# Small Signal Modeling and Fabrication of SWCNT Resonators

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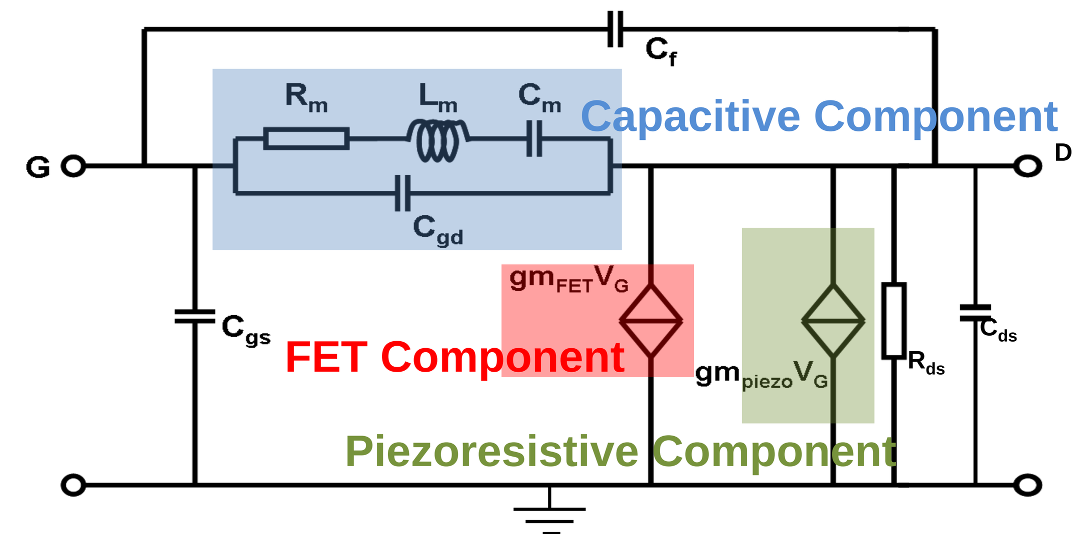
## Abstract

A small signal model for Single-Walled Carbon Nanotube (SWCNT) resonators is under investigation. In this project, the main focus is on the exploitation of the piezoresistive modulation and its use to build oscillators based on resonant body CNT FETs.

A novel precise resist-assisted dielectrophoresis (DEP) method to fabricate SWCNT resonators is proposed for the electro-mechanical parameter extraction of CNT resonators for the small signal model. Various types of self-aligned SWCNT FETs are achieved. We also investigate the optimized DEP parameters for higher yield CNT resonator fabrication.

This self-assembled technique could enable bottom up fabrication for future NEMS devices for RF or sensing applications.

## Small Signal Modeling




$$i_{tot} = i_{cap} + i_{FET} + i_{piezo}$$

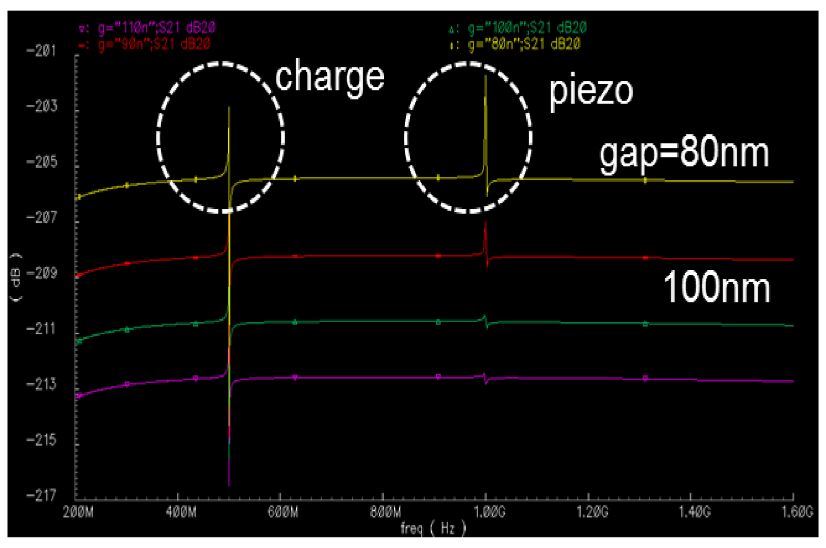
$$C_{gd} = \frac{2\pi\varepsilon l}{\ln\left(\frac{d}{a} + \sqrt{\frac{d^2}{a^2} - 1}\right)} \qquad Rm = \frac{\gamma}{\eta^2} = \frac{\sqrt{km}}{Q\eta^2}$$

