Non-obtrusive lifetime characterization technique for RF-MEMS

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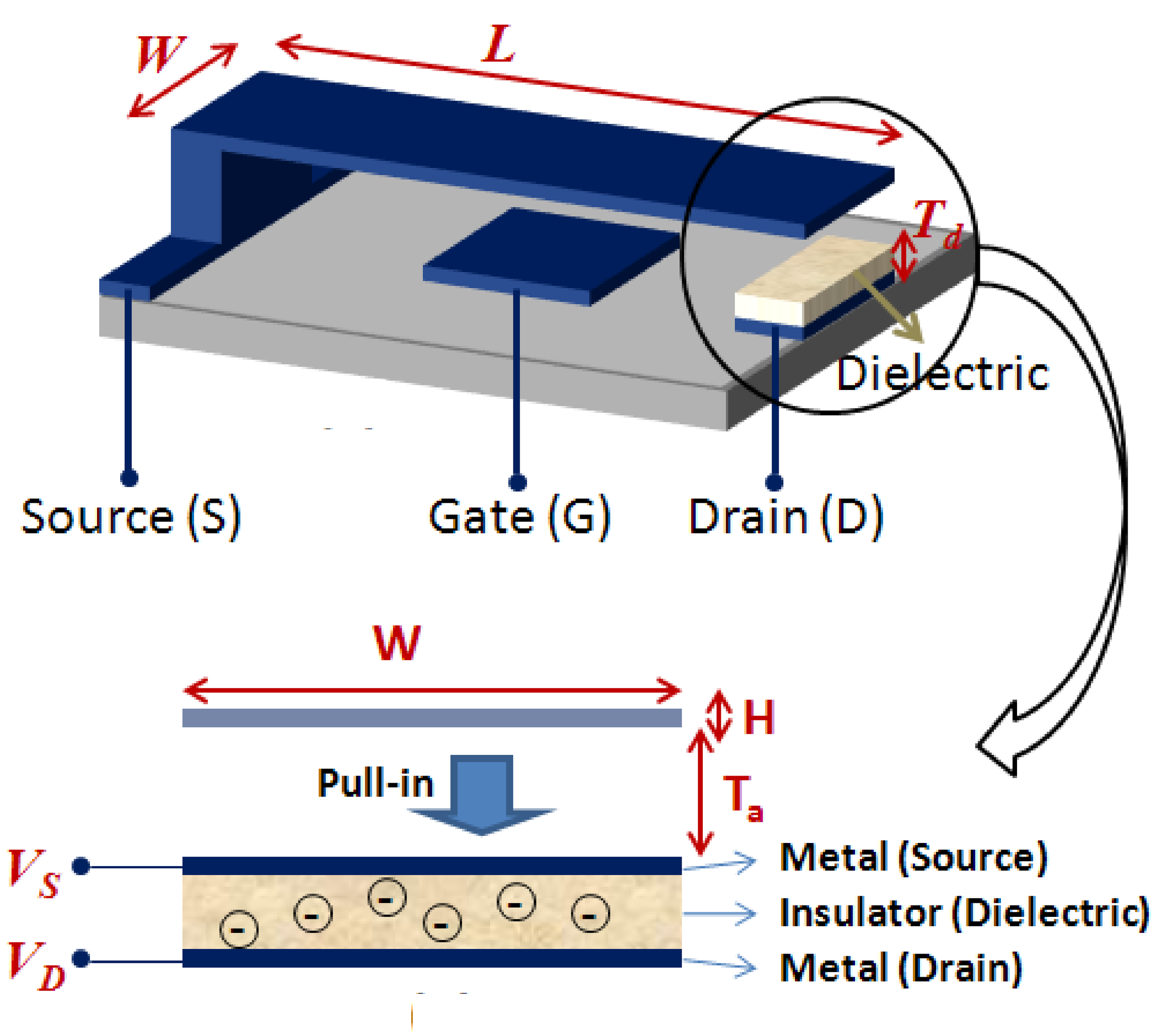
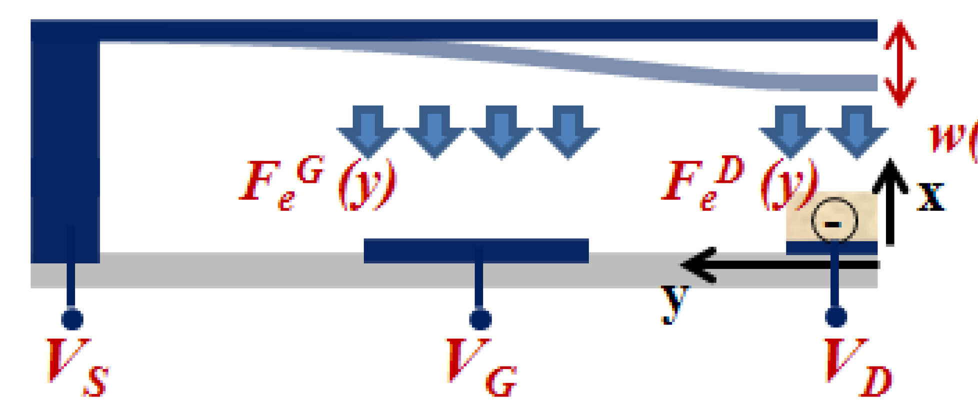
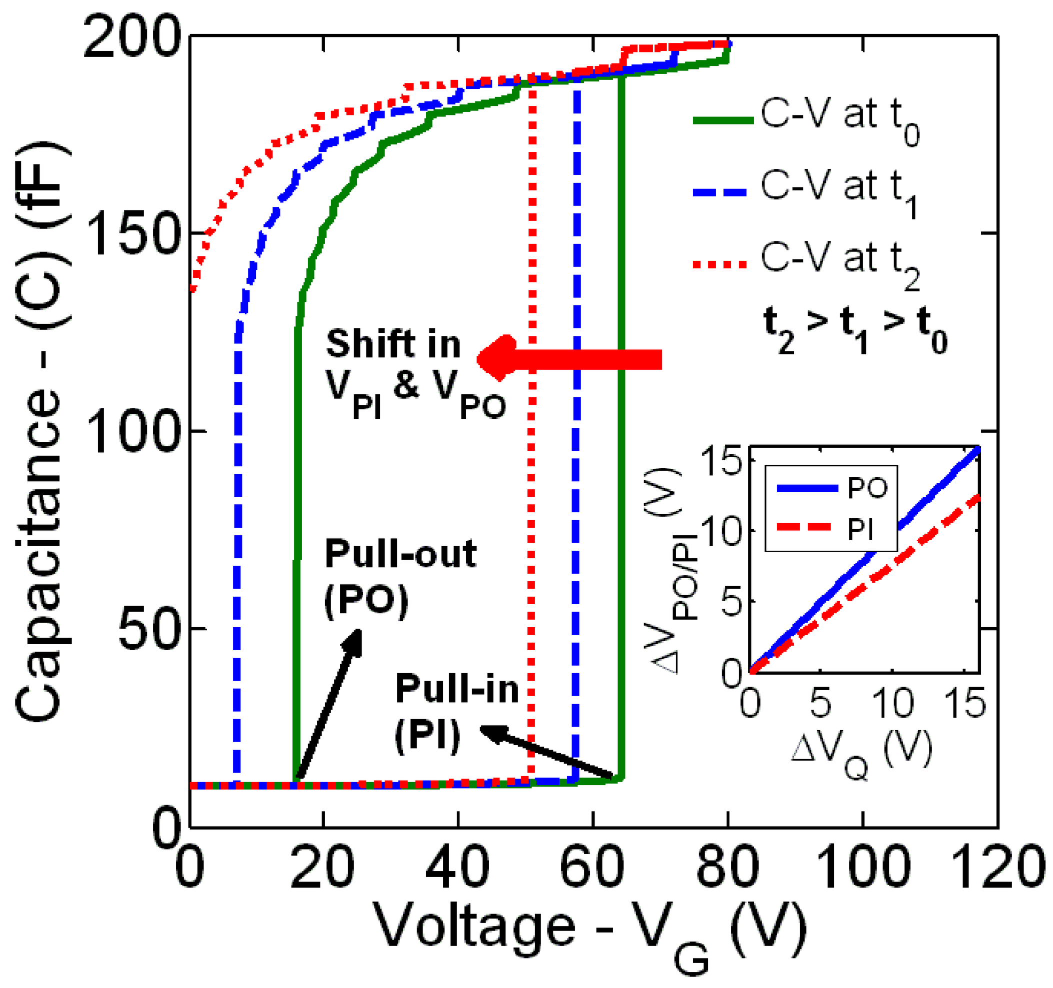
RF-MEMS cantilever switch





