Finite element method simulation of three-terminal graphene NEMS switches

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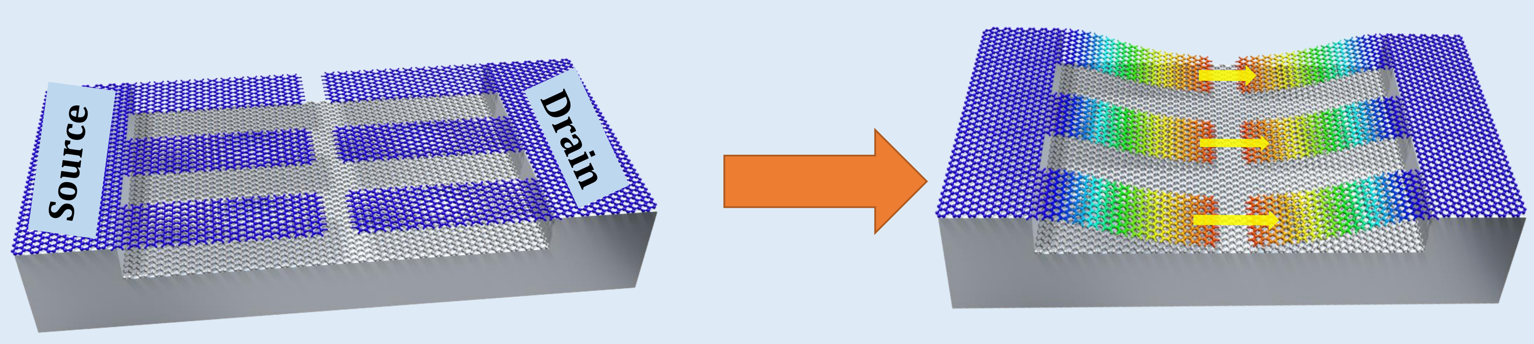
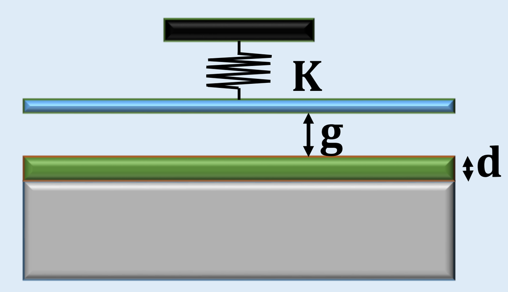
Introduction

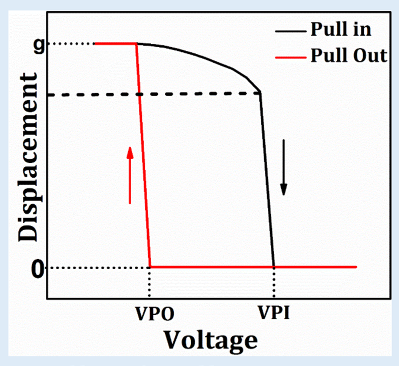
- Graphene based NEMS[1] switch is expected to achieve a very abrupt switching with Subthreshold swing S < 60 mV/dec.
- NEMS switch is experiences a hysteresis, during the ON/OFF operation.
- The mechanical hysteresis is due to pull in and pull out phenomenon of NEMS.
- For Volatile switches, the mechanical hysteresis should be reduced as low as possible.
- An actuation electrode model is employed in order to reduce the hysteresis.
- In the present work, we present a comprehensive three-dimensional FEM (finite-element-method) analysis of the pull-in [2] and pull-out voltages of the graphene cantilevers with actuation electrode.
- Schematic of switching operation of graphene NEMFET is shown in figure.



NEMFET Background



Schematic of electrostatically actuated mechanical switch



Pull in/ pull out characteristic curve

Analytical equations:

$$\text{Pull in } (VPI) = \sqrt{\frac{8Kg^3}{27\varepsilon_0 A}}$$

$$\text{Pull out}(VPO) = \sqrt{\frac{2\,Kgd^2}{\varepsilon_r{}^2\varepsilon_0 A}}$$

$$K = \frac{2Ewt^3}{3l^3}$$

g- thickness of the air gap
A- Area of contact electrodes
d- thickness of dielectric layer
K-Spring constant
ε_r- relative permittivity of dielectric layer.
ε_o- permittivity of free space.