$$Lm = \frac{m}{\eta^2} \qquad Cm = \frac{\eta^2}{k}$$

## For low resonance frequency CNT resonators measured directly

### FET Detection

$$gm(\omega) = gm_0 * \frac{F_{el}/m_{eff}}{\sqrt{(\omega^2 - \omega_0^2)^2 + \left(\frac{\omega\omega_0}{Q}\right)^2}}$$

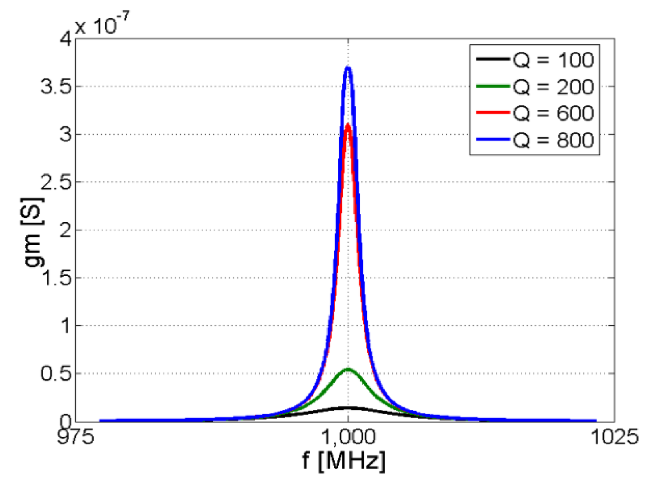



