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ABSTRACT

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Graphene-to-Graphene Nanoelectromechanical Switching Devices

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The Nanoelectromechanical (NEM) contact switches can offer low leakage current, abrupt switching and high ON/OFF ratio. Due to these superior characteristics, NEM contact switch has become one of the demanding candidate to overcome the limitations, such as high off-state power consumption, of conventional CMOS technology. Conventional NEM contact switches exhibit disadvantages such as high pull-in voltage, and interfacial stiction. One of the most promising materials to overcome the demerits of conventional for the NEM contact switch is graphene. Graphene, a single layer of a carbon atom, has excellent electrical and mechanical property. The graphene based NEM contact switches can offer low pull-in voltage switch for ultra-low power application and can also achieve abrupt subthreshold swing (SS<60mV/dec).

The graphene based NEM contact switch is facing contact adhesion problems as the suspended graphene beam is struck to the metal contact surface (Au, Cr/Cr_2O_3) after the pull-in operation. The gold and the carbon atoms form the chemical bonding, and this leads to the stiction of the graphene in the gold surface. In addition, the amorphous and disordered surface of the Cr/Cr_2O_3 also leads to the highly uncontrolled pull-out operation and subsequently results the stiction of the graphene beam to the surface of Chromium oxide Cr_2O_3 contact.

The aim of this study is to achieve clear pull-in and pull-out operation of the graphene based NEM contact switches. To avoid the direct contact between the graphene to metal, a graphene layer is used as the contact material. The suspended graphene can contact with the contact graphene layer in the pulled-in state. The graphene is used as the anti-stiction material to reduce the stiction.

At first, in order to study the structural dimension graphene NEM contact switches, we conducted the Finite Element Method (FEM) based simulation of doubly clamped graphene based NEM contact switches. Firstly, we performed the FEM simulation of the switch with dimensions adapted from our earlier experimental device, based on nanocrystalline graphene (NCG). The results obtained in FEM simulations are consistent with the experimental results. Based on this, the FEM simulation for graphene NEM contact switches are carried out. Pull-in and Pull-out characteristics are analyzed for graphene NEM contact switches with different dimensions. This numerical model is used to study the scaling nature of the graphene NEM contact switches. We have found out the structural dimensions to achieve the possibility of sub-5 V and sub-1V graphene NEM contact switches.

We studied the interlayer resistance between the two graphene layers to understand the static graphene-graphene contact characteristics. Incoherent conduction between the graphene layers has observed. Interlayer tunneling between the two graphene layers is the fundamental conduction mechanism. We have studied the effect of in-situ annealing on the interlayer conduction. The interlayer resistance shows the significant reduction after the in-situ annealing. The interlayer resistance values at low temperature (5 K) is 4.8 kΩ and 800 Ω for before and after the in-situ annealing, respectively. This is attributed to the decrease in the interlayer distance after in-situ annealing.

Finally, we succeeded to demonstrate a graphene-to-graphene NEM contact switches with clear pull-in/pull-out characteristics. We achieved a graphene-to-graphene NEM contact switch with low pull-in voltage of <1 V, the steep switching slope of <10 mV/dec and high ON/OFF ratio $>10^5$. Owing to the high restoring force double clamped graphene beam the clear pull-out was achieved. And we have demonstrated the switches with more than 15 switching cycles. Due to the smooth atomic level contact between graphene-graphene layers, these remarkable graphene NEM characteristics were achieved.

Keywords: NEM contact switches, Graphene, Stiction, contact adhesion, Interlayer resistance, Interlayer tunneling, Twisted bilayer graphene, Finite Element Simulation (FEM).