Graphene Self Switching Diodes

Feras Al-Dirini[1,2,3], Stan Skafidas[1,2,3], Ampalavanapillai Nirmalathas[1,3]

[1] Electrical and Electronic Engineering Department, University of Melbourne, Parkville, Australia
[2] Centre for Neural Engineering, University of Melbourne, Parkville, Australia
[3] Victorian Research Laboratory, National ICT Australia, Parkville, Australia
ferasa@student.unimelb.edu.au

Abstract

Self-Switching Diodes (SSD) are two terminal Nano-devices that rectify current based purely on a field effect, without the need for a third gate terminal to apply this field. They can be fabricated simply by etching two L-shaped trenches back-to-back giving rise to asymmetrical nanowires that have rectifying characteristics similar to those of conventional diodes [1]. SSDs can operate at high frequencies, reaching up to terahertz at room temperature [2], and have shown a great potential for high frequency detector applications [3]. The device's channel length and the charge carrier mobility in the material used to build the device have both proven to be the limiting factors that limit the device's detection frequency [4]; with a shorter channel and higher charge carrier mobility, a higher detection frequency can be achieved. Furthermore, as the channel becomes shorter and the charge carrier mobility becomes higher, the device begins to enter ballistic operation through which resonant detection may be achieved at very high frequencies in the terahertz range [5].

Another important advantage of SSDs is the simplicity of their fabrication; their simple geometry requires only two photolithography steps during fabrication, one to etch the trenches and the other to define the contacts. Also, since rectification in these devices is based purely on a field effect that does not depend on any junctions or barriers they do not require any doping during fabrication, further simplifying the process. Nevertheless, one requirement needs to be satisfied in order to achieve this simple fabrication process, and that is SSDs need to be built on substrates in which current conduction is confined in a two-dimensional plane. This had previously been achieved through the use of either compound semiconductor heterostructures [1] or Silicon-On-Insulator wafers [6]. With the above mentioned factors in mind, namely high charge carrier mobility, the ability for extreme downscaling and two-dimensional confinement of conduction, Graphene, which is a 2-dimentional material with ultrahigh charge carrier mobility, stands out to be a very strong candidate that may fulfill such needs of SSDs.

In this work we present the use of Graphene to make Graphene Self-Switching Diodes (G-SSD). The G-SSD device structure is shown in Figs. 1 and 2, and as can be seen from the figures G-SSDs are similar to SSDs in their architecture except that the channel in them is a nanoribbon rather than a nanowire. This nanoribbon can be either an armchair nanoribbon or a zigzag nanoribbon, where armchair and zigzag refer to the structure of the edges of the nanoribbon, but more importantly result in different electronic properties of the channel. Armchair nanoribbons can be either metallic or semiconducting, while zigzag nanoribbons are metallic, and this suggests that a G-SSD may behave differently from another G-SSD based on the type of nanoribbon that constitutes its channel.

In order to study this effect, two G-SSDs, one with a zigzag nanoribbon (Fig. 1) and the other with a semiconducting armchair nanoribbon (Fig. 2), were investigated using atomistic quantum simulations, and the I-V Curves of both devices were calculated based on NEGF and the Extended Huckel Method. The results for both cases, a G-SSD with a zigzag nanoribbon and another with an armchair nanoribbon, are presented in Figs. 3 and 4 respectively. As can be seen from Fig. 3, for a device with a zigzag nanoribbon as the channel, a linear I-V curve is obtained, suggesting that the device does not operate well as a rectifier. This result is consistent with what has become settled in the literature, namely that zigzag nanoribbons behave close to metals, and since the device's channel is a zigzag nanoribbon it is expected that its conductance will not be affected significantly by a field effect and hence it will conduct equally in both directions, resulting in a straight line for the I-V curve. On the other hand, Fig. 4 shows a different behavior for the semiconducting armchair channel G-SSD. A non-linear I-V curve, in which conduction is much higher in the forward direction when compared to the reverse direction, is obtained resulting in rectifying characteristics that resemble a functional rectifying G-SSD.

