Analytical Results in Nanoscale EMS Modeling

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Continual modeling of the nanoscale electromechanical system (NEMS) is a very powerful tool as analytical expressions can be derived for the pull-in condition, for example. This approach allows me to trace the importance of atomistic corrections for nanoscale devices, which have been often neglect before. The model starts with an expression for an elastic response of the NEMS device which is given by: $T = k(h-x)^2/2$, and the external (electrostatic) force which is the gradient of the energy given by: $V = C\varphi^2/2$
I include the van der Waals energy term: $W \simeq \epsilon x^{-\alpha}$
and write analytically the pull-in voltage and pull-in gap as functions of the device stiffness, k, the device capacitance, C, and the van der Waals energy, W, which may be arbitrary functions:

$$x_o = hA_1 \frac{1}{2}\left(1+\sqrt{1+A_2\frac{W(x_o)}{kh^2}}\right)$$

$$V_o = B_1 \frac{\sqrt{2kh}}{C(x_o)}\sqrt{\frac{1}{2} - B_2\frac{W(x_o)}{kh^2} + \frac{1}{2}\sqrt{1+A_2\frac{W(x_o)}{kh^2}}}$$

here (in case of planar NEMS cantilever switch and Lennard-Jones potential) the four constants are $A_1=3/2$, $B_1=2^{1/2}/3$, $A_2=36$, and $B_2=36$, describing the specific dependence of C and W on x, the internal coordinate of the NEMS device.

As a result of the van der Waals force, the NEMS device cannot operate at very small gaps, h. The critical gap, h_c, is about 2 nm for the switch with following material parameters: $k \sim W/\mathrm{nm}^2$, and $C \sim 2\, k^{1/2}/(3\ \mathrm{V/nm})$. Figure 1 shows that neglecting the van der Waals correction to the pull-in gap, x_o, one underestimates the critical pull-in voltage by 15 %.

The selfconsistent solution for the pull-in gap is plotted in Fig. 2. Again, the neglecting the van der Waals terms results in very non-physical divergence of the pull-in gap when approaching the critical distance h_c.

In conclusion, a new approach revealed what are the atomistic corrections to the NEMS modeling, and at which system size the standard MEMS theory breaks.

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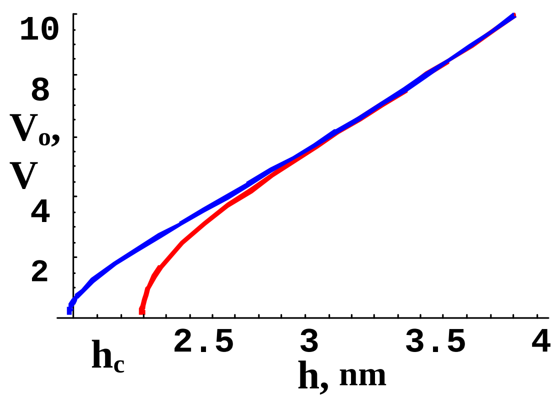

Figure 1 The pull-in voltage as a function of the gap. Blue (top) curve represents the analytical result explained in the text. Red (bottom)curve shows the dependence in neglecting the van der Waals correction for the pull-in gap.

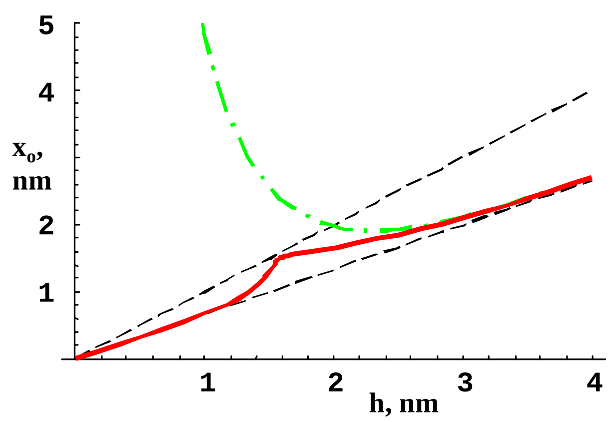

Figure 2 The pull-in gap as a function of the initial device gap. Red solid curve represents the selfconsistent analytical result. Green dash-dotted curve shows the dependence in neglecting the van der Waals correction. Dashed lines are guides for eye, shown a classical range of MEMS operation.