Modulation of bandgap and current in Graphene/BN heterostructures by tuning the transverse electric field

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INTRODUCTION

In spite of excellent transport properties which make it a material of choice for nanoelectronic application, graphene suffers from the lack of an energy bandgap. Recently, the growth of hybrid monolayers consisting of a mixture of BN and carbon nanodomains has been demonstrated [1]. It opens new routes for bandgap nanoengineering. Additionally, it has been shown that a transverse electric field may modulate the bandgap in carbon nano tube and graphene ribbon [2]. We propose a new structure which exploits this effect to switch off the current in a hybrid ribbon. We investigate this structure by means of a tight-binding description of the atomic structure coupled to a non-equilibrium Green's function (NEGF) approach for the quantum transport.

SIMULATED DEVICE AND MODEL

An armchair hetero-structure made of a BN ribbon sandwiched by two graphene ribbons is investigated, as schematized in Fig. 1. The width of each sub-ribbon is characterized by the numbers of dimmer lines $M_{CC1} = M_{CC2} = 15$ and $M_{BN} = 29$. The tight-binding parameters given in [3] have been used here. Two side gate potentials of opposite sign are applied at the edges of the ribbon to generate a transverse electric field. The in-plane relative permittivity is assumed to be 1.8 and 3 in graphene and BN, respectively. The NEGF quantum transport is investigated in the device schematized in Fig 2. The active region is made of a G/BN ribbon between two graphene leads.

RESULTS

In Fig 2 we show the potential profile obtained from self-consistent solution of Poisson and Schrodinger equations for an average transverse field $F_0 = 9$ mV/Å. It induces a redistribution of charge within the ribbon (not shown). The resulting band structure of the ribbon of Fig. 1 is displayed in Fig. 4 for different values of average field F_0 ranging from 0 mV/Å to 9 mV/Å. It is remarkable that the bandgap reduces strongly when tuning the field F_0. As shown in Fig. 5, it falls from 0.54 eV for $F_0 = 0$ V to 0.16 eV for $F_0 = 10$ V and 0.074 eV for $F_0 = 20$ V. Starting from a ribbon with a high bandgap it is thus possible to tune and control electrostatically the bandgap down to almost zero.

This effect is exploited to control the current in the device of Fig. 2. The bandgap in the 10.5 nm-long active region of the device is controlled by the external transverse field while the graphene leads are gapless. The *I*-*V* characteristics are shown in Fig. 6 for different values of transverse field F_0. For $F_0 = 0$ the current is very small due to the large bandgap. When increasing F_0 the current turns on due the field-induced bandgap narrowing. For $V_{bias} = 0.2$ V, the current ratio I_{ON}/I_{OFF} defined as the ratio of currents at $F_0 = 20$ mV/Å and at $F_0 = 0$ mV/Å reaches 3830. It even jumps to 14200 for an active region of length 17 nm (not show).

CONCLUSION

We have investigated the effect of transverse field on the band structure of hybrid Graphene/BN ribbons. We have shown that the field-induced bandgap narrowing can be used to control the current on a large range in side-gated devices.

ACKNOWLEDGMENTS

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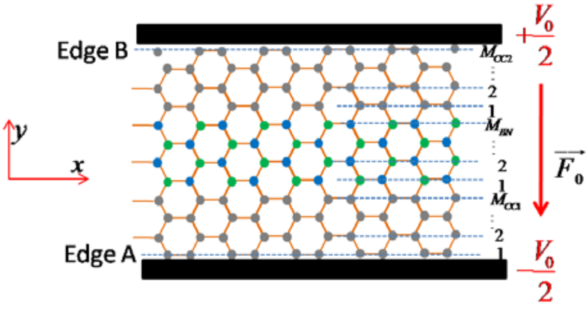

Fig. **1**. Schematic view of the side-gated armchair graphene/BN ribbon studied in this work.

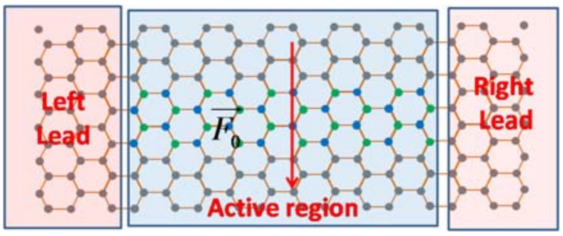

Fig. 2. Schematic view of the device made of hybrid ribbon of Fig. 1 as active region controlled by a transverse electric field connected to two graphene leads.