### Piezoresistive Detection

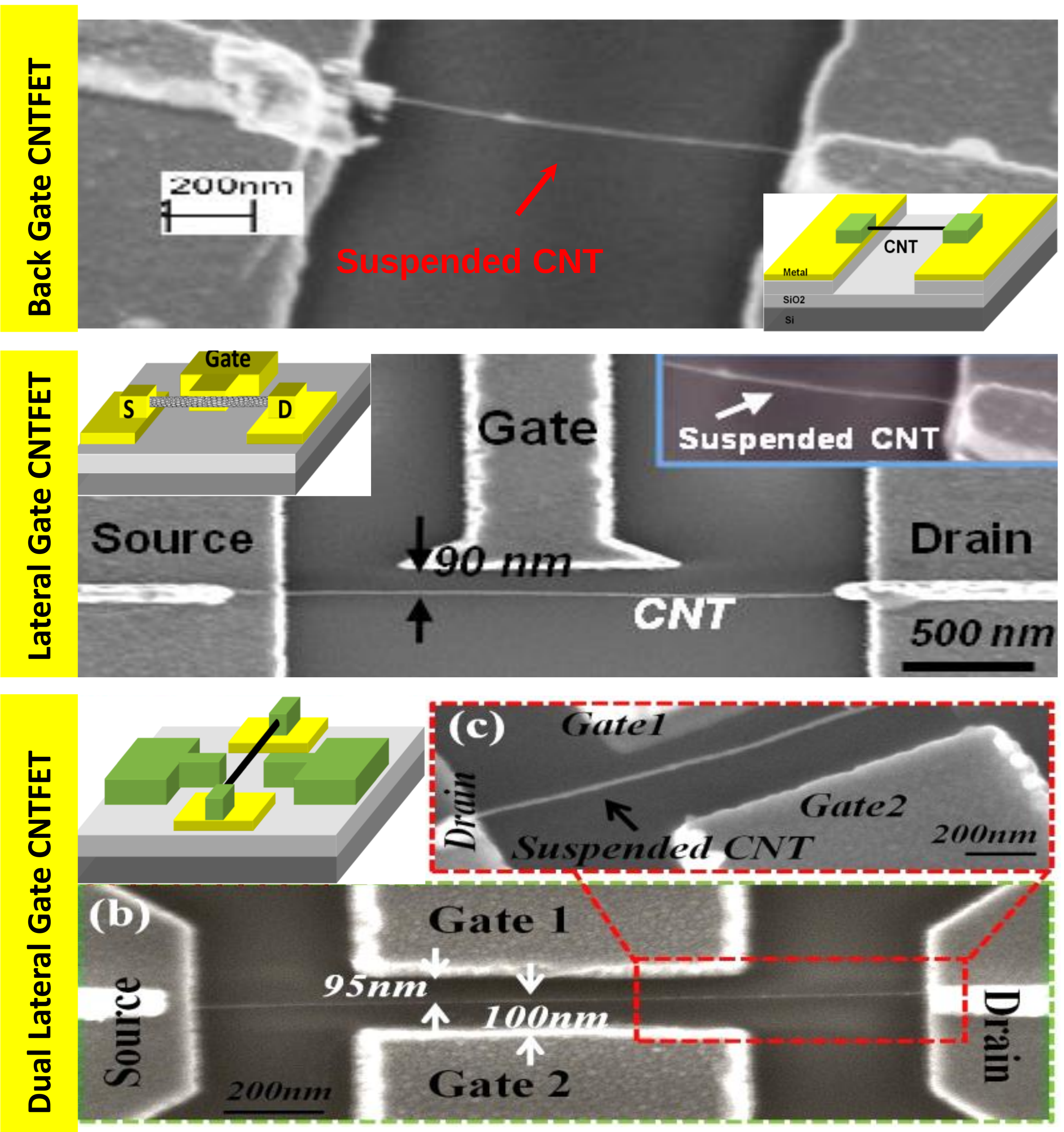
$$gm(\omega) = -\frac{V_D}{R^2}\frac{\partial R'(\omega)}{\partial \varepsilon(z(\omega))}\frac{\partial \varepsilon(z(\omega))}{\partial z(\omega)}\frac{\partial z(\omega)}{\partial F_{el}}\frac{\partial F_{el}}{\partial V_g}$$

