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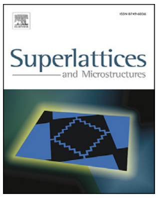

Lattice-pseudospin and spin-valley polarizations in dual ferromagnetic-gated silicene junction

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ABSTRACT

We study spin-valley and lattice-pseudospin currents in a dual ferromagnetic-gated silicene-based junction. Silicene has buckled atomic structure which allows us to take sublattice-dependent ferromagnetism into account in the investigation. One of the study results show that transmission at the junctions exhibits anisotropic property only in anti-parallel cases. Interestingly, the studied junctions can be switched from a pure spin-polarizer to a pure valley-polarizer by reversing directions of exchange fields in the parallel junctions. The perfect control of spin-valley currents can be done only in the parallel cases and its resolution can be enhanced by increasing gate potential between the ferromagnetic barriers. The asymmetric barriers of anti-parallel junction is found to destroy both spin and valley filtering effects and yield a novel result, pure sub-lattice pseudospin polarization. The current in the anti-parallel junctions can be controlled to flow solely in either A or B sub-lattice, saying that the controllable lattice current in silicene is created in double ferromagnetic-gated junction. Our work reveals the potential of dual ferromagnetic-gated silicene junction which may be possible for applications in spin-valleytronics and lattice-pseudospintronics.

1. Introduction

After graphene [1], many other two-dimensional (2D) materials [2] are theoretically discovered, such as germanene (Ge) [3], phosphorene (P) [4], stanene (Sn) [5–7] and silicene (Si) [8]. Silicene has atomic structure akin to graphene but with out-of-plane buckling, so some electronic properties are different from those in graphene. At first, silicene seemed to be elusive materials due to its chemically sensitive surface. However, after experimental success [9,10], it is considered to be one of the most promising 2D materials in electronics applications due to the accumulation of silicon-related technology and knowhow in semiconductor industry. One important development in controlling the characteristics of silicene is by hydrogenation. The fully hydrogenated silicene is called silicane which is another interesting material for field effect transistor (FET) application [11], and the half-hydrogenated silicene can be used to introduce magnetism and generate band gap in silicene [12,13]. The recent study on field-effect transistors operating at room temperature made from silicene [14] is particularly considered to be a big leap in this area. To enhance the capability of conventional electronics devices based on charge degree of freedom, spintronic devices based on spin degree of freedom have become important [15]. More recently, valley degree of freedom

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based on two inequivalent Dirac points at k and k' has also attracted interests [16] as a pathway towards quantum computing. The presence of large spin-orbit interaction and buckled atomic structure lead silicene to be a candidate for these growing fields of spintronics [17] and valleytronics [18].

Silicene and other monolayers of honeycomb-lattice atoms are parts of Dirac materials [19], which also include topological insulators and high-temperature d-wave superconductors. The properties that make these group of materials unique and exciting are from the fact the low-energy electrons in these condensed matter systems obey Dirac equation instead of Schrödinger equation. The massless Dirac fermions in the systems give rise to many interesting phenomena, for example, integer quantum Hall effect (QHE) [20], Klein paradox [21], fractional quantum Hall effect (FQHE) [22]. One particular interesting quantum state is the Quantum spin Hall (QSH) effect, which recently has a breakthrough in achieving large gap in room temperature, especially in stanene [23] and plumbene [24] with its strong spin-orbit coupling (SOC) effect. With better understanding in the properties of this group of materials including silicene, we expect to make impact on the higher computing power and other technological areas.