FEM Simulation in IntelliSuite

- The FEM (Finite Element Method) simulation of the graphene cantilever switch is conducted using IntelliSuite software.

Structural dimensions
- ✓ Cantilever thickness 1 to 3 nm
- ✓ Bottom graphene layer 2 nm
- ✓ Air gap is 90 nm

Device model.
- ✓ Si-Back gate model (SG)
- ✓ Graphene bottom gate model (GG)
- ✓ Actuation Electrode(Au) model (AE)

Device types

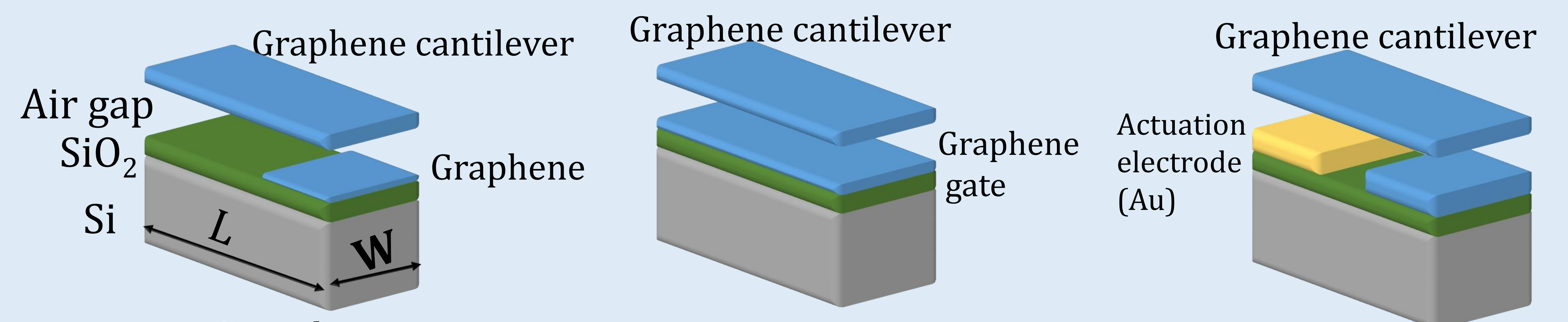
Si-Back gate types.(SG)
- ✓ SG1-0.5 X 0.5um
- ✓ SG2- 1 X0.5 um
- ✓ SG3-0.5 X 1 um
- ✓ SG4-1 X 0.5 um

Activation Electrode types(GG).
- ✓ AE1-0.5 X 0.2um
- ✓ AE2- 1 X 0.25 um
- ✓ AE3-0.4 X 0.2 um

Graphene bottom gate types (AE).
- ✓ SG1-0.5 X 0.5um
- ✓ SG2- 1 X 0.5 um
- ✓ SG3-0.5 X 1 um
- ✓ SG4-1 X 0.5 um

[0.5x0.5 um] → (Width x Length)