$$\rho WH\frac{\partial^2 w(y,t)}{\partial t^2}+b\frac{\partial w(y,t)}{\partial t}+\frac{EWH^3}{12(1-\nu^2)}\frac{d^4 w(y,t)}{dy^4}=\begin{cases}F_e^G(y)\\F_e^D(y)\end{cases}=\begin{cases}\dfrac{W\varepsilon_0(V_G)^2}{2(w(y,t))^2}\\[2ex]\dfrac{W\varepsilon_0\varepsilon_r^2(V_D-\Delta V_Q(t))^2}{2(T_d+\varepsilon_r w(y,t))^2}\end{cases}$$

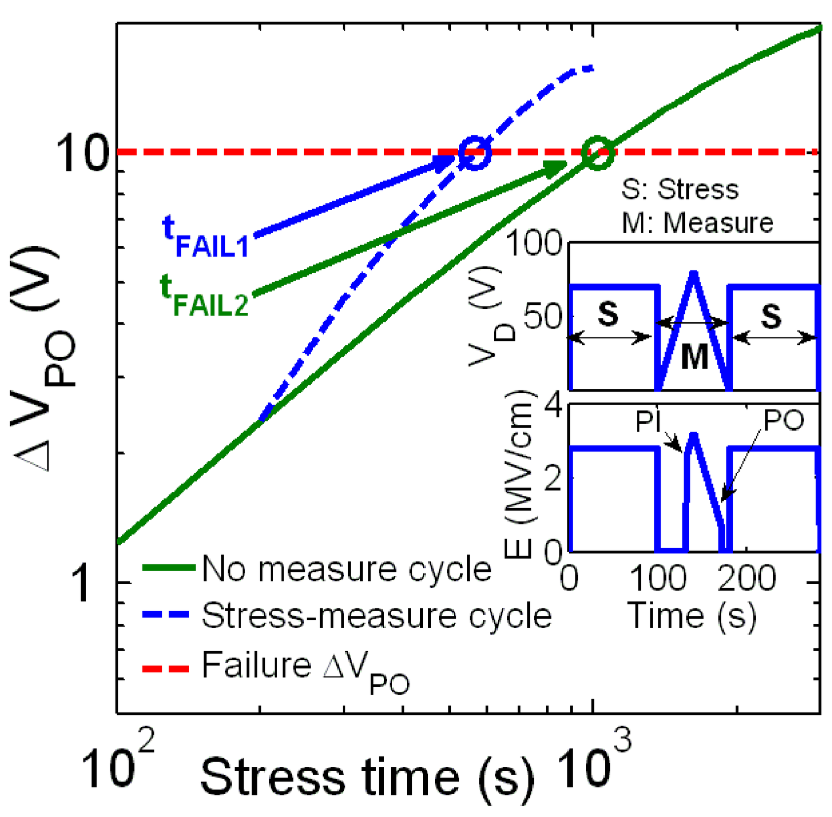
$$\Delta V_Q(t)=-\frac{q}{\varepsilon_0\varepsilon_r}\int_0^{T_d}(T_D-x)\,n_T(x,t)\,dx$$



Charge in dielectric is represented by an effective shift in drain voltage – ΔV_Q.

Presence of non-zero ΔV_Q results in actuation voltage shifts of RF-MEMS.

Why do we need non-obtrusive characterization technique?



