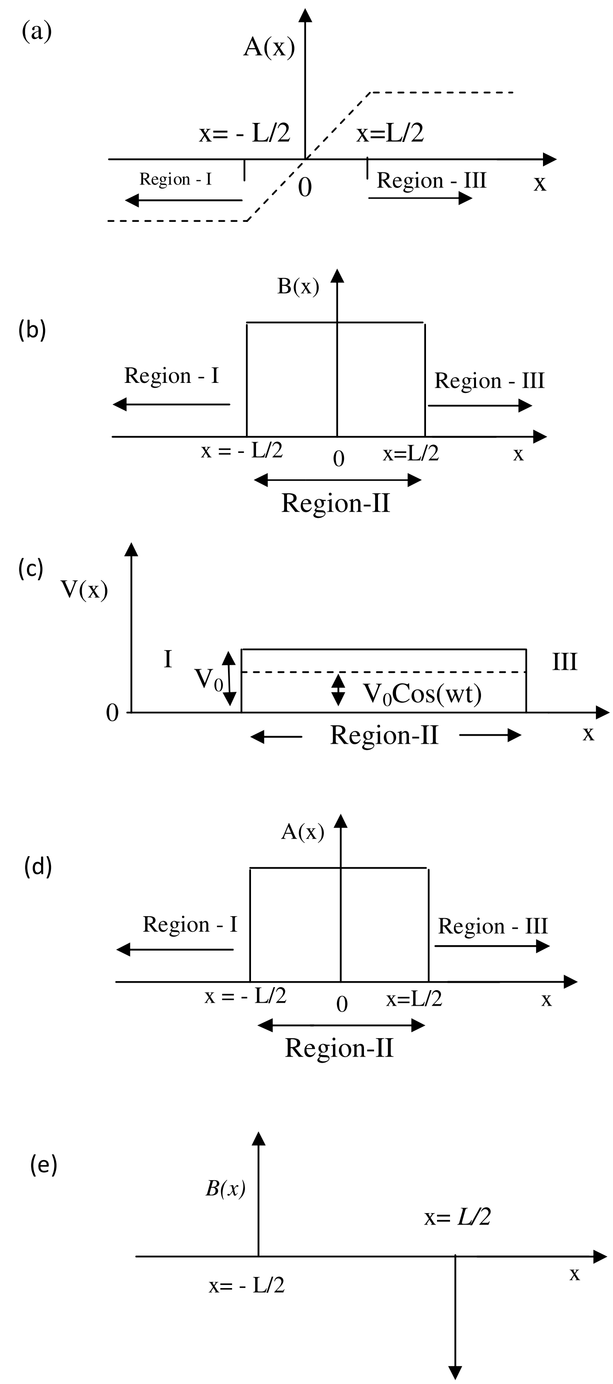

Fig. 1. (a) Vector potential profile $A(x)$ corresponding to a rectangular magnetic barrier (RMB) of width 'L' and height 'B'. (b) The magnetic field profile in the three regions (I, II and III) corresponding to the potential of Fig. (a). (c) Sinusoidally varying time dependent scalar potential of amplitude V_0 and frequency ω applied in region II (the dash line represents the value at any instant t). (d) Vector potential profile corresponding to a pair of oppositely directed δ-function magnetic barriers (DFMB) of strength 'B' and separated by a distance 'L'. (e) Magnetic field profile corresponding to the vector potential as shown in Fig. (d).

$$\begin{aligned} \vec{A}(x) &= -(LB/2)\hat{y} \quad \text{for } x < -L/2 \\ &= xB\hat{y} \quad (\text{in units of } B_0 l_0) \quad \text{for } -L/2 < x < L/2 \\ &= (LB/2)\hat{y} \quad \text{for } x > L/2 \end{aligned} \tag{2a}$$

and

$$\begin{aligned} \vec{B}(x) &= B\hat{z} \quad (\text{in units of } B_0) \quad \text{for } |x| < L/2 \\ &= 0 \quad \text{elsewhere.} \end{aligned} \tag{2b}$$