Device geometry

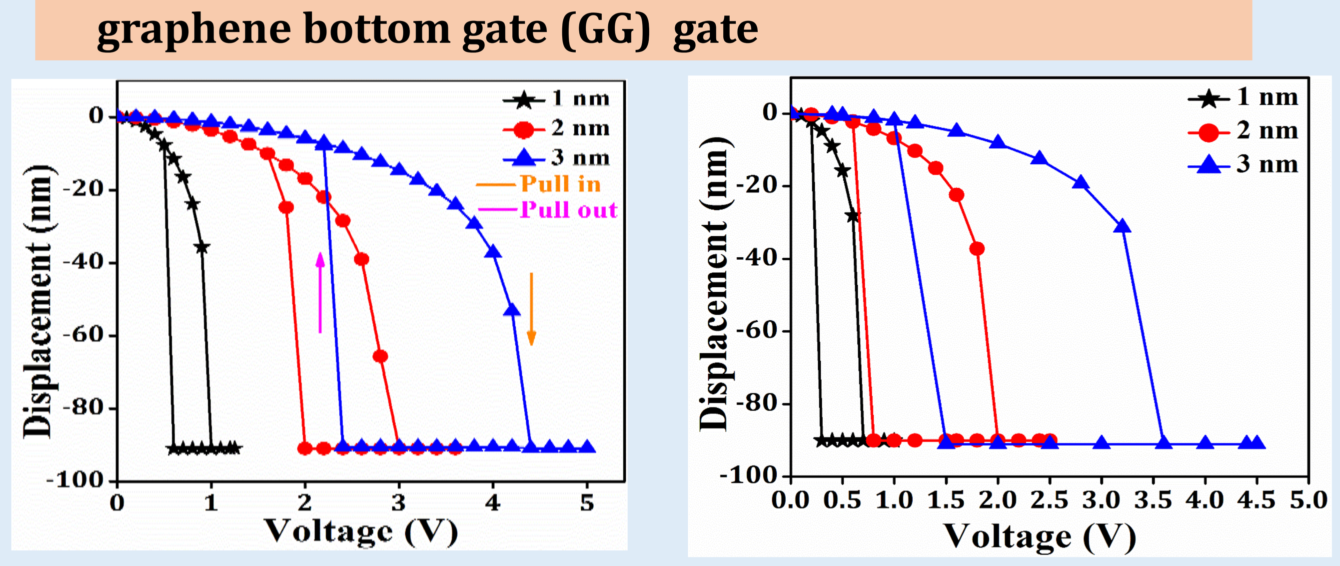


Si-Back gate model(SG)

Graphene bottom gate model(GG)

Actuation electrode model(AE)

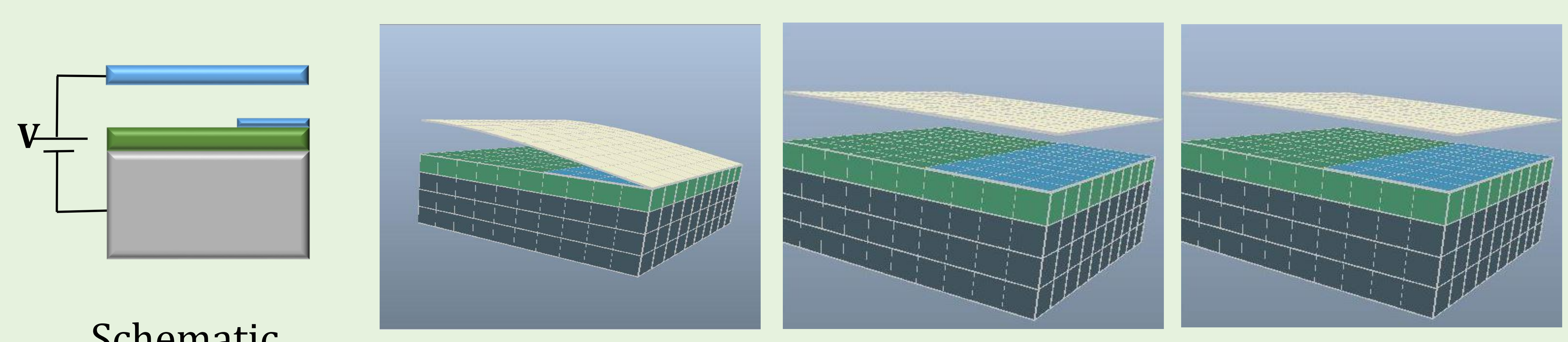
Pull in / Pull out Hysteresis of Si-Back gate (SG) and graphene bottom gate (GG) gate



0.5 X 0.5 um(SG1)

0.5 X 0.5 um (GG1)

Cantilever motion (Pull out) in Si-Back gate model (SG1-2nm)