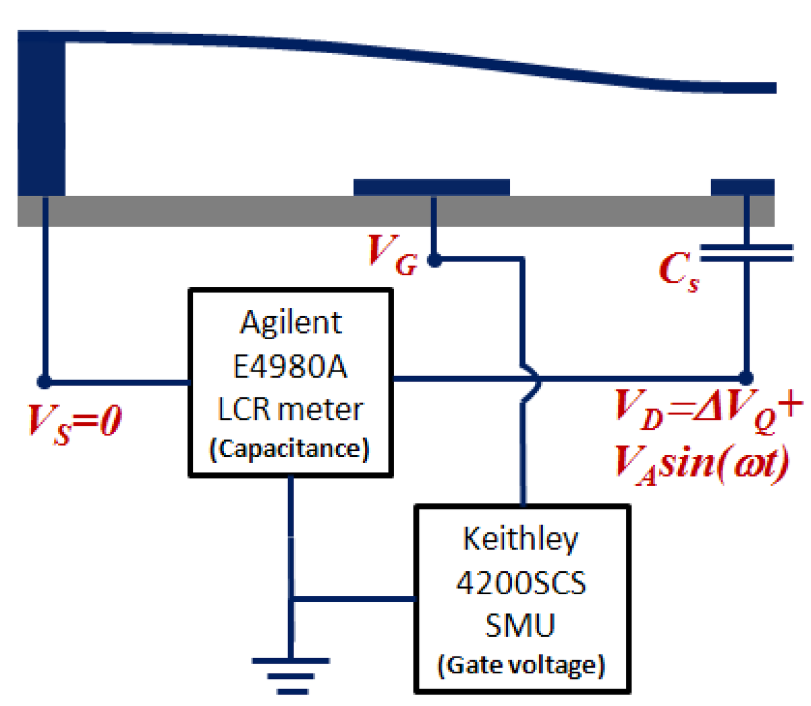
Simulation of a typical characterization procedure for RF-MEMS lifetime using consecutive stress-measure cycles, comparing expected $\Delta V_{PO}(t)$ with (*Measured*) and without (*Actual*) measure step. The device is said to have failed when DV_{PO} exceeds a preset value of 10V.

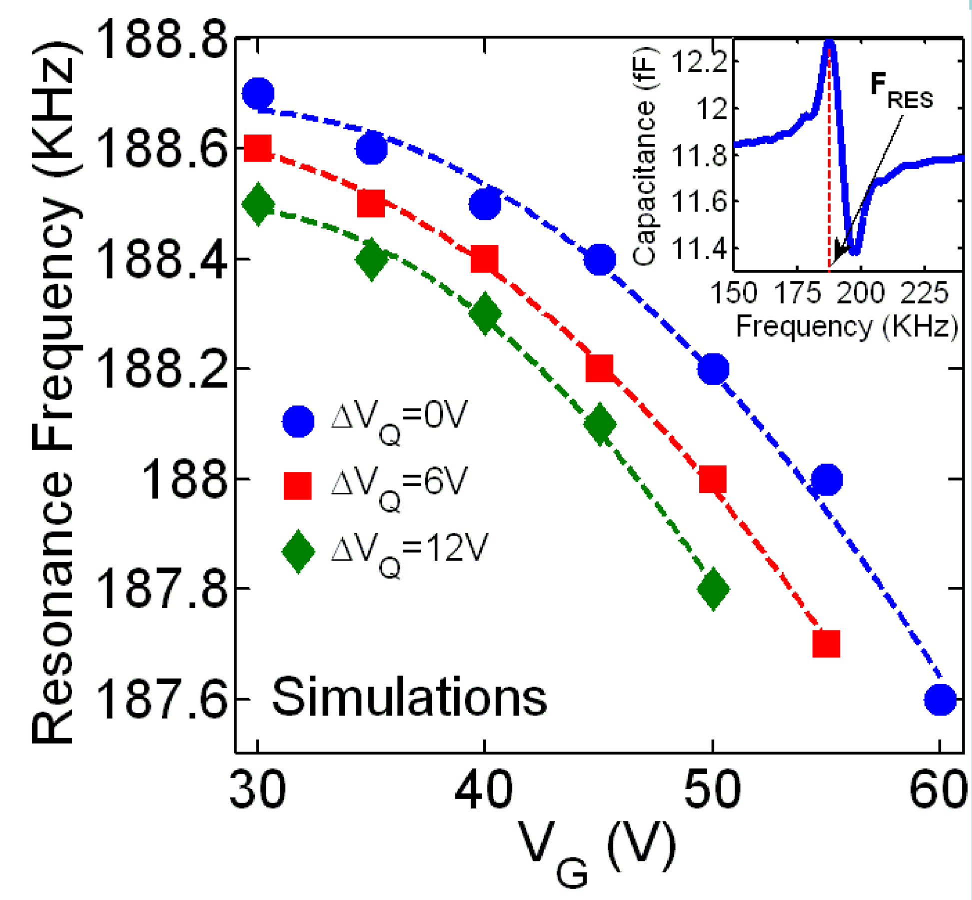
Characterization using stress-measure cycles yields pessimistic estimates of device lifetime.

