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Modeling and Simulation of Perforated Graphene Nano-Electro-Mechanical (NEM) Switch by 3D Finite Element Simulation

The success of semiconductor industry depends on reliable performance and scalable manufacturing processes. As the size of semiconductor devices miniaturize to a few tens of nanometers and the demand for more applications keep increasing, another strategy will be needed. Nanoelecromechanical (NEM) switch is one of the promising devices to solve the problems of high power consumption in complementary metal-oxide semiconductor (CMOS) circuits [1]. NEM switch is built into logic circuits, relays, data storage and high frequency communication because of its high ON-OFF current ratio and low leakage current. However, conventional NEM switch still underperforms compared to the conventional semiconductor switch because of low reliability and high actuation pull-in voltage [2]. There are two common ways to reduce the mentioned problems such as the introduction of new materials and proper geometrical design [3, 4]. Graphene is one of the suggested 2D materials for this NEM switch application because of its superior properties namely high electron mobility excess of ~200,000 cm^2/V.s, high Young's modulus of ~1 TPa, superior current density capacity of ~108 A/cm^2, the ultra-thin thickness of ~0.335 nm and low resistivity of ~1 µ.Ω-cm [5-7]. For these reasons, graphene can provide better reliability and lower actuation pull-in voltage than conventional switch. An optimized geometrical design of NEM switch can also achieve the same objectives of better reliability and low actuation pull-in voltage. In the past few years, the geometrical design of graphene switch has changed to actuated bottom and top electrode to improve its mechanical stability and actuation pull-in voltage [8, 9]. Others introduced the concept of perforation in the beam structure of RF MEMS switch to increase the beam flexibility, lower the actuation pull-in voltage and enhance the switching speed [10]. There are also previous work who achieved different shapes of perforation in graphene sheets through experimental work [11]. However, to the best of our knowledge, similar perforation concept was not introduced in the graphene beam based NEM switch application to reduce the actuation pull-in voltage. In this work, we emphasize on the actuation pull-in voltage reduction for NEM switch by using 3D FEM modeling and simulation of multilayer graphene beam with and without the perforated structure of different geometrical dimensions. These simulation works were carried out with the FEM-based CAD tool IntelliSuite (8.8.5.1, IntelliSense, Lynnfield, MA, USA) under Thermo-electromechanical model. Firstly, we used the device structure and dimensions from previous work to validate our proposed model [12]. Based on this experimental work, we used 860 GPa as the Young's modulus for graphene in all the FEM simulations which are comparable to the values of 500 GPa measured for the multilayer graphene between 2 to 8 nm of thickness [13]. Afterwards, we studied the design parameters of the NEM switches, such as, graphene beam length *L*, thickness *t*, and air gap thickness *g* because of their influence on the mechanical and electrical properties of the switch. The length and thickness of the graphene beam were varied from 0.8 µm to 1.5 µm and 3.0 nm to 9.0 nm, respectively. The air gap thickness was varied from 50 nm to 130 nm. The optimized design from this initial model was then re-analyzed with a perforated beam. In the perforated beam as shown in Figure 1, we varied the hole length *HL*, hole width *HW*, distance between two holes *DL* and number of hole column *CN*. This perforation is expected to reduce the biaxial residual stress and the graphene beam stiffness, thus contributing to the reduction of graphene beam buckling-effect to increase the switch lifetime and reduced actuation pull-in voltage. This analysis confirms that the small air gap, long and thin graphene beam contribute to the actuation pull-in voltage reduction as shown in Figure 2. The introduction of perforation in the graphene beam further reduced the actuation pull-in voltage by 9% and 32% for the 6-column and 12-column of hole, respectively. Their hysteresis value is also reduced by 25% for the 12-column of hole. These results presented here is expected to expedite improvements in the working parameter and dimension for low voltage operation of graphene NEM switch device fabrication.

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Figures

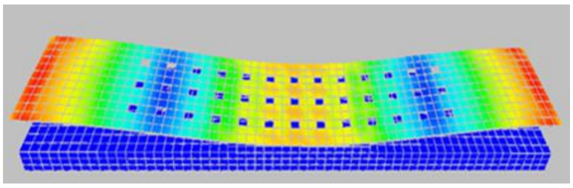

Figure 1: Graphene NEM switch with bottom actuation electrode during 'on-state' mode for the perforated graphene beam

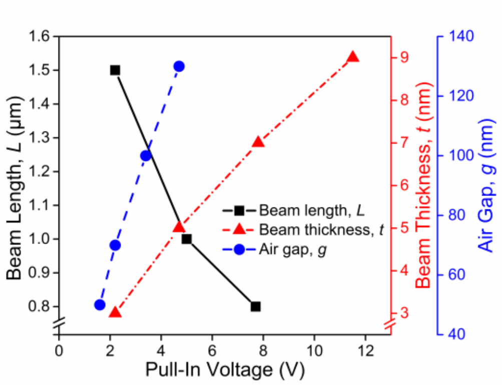

Figure 2: Trends of actuation pull-in voltage against beam length, beam thickness and air gap thickness of graphene NEM switch device.