Magneto-transport and Aharonov-Bohm effect in graphene nanoribbon rings

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Graphene, due to its unusual electronic properties, has become an attractive material for researchers in material science, condensed matter physics, and device applications [1-3]. Many unusual transport phenomena in graphene nanostructures such as finite minimal conductivity, Klein tunneling, and unconventional quantum Hall effect were explored [1]. Hence, it is not surprising that Aharonov-Bohm (AB) interference, a quantum phenomenon of particular interest, was also investigated intensively in graphene rings (see the review [4]).

However, in almost all previous studies [4], the phase coherence was not as strong as expected and hence the amplitude of AB oscillations and magnetoresistance (MR) was relatively small even at low temperature. In this talk, we present the studies [5-6] on the magnetotransport in ~~the~~ graphene nanoribbon rings schematized in Fig. 1. In particular, we focus on the possibility of achieving strong AB interference/large MR and some peculiar properties of this interference effect. First, as shown in Fig. 2, we find that the phase coherence behaves differently depending on whether the energy is smaller or higher than E_{2e}, i.e. the edge of the second subband of contact GNRs. In the range $E < E_{2e}$, only a single (first) subband of contact GNRs is active, i.e., contributes to the transport. The AB interference can be perfectly achieved. At higher energy, several subbands can carry electrons and the incoming wave is no longer a pure state. Hence, the AB interference cannot take place properly in this case. In Fig. 3, the conductance and magnetoresistance are displayed as a function of magnetic field at room temperature. Strong AB effect with giant MR of thousands is obtained. Our study tells us also how the AB interference can be perturbed by (i) the contribution of high energy subbands to the transport, (ii) the inhomogeneity of the ring arms, and (iii) the disorder (not shown here).

By investigating the magnetotransport in a zigzag GNR ring, we additionally found a peculiar property of AB interference when a p-n junction is generated along the ring. Actually, it was shown that in zigzag GNR p-n junctions, the transmission opens only between the subbands of same parity and is forbidden in the case of different parity (see Fig. 4(a)). The same feature is observed in the ring structure and we found an interesting phenomenon that the AB effect can reverse the parity symmetry of the incoming wave and hence can modulate strongly the transmission through the system. Indeed, as shown in Fig. 4(b), the transmission between the subbands of different parity in the energy regime (II), which is forbidden in the normal zigzag GNR p-n junctions, is significantly modulated by the applied magnetic field. Moreover, there is a π-phase shift of AB oscillations in this case, compared to the cases of same parity (see in the energy regimes (I) and (III)). This feature is illustrated more clearly in Fig. 5 of the current at low (different parity) and high (same parity) biases. On this basis, interesting phenomena as giant positive (resp. negative) magnetoresistance at low (resp. high) bias and strong negative differential conductance can be obtained in this ring.

In summary, we present a numerical study on the AB interference and show its peculiar properties with the possibility of large magnetoresistance in graphene nanoribbon rings. The study hence provides good guides for further investigations of the AB interference and high magnetoresistance in this type of graphene nanostructure.

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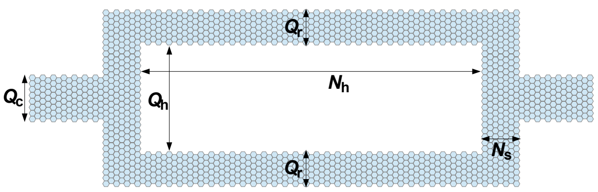

Fig. **1**. Graphene nanoribbon rings studied in this work.

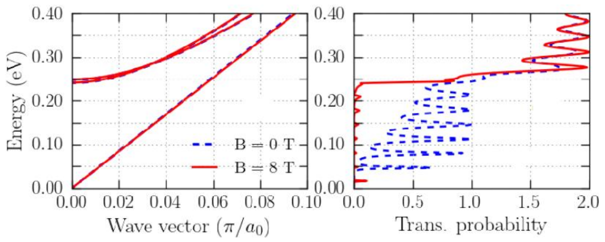

Fig. **2**. Band structure of the contact GNR and corresponding transmission probability of a armchair GNR ring.