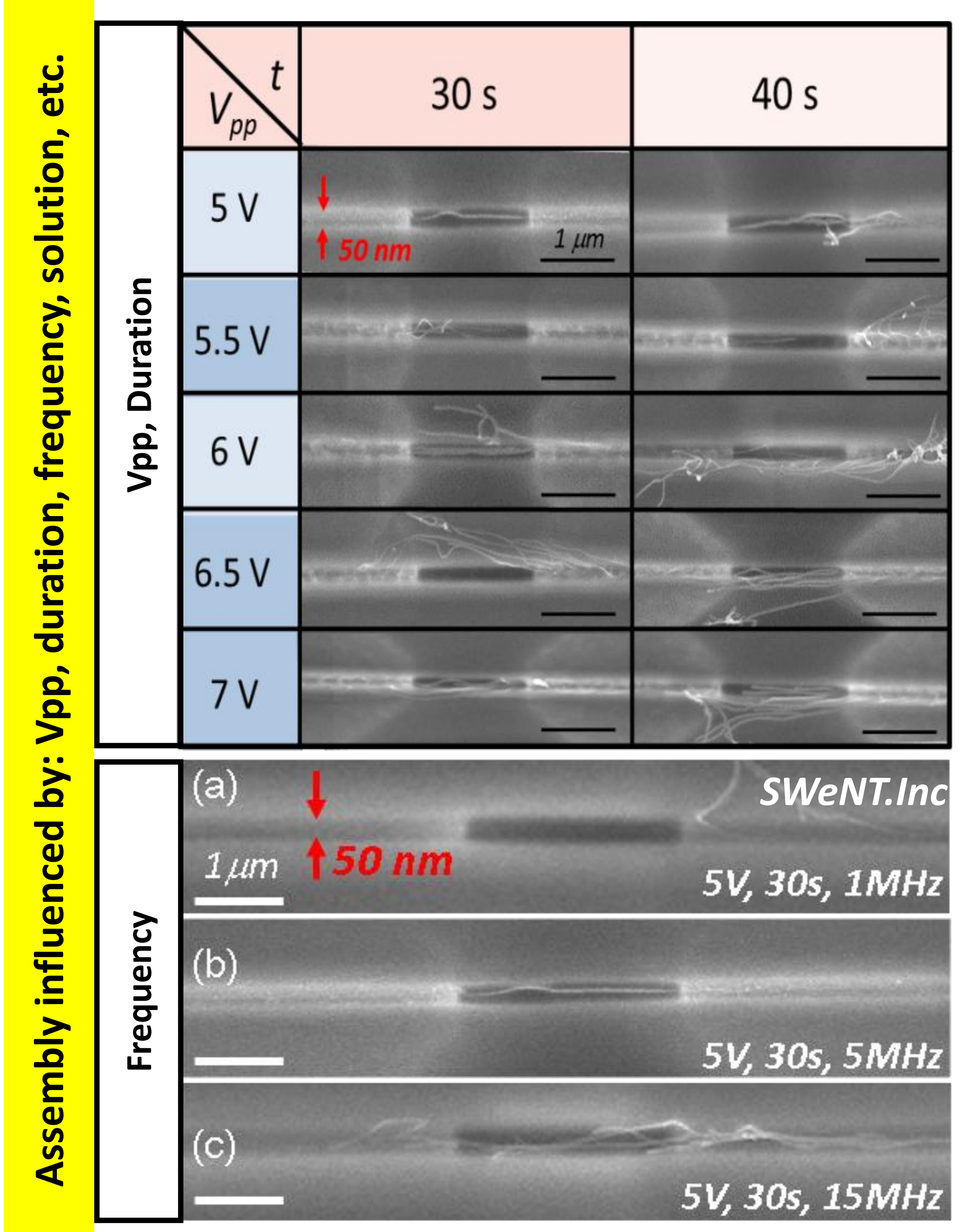
$$= -\frac{V_D}{R^2}\frac{1}{|t|^2}\frac{h}{2e^2}\frac{\frac{dE_g}{d\varepsilon}}{\kappa T}\exp\left[\frac{E_g^0}{\kappa T} + \frac{\frac{dE_g}{d\varepsilon}}{\kappa T}\left(\sqrt{1+\left(\frac{2z(\omega)}{l_0}\right)^2} - 1\right)\right]\frac{1}{l_0^2\sqrt{1+\left(\frac{2z(\omega)}{l_0}\right)^2}}\frac{[z(\omega)]^2}{|\upsilon_g|}$$