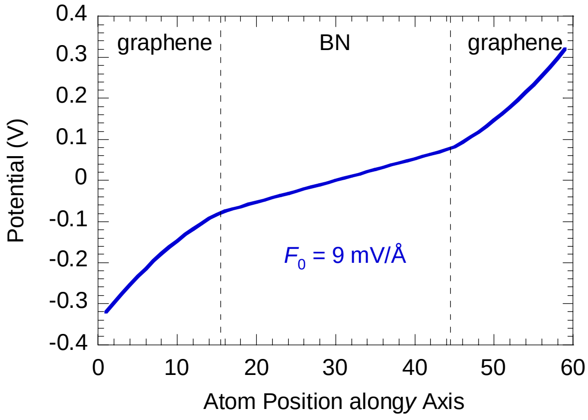

Fig. 3. Typical Potential profile along the width of the BN/graphene ribbon of Fig. 1 (with $M_{CC1} = M_{CC2} = 15$, $M_{BN} = 29$) for an average transverse field F_0 = 9 mV/Å.

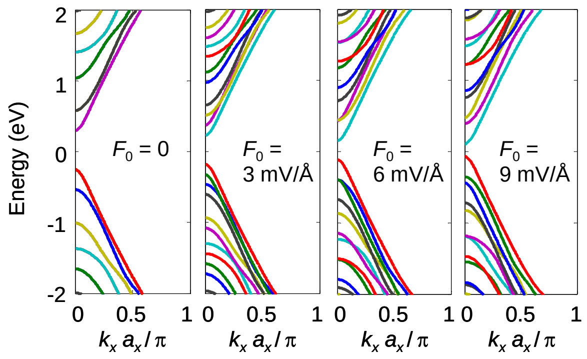

Fig. 4. Energy band structures of the ribbon of Fig. 1 (with $M_{CC1} = M_{CC2} = 15$, $M_{BN} = 29$) for different average transverse electric fields.

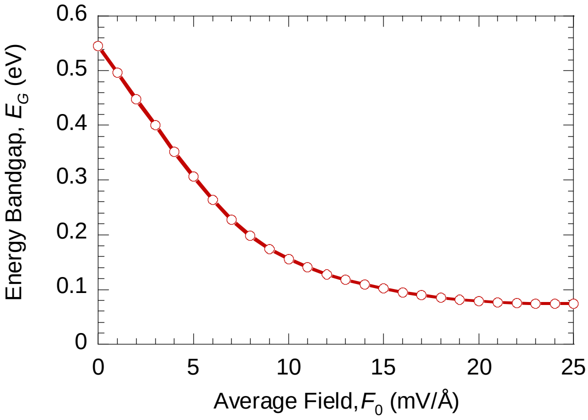

Fig. 5. Energy bandgap of the ribbon of Fig. 1 (with $M_{CC1} = M_{CC2} = 15$, $M_{BN} = 29$) as a function of the average transverse field F_0.

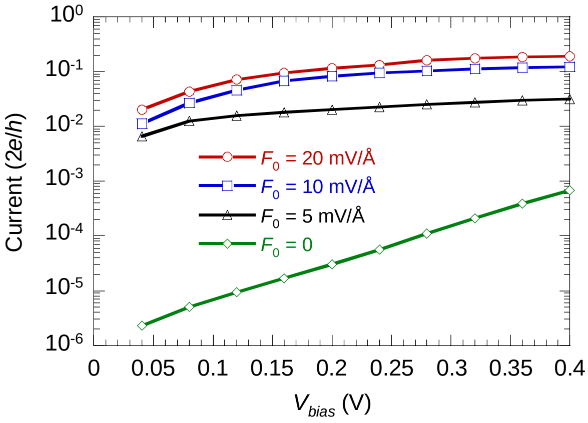

Fig. 6. Drain current as a function of bias voltage for different values of the electric field in the device of Fig. 2 (with $M_{CC1} = M_{CC2} = 15$, $M_{BN} = 29$).