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In-plane Nano-electro-mechanical Resonators: Design, Fabrication and Measurement

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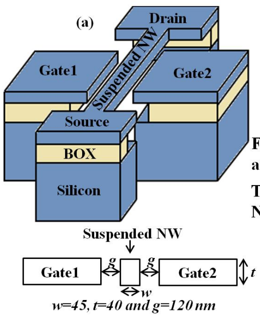
Micro/nano-electro-mechanical (MEM/NEM) resonators are a very important component needed to integrate the frequency reference oscillator in chips [1]. The detection of resonance frequency is the bottleneck of NEM resonators due to the need of good signal to noise/background ratio to single out very small output signals [2]. The usage of monolithically integrated transistors with resonators as the detection circuit is a solution to this issue due to the short distance between NEM resonators and transistors [3]. Recently, a resonant-body silicon nano-wire field-effect-transistor (NW FET) without junctions and doping concentration gradients has been proposed [4]. The presented in-plane NEM resonator in this paper consists of a clamped-clamped (CC) NW that plays the role of the suspended channel for the junction-less FET (JL FET) (Fig. 1 (a)). The changes of displacement for the resonating NW causes changes in the current of JL FET that is used for the detection of the resonance frequency. The resonator was fabricated on silicon on insulator (SOI) platform with the uniform boron doping of 10^{19} cm^{-3}. A 15 nm-tick thermal oxide layer was grown around the NW for passivation of the NW. Two side gates were considered for the NW to increase the controllability of gates over the channel. Fig. 1 (b) shows the top scanning electron microscopy (SEM) view of the fabricated CC NEM resonator. Figure 2 (a) shows the effects of applying different gate biases on I_d-V_g and g_m-V_g (inset to Fig. 2 (a)) characteristics of the resonator. The optimum applied bias to gates should provide higher ON current as well as high g_m. The analytical resonance frequency and quality factor (Q-factor) for two CC NEM resonators are shown in TABLE I. The usage of a free-free (FF) NW for the resonator (Fig. 2 (b)) improves the total quality factor five orders of magnitude in the case of doing the characterization of the resonator in vacuum and at low temperature. CC NEM resonators were characterized using a down-mixing technique [5] as shown in Fig. 2 (c). A signal generator was used to apply a low frequency modulation signal to drain. The measurements were done at high vacuum (10^{-6} mbar) and room temperature, and a lock-in amplifier was used to detect the output current signal from source. Figure 2 (d) shows the lock-in current versus the frequency of resonators. The measured resonance frequency for the resonators and their related Q-factors are less than the analytical values in TABLE I that may be explained due to changes of dimensions or deformation of NWs.



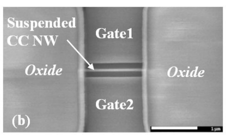
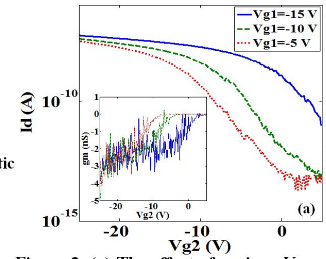


Figure 1. The CC NEM resonator: (a) Schematic and dimensions, and (b) top SEM view.

TABLE I. Analytical key parameters for CC NEM resonators with 15 nm-thick oxide layer

Length	Resonance frequency	Q-factor
1.5 µm	158.98 MHz	9762
2 µm	89.42 MHz	23141



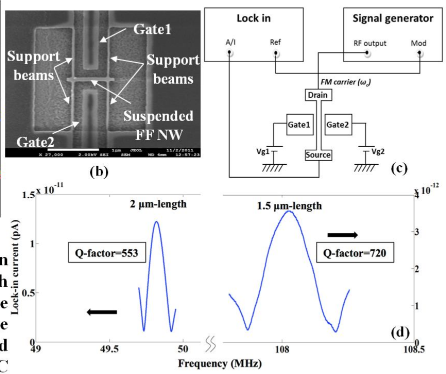


Figure 2. (a) The effect of various V_{g1} on DC characteristics of the 1.5 µm-length CC NEM resonator at V_d=50 mV, (b) the SEM view of FF NEM resonator, the down-mixing measurement setup, and (c) high frequency characteristics of CC NEM resonators.

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