Other non-obtrusive characterization techniques for dielectric charging:

1) Kelvin Probe Force Microscopy (KPFM) (U. Zaghloul et. al., JVSTA, 2011)
   - Requires exposed dielectric surfaces.
2) Optical resonance detection (J. W. Lee et. al., JMEMS, 2010)
   - Requires optical access to the membrane.
3) Center-shift method (R. W. Herfst et. al., ICMTS, 2006)
   - Sensitivity and accuracy in determining ΔV_{PO} is unknown.

Measurement setup and simulation



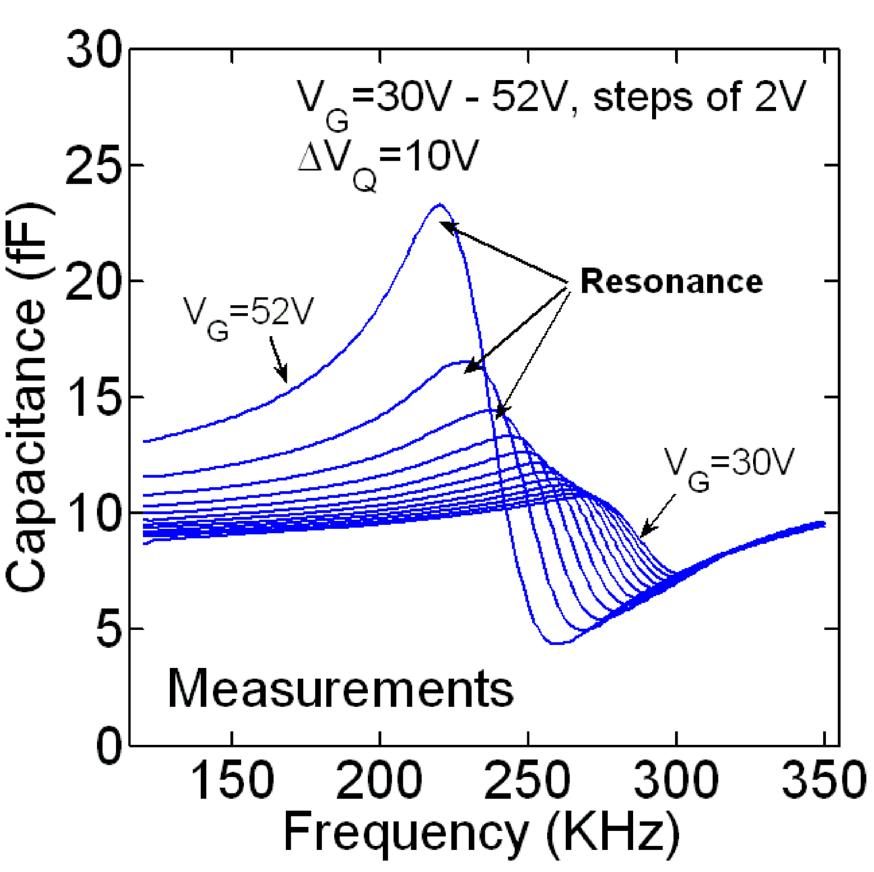


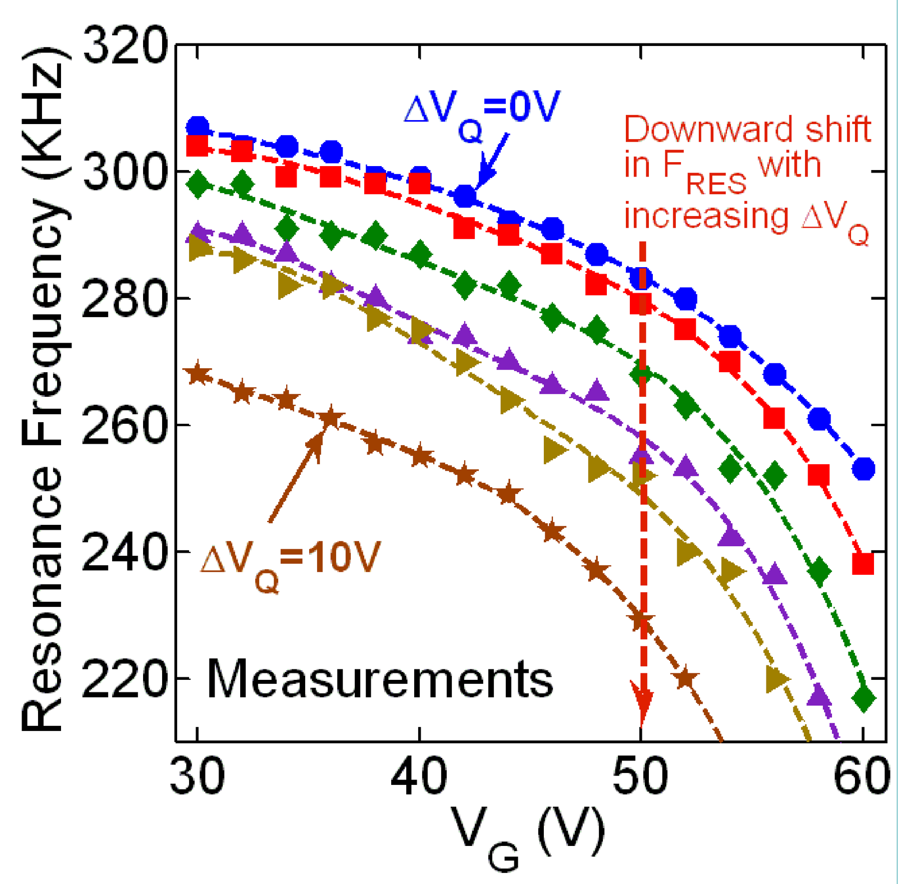
Capacitance of the cantilever RF-MEMS device is measured with varying AC measurement frequency. Resonance frequency (FRES) is determined as the frequency of peak in measured capacitance.

From simulations, FRES is found to decrease with increasing VG (spring-softening effect) and increasing dielectric charge (increasing DVQ).

The complete electronic nature of this characterization technique opens possibilities for measurements on packaged devices, as well as for in-situ implementation of degradation detection circuits.

