# Fabrication of carbon nanotube film-piezoelectric (CNF-PZT) microcantilevers for energy harvesting application

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Recently, *self-reciprocating* characteristic of carbon nanotube film (CNF)-based cantilever has been observed upon exposure to the light and thermal radiation.[1-2] This unique property has been used to harvest both light and thermal energy with a prototypical CNF-lead zirconate titanate (PZT) *macrocantilver*.[1-2]

Herein, the fabrication of CNF-PZT microcantilevers by combining CNF-transfer and microlithography is reported for the *first* time. The sketch of the microcantilever is given in **Fig. 1**, which consists of one PZT layer sandwiched between two Pt-electrode layers, one CNF layer and one SU8 layer. The detailed fabrication process flow is illustrated in **Fig. 2**. It involves two main steps: the preparation of CNF using the vacuum filtration method [3] followed by the transfer of CNF to silicon substrate for further microfabrication and integration. Briefly, first, the bottom electrode (Pt/Ti) is defined on the silicon substrate. Using sol-gel method,[4] a PZT layer is then uniformly formed on the wafer, followed by top electrode (Pt/Ti) deposition. A second mask is used to define the top electrode and PZT cantilever. The CNF is prepared by vacuum filtration through mixed cellulose ester (MCE) filter and then transferred on the wafer.[3] Upon drying of CNF and subsequent annealing at 75°C for 20 minutes, the CNF sticks to the substrate with enough adhesive strength for further processing. After dissolving of the MCE filter with acetone, a uniform CNF is formed on the substrate. SU8 is coated and the third mask is used to define the cantilever which consists of electrodes, PZT, CNF and SU8 layers. Finally the microcantilever is released by $XeF_2$ gas based dry etching.

Several microcantilevers have been designed and modeled using *finite element* analysis. One representative result is given in **Fig. 3** (a). For a typical device with its dimensions summarized in the caption, the *peak* open circuit voltage (OCV) generated by this device is ~12 mV when the cantilever tip is displaced by 0.2 μm. It should be noted that the OCV can be readily tuned by varying the dimensions of the microcantilever device. A representative 2-D electrical potential profile on the PZT layer is shown in **Fig. 3** (b).

A SEM image of one of fabricated CNF-PZT microcantilevers is given in **Fig. 4**. The whole device is shown in **Fig. 4** (a). The close-up of the released cantilever is shown in **Fig. 4** (b). More details will be provided in the final manuscript.

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[2] V. Kotipalli, Z. Gong, Y. He, S. Yadav, L. Que, *Proc. of IEEE Sensors Conference*, 1165( 2010)
[3] Z. Wu, et al, *Science* **305**, 1273 (2004)
[4] M. Hu, et al, *Proceedings of the SPIE* **5650**, 180 (2005)

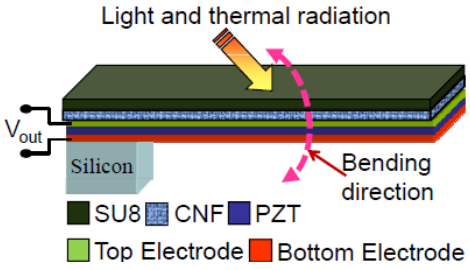


**Fig. 1** 3-D sketch of a CNF-PZT microcantilever. It is a layered structure with one PZT layer sandwiched between two electrode (Pt) layers, one CNF layer and one SU8 layer, which make the microcantilever mechanically robust

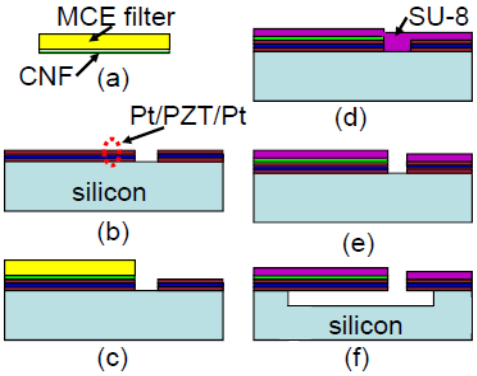


**Fig. 2** Fabrication process flow: (a) CNF is synthesized on a MCE filter; (b) a Pt/PZT/Pt pattern is fabricated on silicon substrate; (c) CNF is transferred on top of the Pt/PZT/Pt layer. The MCE filter layer is dissolved; (d-e) SU8 layer is coated and patterned; (f) cantilever is released by $XeF_2$ gas based dry etching

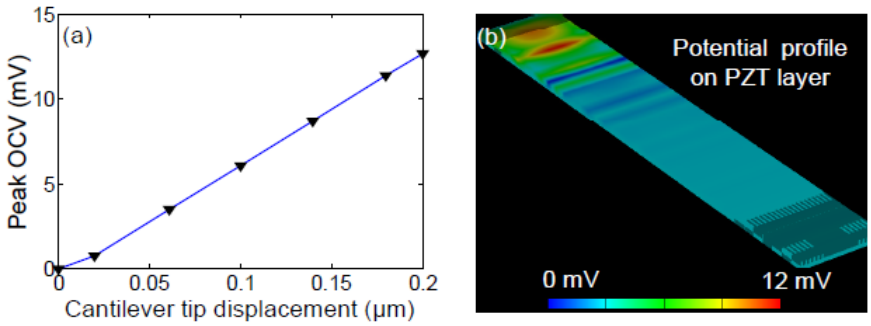


**Fig. 3** (a) A representative calculated peak open circuit voltage (OCV) when the cantilever tip is deflected. The length and width of the cantilever are 200 μm and 25 μm, respectively. The thicknesses of PZT layer, electrode layer, CNF layer and SU8 layer are 1μm, 200 nm, 2 μm and 2.5 μm, respectively for the modeling; (b) A representative calculated potential profile on PZT layer using finite element analysis when the cantilever tip is displaced

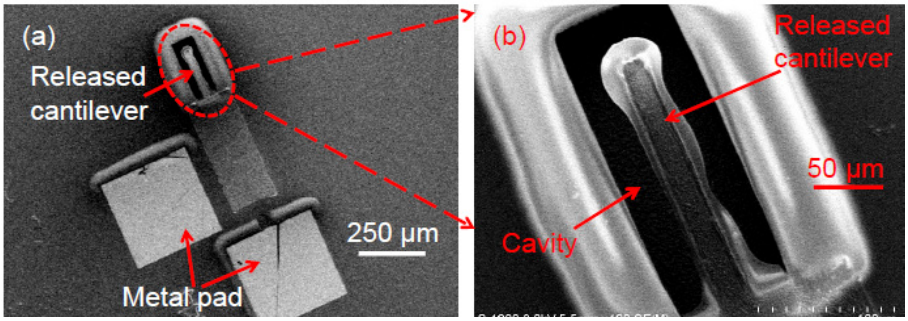


**Fig. 4** (a) SEM image of one of fabricated devices showing the released cantilever and the electrodes; (b) close-up showing the released cantilever, underneath is the cavity formed in silicon by $XeF_2$ gas based dry etching