Finite element method simulation of three-terminal graphene NEMS switches

JAIST [1], Univ. of Southampton [2], ○K. Jothi Ramalingam[1], M. Manoharan[1], Hiroshi Mizuta[1,2]

E-mail: jothi@jaist.ac.jp

Graphene possesses an exceptional mechanical and electrical properties, and combining these properties makes graphene a promising candidate for Nano-Electro-Mechanical Systems (NEMS) [1]. A three-terminal graphene NEMS switch (Figure. 1(a)) is expected to achieve a very abrupt switching with Subthreshold swing S < 60 mV/dec. Structural dimensions of the graphene cantilevers and the air gap are key structural parameters for the design of the low-voltage graphene NEMS switch. In the present work, we present comprehensive three-dimensional FEM (finite-element-method) analysis of the pull-in [2] and pull-out voltages of the graphene cantilevers and comparison with some recent experimental results.

We conducted the FEM simulations of the graphene NEMS switch structures by using IntelliSuite software. Figure. 1 (a) shows a schematic of our new 3-terminal graphene NEMS switch with a pair of multi-layer graphene cantilevers set in face which are connected to the source and drain electrodes. This graphene NEMS switch features a graphene-based bottom gate which enables the graphene cantilever pairs pulled in onto the graphene bottom-gate to connect the channel (ON state, Figure. 1(b)) and pulled them out to disconnect the channel (OFF state). A top-gate was also introduced to control the pull-out voltage of the graphene cantilever. Thickness of the graphene bottom gate was assumed to be 2nm, and the length and width of the beam were 500 nm X 500 nm, and the air gap was set to be 90 nm. Thickness of the graphene cantilever was varied from 1 nm to 3 nm, by assuming the number of graphene layers from 4 to 10. In order to analyze the pull-in and pull-out characteristics for the cantilever structure, the voltage applied between the bottom graphene gate and the graphene cantilever was first increased till the pull-in was confirmed and then decreased back to zero. Figure. 1(c) shows the pull-in / pull-out characteristics obtained for the graphene cantilevers of 1, 2 and 3 nm in thickness with the pull-in voltages were approximately 0.7 V, 2.0 V and 3.5 V, respectively. In order to clarify the impact of the graphene bottom gate, we showed in Figure. 1(d) the results when the voltage was applied to the substrate back gate. With the substrate (Si) back-gating, the pull-in voltages were evaluated to be 1.0 V, 3.0 V and 4.5 V, respectively. This result signifies that introduction of the graphene bottom-gate leads to reduction of the pull-in voltage by 25 – 30%. Detailed discussion on the cantilever structural design and the pull-in / pull-out characteristics will be presented along with the comparison with recent experimental data.

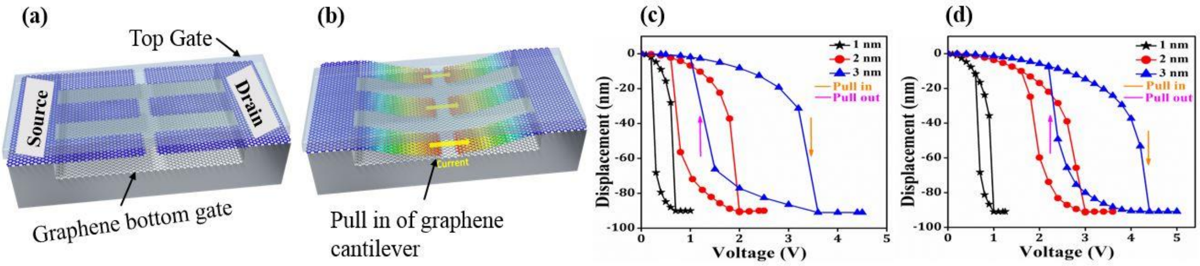

Figure. 1 (a) Schematic of graphene cantilever structure with topgate. (b) Deflection of cantilever structure under applied voltage. (c) Pull in and pull out voltage of the graphene bottom gate – graphene cantilever structure (d). Pull in and pull out voltage of the substrate back gate (Si) – graphene cantilever structure.

Acknowledgements

This research was supported by Grant-in-Aid for Scientific Research (S) No. 25220904 from Japan Society for the Promotion of Science.

References

[1] J. Sun, W. Wang, M. Muruganathan, and H. Mizuta, Appl. Phys. Lett. **105**, 033103 (2014).
[2] S. Pamidighantam, R. Puers, K. Baert, and H. a C. Tilmans, J. Micromechanics Microengineering **12**, 458 (2002).