Resonance frequency measurements

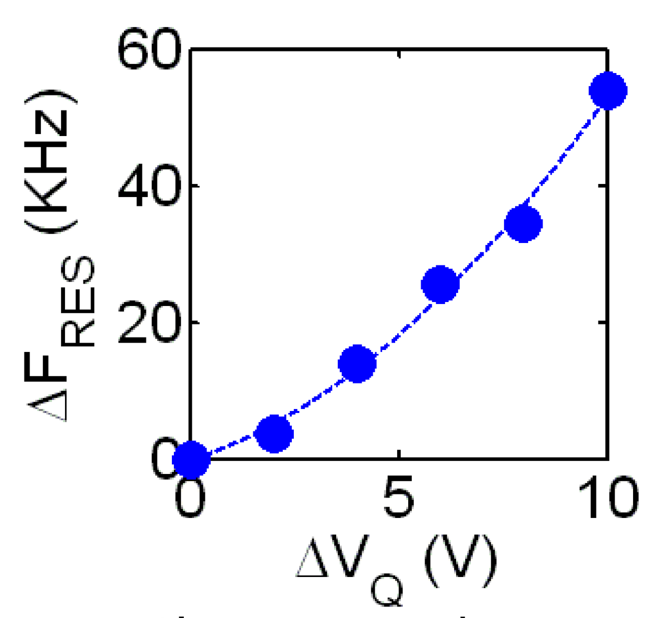




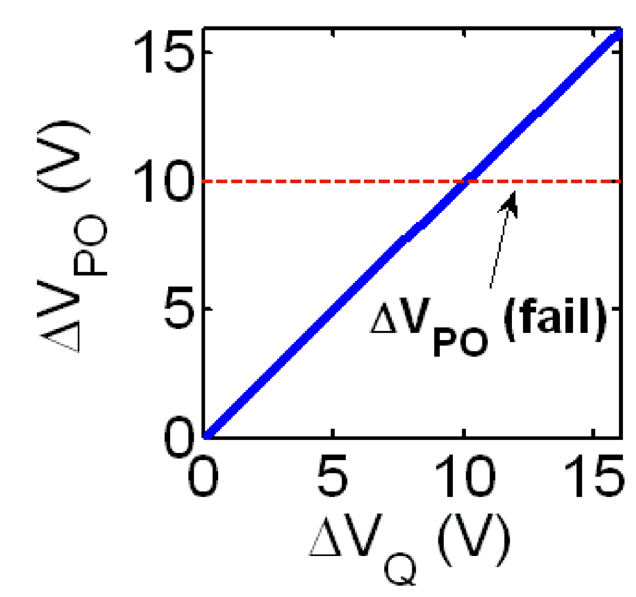
Measurement of capacitance-frequency characteristics of a **packaged** RF-MEMS switch for different gate voltages (V_G) and voltage shifts due to dielectric charging (ΔV_Q) were performed to obtain resonance frequencies for each operating conditions. The obtained measurement data is found to have trends similar to those obtained from simulations.

