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Research Article

Effect of integer quantum Hall effect at the presence of Gaussian and quantum dot dopants

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ABSTRACT

In this study, the effect of integer Hall effect on nanoribbons of boron nitride at the presence of impurity function concerning magnetic resistance in terms of filling ratio was investigated. First, a dopant will be applied to the system in the form of Dirac Delta function, at the presence of this dopant, Landau levels will be divided into extended and localized levels giving rise to Hall step. In this model, the Aharanov-Boehm fluctuations are observed and impurity eradicates stagnation in energy levels. In fact, by increasing the width and height of the quantum dot destroys the step, and finally, the quantum-hall effect vanishes Then, another dopant will be applied to the system in the form of quantum dot. By increase of the width and height of quantum dot, the Hall step will fade and quantum Hall effect will disappear. The more the increase of quantum hall domain, the faster the Hall step and therefore quantum effect will fade.

Keywords: Quantum Hall Effect; Landau levels; quantum dot; Hall conductivity

1. Introduction

Hall Effect (HE) is created as the result of charged particles motion in combined electrical and magnetic fields. 100 years after discovery of classic Hall Effect, quantum Hall Effect (QHE) was discovered. In this effect, the Hall resistivity changes in step form and the resistance of each of these steps is constant [1].

Numerous studies have addressed Quantum Hall effect and its impacts. Many of them were conducted at the presence of dopant where the Landau levels would be divided into extended and localized levels giving rise to hall step [2, 3].

Application of a quantum dot to a system in which Hall Effect was observed, will result in disappearance of Hall step and by increase of quantum dot domain, the quantum effect will be disappeared faster. This behavior was mainly seen in isotropic systems [2].

According to Quantum Hall Effect, if the current I passes a conductor or semiconductor cuboid wit cross section of ab along x axis, the charge carriers will have a drift velocity of V_d; for the case of electrons, V_d direction is opposite to electrical field direction. At the absence of magnetic field, the potential difference between the lateral walls is zero. Now, if the magnetic field of B is applied in z direction perpendicular to current and slab surface, the Lorentz force of the magnetic field will cause deviation of the carriers to lateral walls; hence an increasing potential difference will be created between the lateral walls giving rise to an electric field called E_H along y axis. This potential difference is known as Hall potential [1].

Giuliani et al. (1983) added two types of dopants in the form of Dirac delta function and Gaussian function to the system and investigated the Landau sub-levels response to the flux variation. It was observed that in low temperatures and high magnetic fields, the Hall resistance varied in step-like manner. Simultaneous with constant Hall resistance in the steps, the longitude electrical resistance of the sample would be dropped drastically and decreased to a value smaller than the normal metals [2]. QHE was observed in a situation which is abnormal in comparison with the classic HE; this means that for this phenomenon high magnetic forces B>10T and low temperatures, near zero Kelvin (T< 4K), are required [3].

2. Experimental

In gauge method, increase of magnetic flux ∅ by flux quantum of $\phi = \frac{ch}{e}$, will transfer an electron from one edge to another which corresponds to the situation in which the system conductivity is quantized by $\frac{ie^2}{h}$. It requires:

1- The doping was adequately low
2- Chemical potential between the two Landau levels was situated in energy gap [4].

Flux variation response by application of dopant potential

At the presence of electric and magnetic fields, Hamiltonian can be written as [5]:

$$H = \frac{1}{2m}\left[\vec{P} + \frac{e\vec{A}}{c}\right]^2 + eEx \qquad (1)$$

The answers to the Schrödinger equation, if the electric and magnetic fields are in x and z directions, respectively are:

$$\psi_{nk} = \pi^{\frac{-1}{4}} L_y^{\frac{-1}{2}} \exp(iky)\, \phi_n(x - l^2 k) \qquad (2)$$

Where, $l = \left(\frac{hc}{eB}\right)^{\frac{1}{2}}$ is the magnetic length and ϕ_n represents simple harmonic oscillator harmonics. By application of periodic condition and Aoki gauge [6], the solution of the Schrödinger equation will be:

$$\varphi = \sqrt{2}\pi^{-1/4} L_y^{-1/2} \exp(iXy)\,(x - X)\, e^{\frac{-(x-X)^2}{2}} \qquad (3)$$