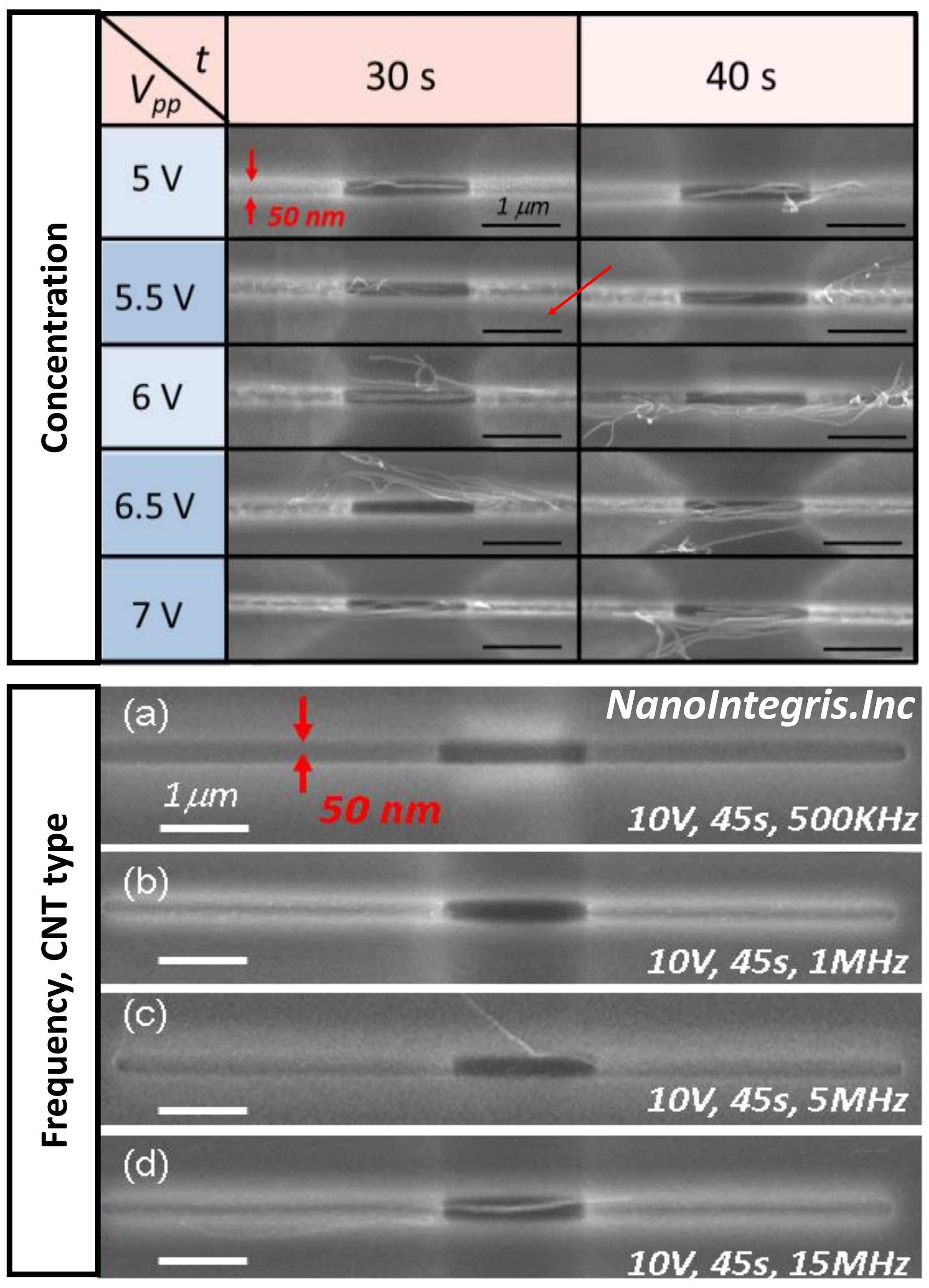
$$z(\omega) = \frac{F_{el}}{m_{eff}}H(\omega)$$




## Self-Aligned Fabrication of CNT Resonators with Various Gate Configurations




## References

[1] D.Grogg, The Vibrating body transistor, 2011.
[2] J. Cao, A. M. Ionescu, *Carbon* 50, pp. 1720, 2012.
[3] J.Cao, A.M.Ionescu, *APL* 100, pp. 063103, 2012.
[4] J.Cao, A.M.Ionescu, IEEE Nano, UK, submitted.

## Aknowledgments

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