Dielectric charging (represented by ΔV_Q) is characterized by a downward shift in F_{RES} for a given V_G.

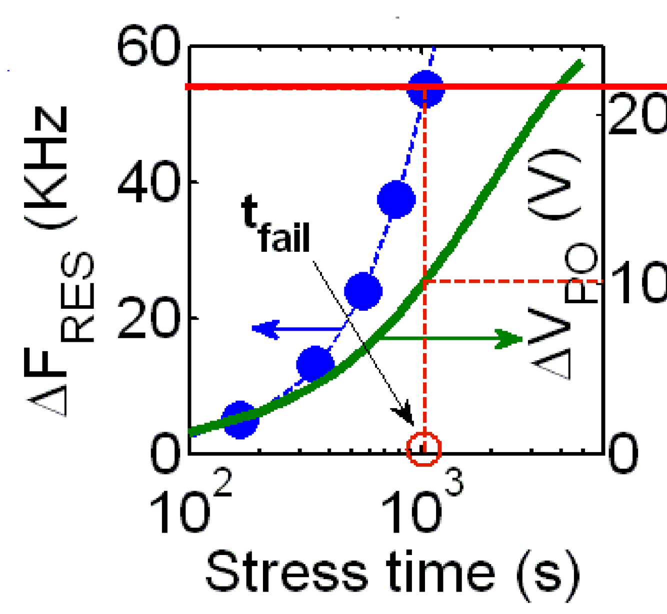
Lifetime determination



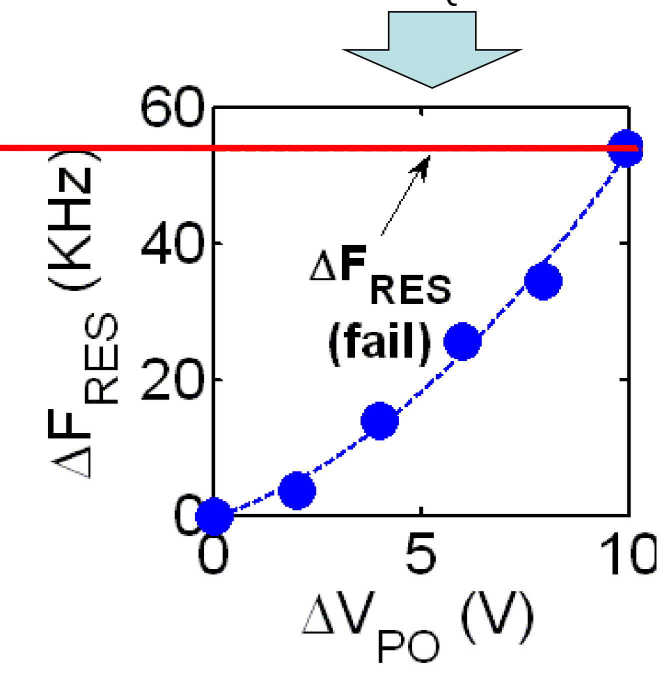
Plot measured ΔF_{RES} v/s dielectric charge (ΔV_Q)



Plot expected ΔV_{PO} as a function of ΔV_Q,



Determine RF-MEMS lifetime from measured transient of ΔF_{RES}.



Determine ΔV_{PO} for a given measured ΔF_{RES}.

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