In non-doped state, the elements of diagonal matrix of H_0 are:

$$E_{ii} = \left(1 + \frac{1}{2}\right) + 10^{-4}\left(i\Delta x + \frac{\phi}{\phi_\circ}\Delta x\right) \qquad (4)$$

Now we add a diagonal Hamiltonian of N=100 dopants in the form of Gaussian function:

$$H'(i,j) = \sum_{k=1}^{100} V(-1)^k \exp\left(-\frac{\alpha\,(X - Xim(k)^2)}{2}\right) \exp\left(-\frac{\alpha\,(Y - Yim(k)^2)}{2}\right) \quad (5)$$

In which $\alpha = \frac{1}{d^2}$ is the width of Gaussian function, d is the nanoribbon width and Xim(k) and Xim(k) are the dopants positions.

At the presence of H', total matrix which is written as $H = H_0 + H'$, wouldn't be diagonal any more.

Therefore, to obtain the energy Eigenvalues, the total Hamiltonian has to become diagonal. Hamiltonian eigenvalues were calculated by Matlab software and the results are illustrated in

figures 1-3 for different V and α values. Hall conductivity is equal to $\frac{de}{d\varphi}$. In figures 1 to 3, $\alpha = \frac{1}{2}$ and V is 0.002, 0.02 and 0.2, respectively [7].

As it can be seen, by increase of V, the number of extended levels decreased and the number of localized levels increased and Hall step is created. Hall step is completely observable in figure 3 for V=0.2. It has to be noticed that in the absence of dopants, all the levels are extended.

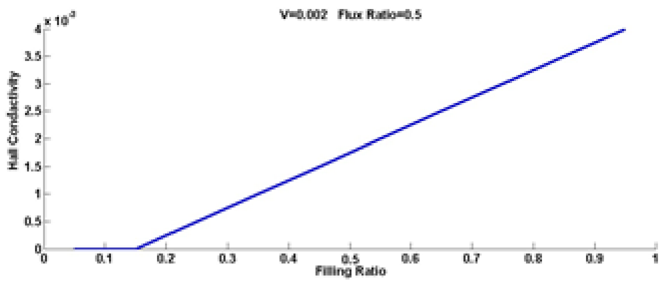

Fig. 1. Hall conductivity Vs. filling ratio for V=0.002 and α=0.5

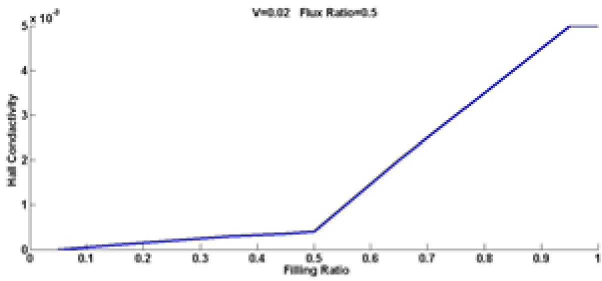

Fig.2. Hall conductivity Vs. filling ratio for V=0.02 and α=0.5

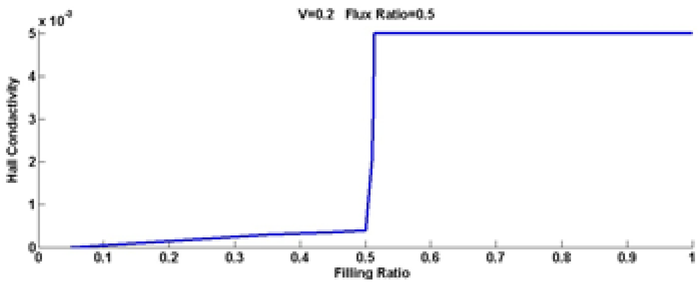

Fig.3. Hall conductivity Vs. filling ration for V=0. 2 and α=0.5

In this section, the effect of a quantum dot on Hall Effect will be addressed. In addition to N Gaussian-like dopants which gave rise to emergence of the Hall step, a quantum dot was added to the system which is larger than the N dopants in terms of width and height. Hamiltonian of this perturbation will be:

$$H = V\, exp\left(-\frac{\alpha\,(x-x_1)^2}{2}\right)\exp\left(-\frac{\alpha\,(y-y_1)^2}{2}\right) \qquad (6)$$

In which x_1 and y_1 shows the location of the quantum dot. At the presence of such potential, the total matrix has to become diagonal and the eigenvalues have to be calculated.