Although silicene and its more analyzed predecessor, graphene, are the same 2D Dirac materials, there are few significant differences between them. For example, silicene has buckled honeycomb lattice structure which in turn allows Dirac electron mass to be manipulated by electric field [25,26]. Silicene also has stronger spin-orbit coupling which gives rise to the spin-valley coupling [27]. There have been various theoretical studies in spin-valley transport at silicene junction, which helps the advancement in this area. The topics of investigations are, for example, the electric field condition for the fully valley and spin polarized transports [28], the mechanism of magnetism opening different spin dependent band gaps at k and k′ points which results in spin and valley polarized transports [27], ballistic transport through silicene FM junctions [29], and the transmission probability and valley conductance relating to the local electric field and exchange field [30]. Other studies have also been made in electron transport of silicene based spintronics and valleytronics devices [31–37], where more attention is attracted recently. The topics of studies are such as spin filter and spin-valley filter [31–33], spin thermoelectric properties [34], spin-polarized transport in a dual-gated silicene system without exchange field [35], epitaxial growth of multilayer silicene [36] and using electric and exchange fields to tune the plasmonic response of the electron gas in silicene [37]. However, more analysis must be done to completely understand the properties of this material, not only spin and valley currents, for being used in real-world applications. The lattice-pseudospin currents are also applicable for the so-called "lattice-pseudospin-tronics", devices that control currents to flow in either A or B sublattice atomic structure.

In this paper, we study the spin-valley current and lattice-pseudospin current in silicene-based normal(NM)/ferromagnetic(FM)/normal(NM)/ferromagnetic(FM)/normal (NM) junction, effected by the presence of ferromagnetic dual gated barriers. The wave equation of the carriers is described by low energy tight-binding-based Hamiltonian [18,31]. Electric field and exchange fields are applied to our device structure, which have effects in topological phase transition resulting in quantum spin Hall (QSH), quantum anomalous Hall (QAH), and band insulator (BI) phases [25,26] similarly to graphene. However, the larger spin-orbit interaction causes larger fractional quantum Hall effect (FQHE) gaps. Due to the buckled structure, the electric field enhances the interaction in the conduction band Landau level in one valley, but suppresses the interaction in another valley [38]. In this work, we show that the studied junction may be anisotropic transport property and destroy spin-valley filtering, in the anti-parallel type. By focusing on the anisotropic properties of the device and the characteristics of spin and valley currents, we propose a new way to control spin-valley currents and lattice-pseudospin currents in silicene with dual magnetic gates for both parallel and anti-parallel junctions. The potential of double magnetic-gated silicene junction would be revealed for applications in spin-valley-current and lattice-pseudospin current based devices.

2. Model

The schematic model of double-barrier silicene-based structure, NM1/FM1/NM2/FM2/NM3, is shown in Fig. 1. Each of the magnetic barriers, FM1 and FM2, has length d with distance L separating from each other. The magnetic barriers are

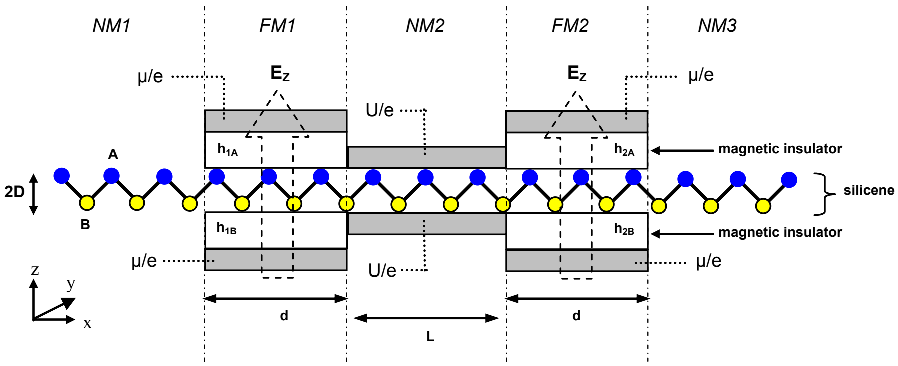

Fig. 1. Cross-sectional schematic model of double-barrier silicene-based NM1/FM1/NM2/FM2/NM3 structure. Electric field E_Z and gate potential μ/e are applied into the magnetic barriers, while gate potential U/e is applied at the silicene NM2 layer.