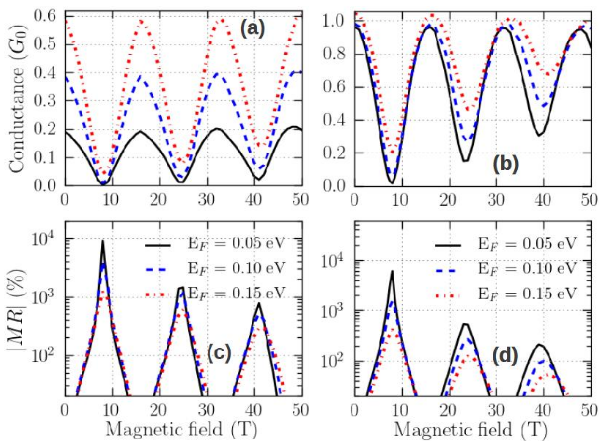

Fig. **3**. Conductance and corresponding magnetoresistance as a function of magnetic field in the rings of armchair (a,c) and zigzag (b,d) GNRs.

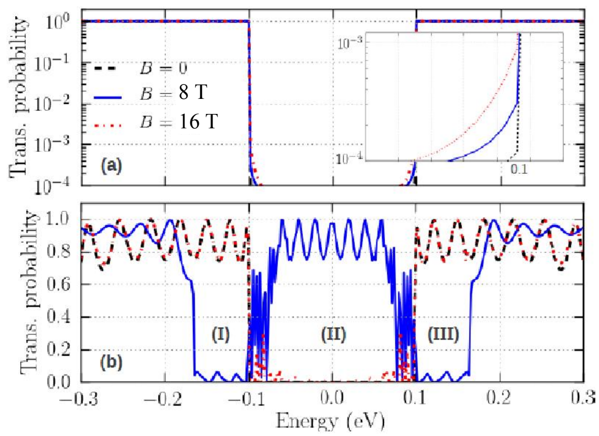

Fig. **4**. Transmission probability as a function of energy for different magnetic fields in (a) the p-n zigzag GNR junction and (b) the ring structure of such the junction. Inset of (a): zoom of the transmission around $E = 0.1$ eV.

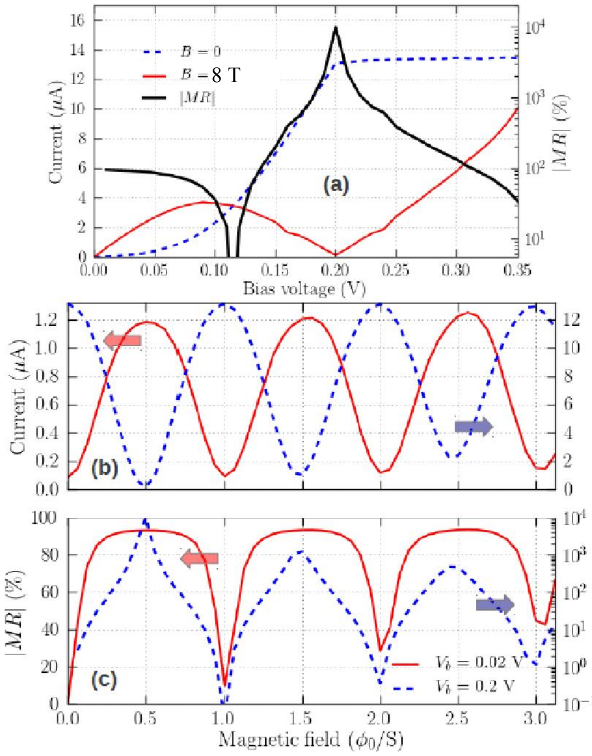

Fig. **5**. I-V characteristics and the current as a function of magnetic field in the ring studied in Fig. 4(b).