Results of simulations are plotted for different V and α in figures 4 to 7. In figures 4 and 5, α =5 and V was considered -5 and -10. Presence of quantum dot removed the symmetry of the system, but the Hall step is still present. Therefore, it can be concluded that if the width of quantum dot function is low, such quantum dot can't remove the Hall step. Now we increase α; hall conductivity is plotted in figure 6 for α =10 and V=2 and in figure 7, it is plotted for α =10 and V=2. Figure 6 shows that by increase of α, Hall step started to disappear and for high values of α and V, this step is completely disappeared in figure 7 [7].

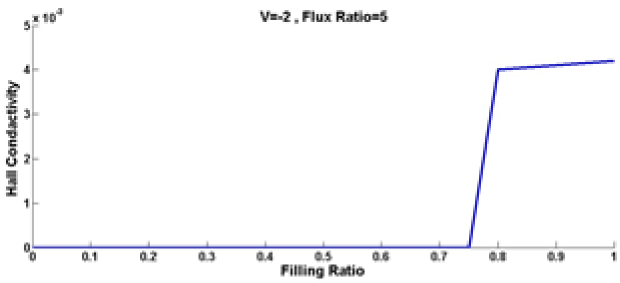

Fig.4. Hall conductivity Vs. filling ratio for V=-2 and α=5

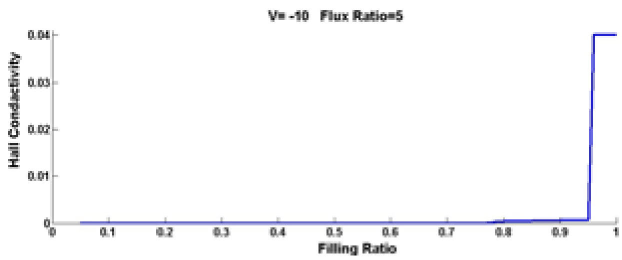

Fig.5. Hall conductivity Vs. filling ratio for V=-10 and α=5

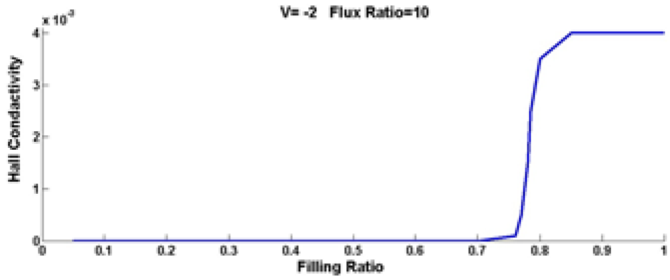

Fig.6. Hall conductivity Vs. filling ratio for V=-2 and α=10

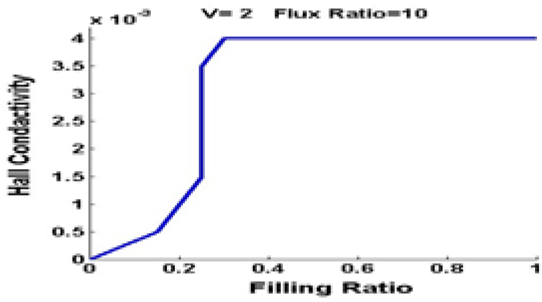

Fig.7. Hall conductivity Vs. filling ratio for V=2 and α=10

3. Conclusions

In this study, the effect of doping on the integer Quantum Hall effect was investigated. At the presence of dopants in the form of Gaussian functions, it was observed that landau levels were divided into extended and localized levels. By increasing the dopant concentration, the number of extended and localized levels decreased and increased, respectively and a Hall step would appear in hall conductivity. In the next stage, a dopant in the form of a quantum dot was considered which caused the Hall step to fade. By increasing the quantum dot domain, the hall step and therefore the QHE will fade faster.

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