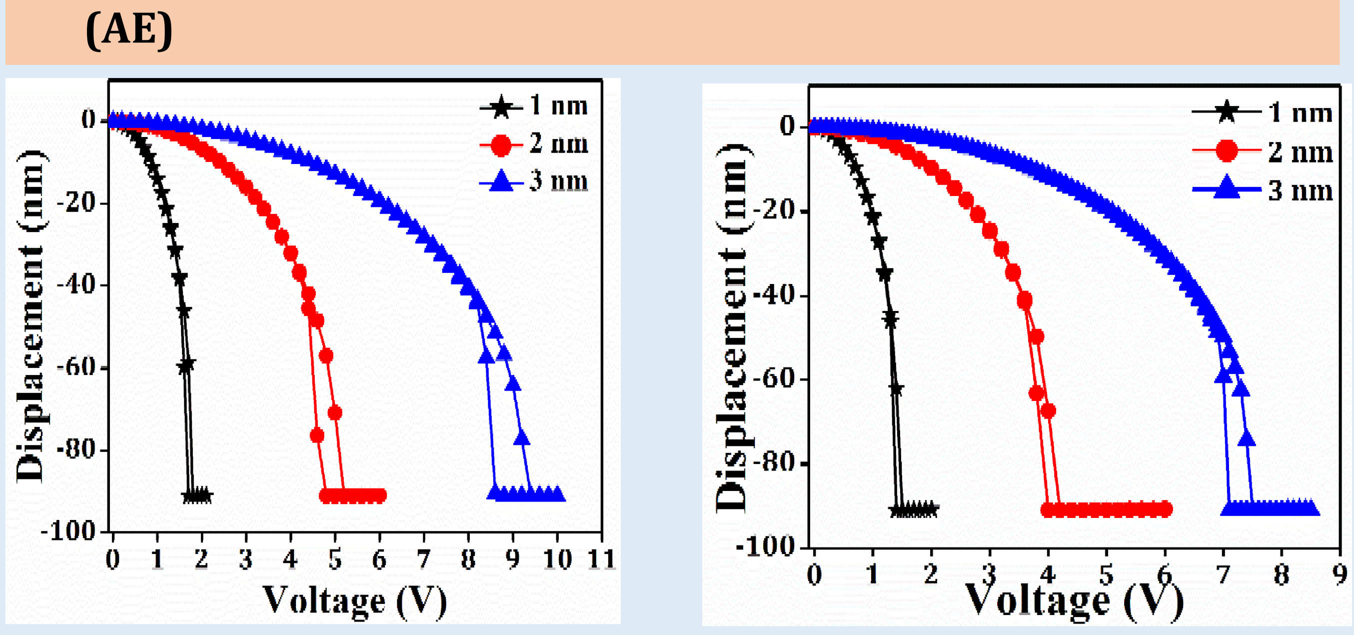
Schematic

@ 1.8 V

@ 1.6 V

@ 1.4 V

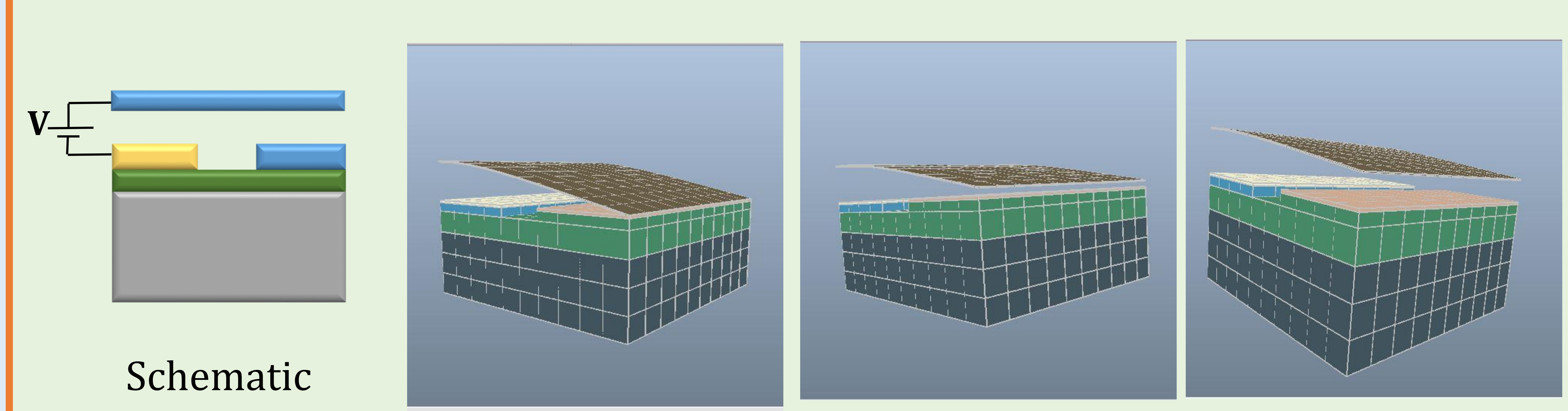
Pull in / Pull out Hysteresis of Actuation electrode model (AE)



0.5 X 0.2 um (AE1)

0.5 X 0.25 um (AE2)

Cantilever motion (Pull out) in Actuation electrode model (AE1-2 nm)



Schematic

@ 4.8 V

@ 4.6 V

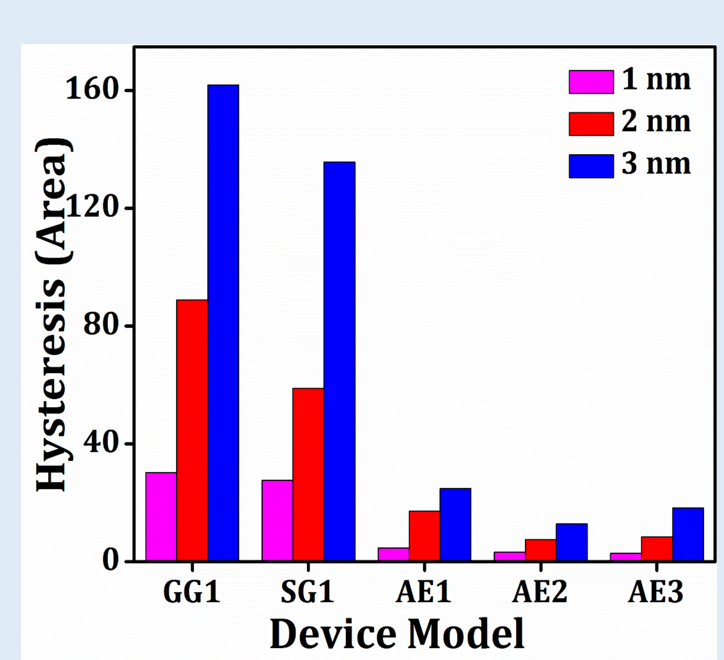
@ 4.4 V

Pull in voltage summary of SG and GG gate model

Thickness versus Dimension	0.5 X 0.5 um	0.5 X 1um	1 X 0.5 um	1 X 1 um
SG 1 nm	1.0 v	0.2 v	1.0 v	0.2 v
SG 2 nm	2.5 v	0.6 v	2.5 v	0.6 v
SG 3 nm	4.4 v	1.1 v	4.4 v	1.1 v
GG 1 nm	0.7 v	0.15 v	0.7 v	0.15 v
GG 2 nm	2.0 v	0.5 v	2.0 v	0.5 v
GG 3 nm	3.5 v	0.9 v	3.5 v	0.9 v

[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).

Hysteresis analysis



Conclusion

- The Actuation electrode model achieved efficient reduction of hysteresis in NEMS Switch and the pull in / pull out hysteresis is highly depends on the width and length of actuation electrode.
- The obtained hysteresis results does not taken into account of short range forces (Van der Waals force).
- The effect of short range forces further to be investigated.

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