These results confirm the ability of realizing SSDs with strong non-linear characteristics using Graphene, by ensuring that the channel in the device is an armchair nanoribbon, launching a new line of Graphene devices that exploit Graphene's unique properties, and paving the way towards achieving resonant Terahertz detection using Graphene Self-Switching Diodes in the near future.

References

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Figures

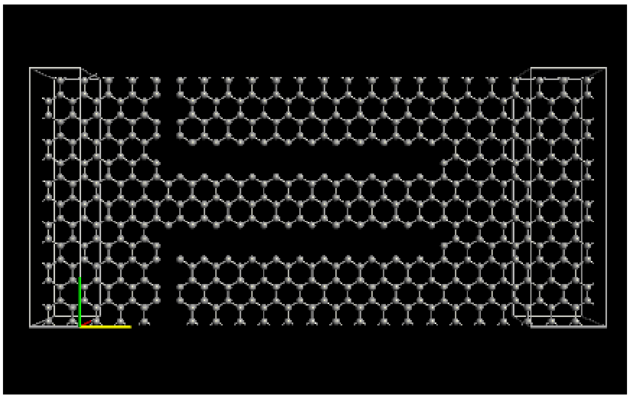

Figure 1 – G-SSD with a zigzag edged channel

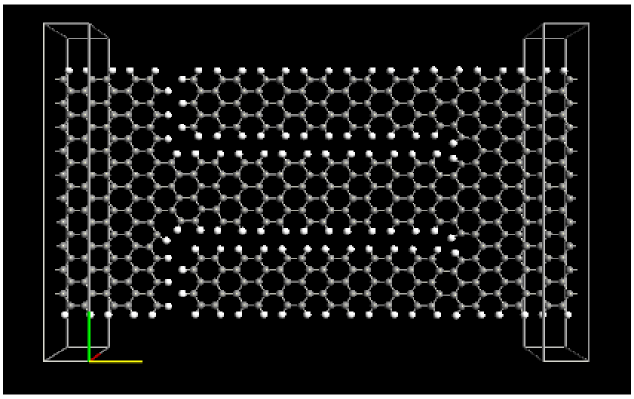

Figure 2 – G-SSD with an armchair edged channel and hydrogen passivated dangling bonds

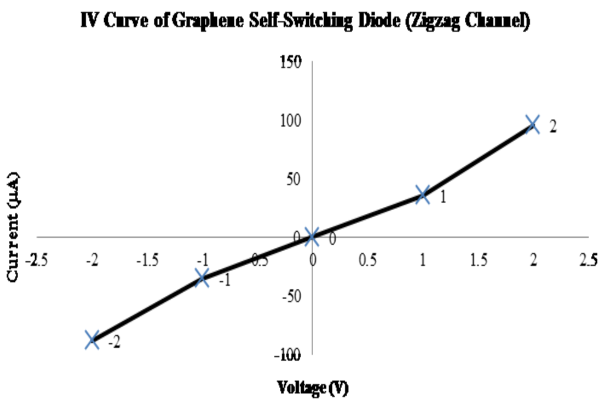

Figure 3 - IV curve for the G-SSD with a zigzag channel

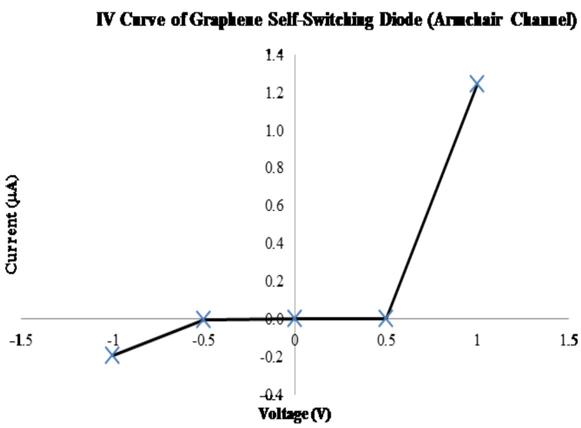

Figure 4 - IV curve for the G-SSD with an armchair channel