Nanocomposite-beam based microresonator fabricated by combining microlithography and layer-by-layer nanoassembly

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Micromachined resonators, vibrating in response to an applied external force, play a very important role for a variety of applications, such as information and signal processing, ultra-low mass detection, biomolecule sensing and detection. As a result, various methods and materials have been used to fabricate this type of microdevices. Recently, a class of resonators fabricated from graphene sheets has been demonstrated, in which the graphene sheets are suspended over a trench.[1-2] Typical thickness of the graphene sheets inside these devices is ~15 nm.

This paper reports the fabrication of nanocomposite-beam (NanoBeam) based microresonators by combining optical microlithography and layer-by-layer nanoassembly (LbL).[3] Using this combined approach, both the composition and the thickness of the NanoBeam can be readily tuned at *nanoscale resolution* for optimum performance, which is impossible or very difficult otherwise using other fabrication techniques.

The sketch of the device is shown in **Fig. 1**. It consists of a NanoBeam (its length is L and width is W) suspended over a trench, which is formed in SiO_2 and silicon layer. The NanoBeam is connected to an Au electrode. The other electrode, which is the highly doped silicon substrate, is electrically insulated from the NanoBeam by a layer of SiO_2. For prototype devices, the NanoBeam contains single wall carbon nanotubes (SWCNTs) and SnO_2 nanoparticles (NPs).

Some microresonators have been designed and their corresponding resonant frequencies (Table 1**)** are calculated using formulas reported previously.[1] In these designs, we assume the thickness of the NanoBeam is 200 nm and its Young's modulus and density are similar to that of the bulk graphite (e.g., E=1.0 TPa and ρ=2200 kg/m^3).[1] Typical resonant frequencies of these designs are in the range of 15-40 MHz, which can be easily tailored by changing their dimensions.

The detailed fabrication process flow is illustrated in **Fig. 2**. First, a Si wafer is oxidized to have 2 μm thick SiO_2 layer. Then a trench upto 5 μm deep is formed in SiO_2 and Si layer by BOE wet etching and then dry etching. Thereafter, the Au electrodes are patterned on the top of SiO_2 layer, followed by fabricating the NanoBeam by using lift-off technique and LbL.

The SEM image of a fabricated microresonator is shown in **Fig. 3** (a). The close-up of the NanoBeam region is given in **Fig. 3** (b). The thickness of the NanoBeam is 200 nm. More details will be provided in the final manuscript.

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[1] J. Scott Bunch, et al, *Science* **315**, 490(2007).
[2] C. Chen, et al, *Nature Nanotechnology* **4**, 861(2009).
[3] G. Decher, *Science* **299**, 1232(1997).

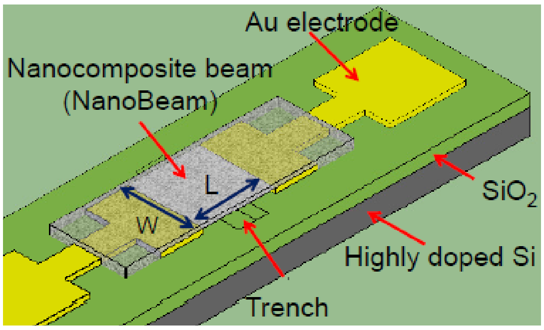

Fig. 1 A 3-D sketch of the NanoBeam based microresonator. The NanoBeam, suspended over a trench, vibrates when an AC voltage is applied between the Au electrode and the bottom electrode, which is the highly doped silicon and electrically insulated from the Au electrode by the SiO_2 layer. (*L* and *W* are the length and width of the NanoBeam)

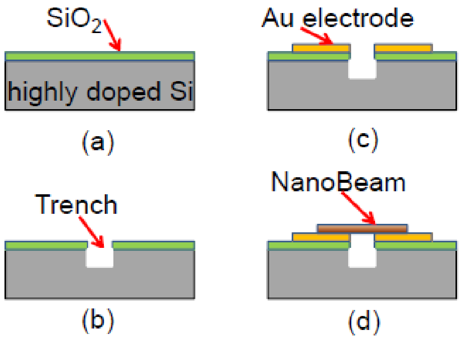

Fig. 2 Fabrication process flow: (a) 2 μm SiO_2 deposited on Si wafer; (b) a trench (~5μm) is formed in SiO_2 and Si; (c) using lift-off process, Au electrodes are patterned on SiO_2 layer; (d) using lift-off technique and layer-by-layer nanoassembly process, NanoBeam, containing CNTs and SnO_2 NPs, is patterned and suspended above the trench

Table 1. Summary of several designs of the NanoBeam microresonators

Device number	Length (***L***) (μm)	Width (***W***) (μm)	Thickness (***T***) (nm)	*Calculated resonant frequency f_r (MHz)[1]
1	16	10	200	15
2	14	10	200	20
3	11	10	200	30
4	10	10	200	40

* $f_r = \{[A(E/\rho)^{1/2}T/L^2]^2 + A^2 0.57t/\rho L^2 WT\}^{1/2}$. A=1.03 for doubly clamped beams.

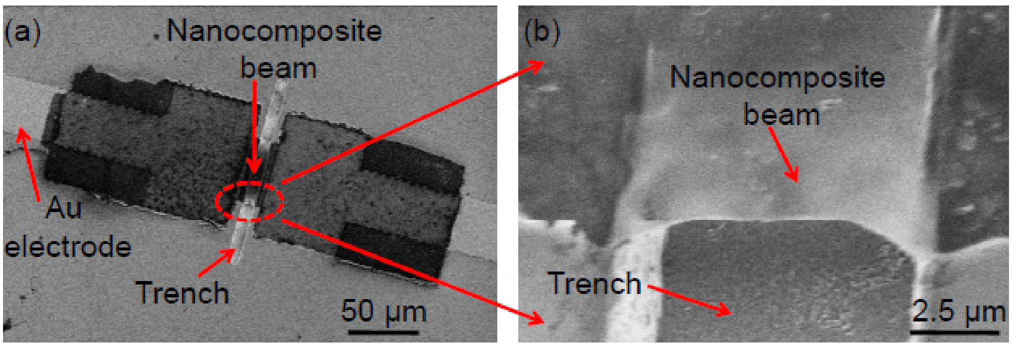

Fig. 3 (a) SEM image of one of fabricated NanoBeam based microresonators; (b) close-up showing the nanocomposite layer (200 nm thick) suspended above the trench