

Microcantilever sensors loaded with sensing nanomaterial for on-site detection and monitoring of trace-level bio/chemical molecules

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In a physical sensor such as a pressure sensor or an accelerometer, only one transduction interface exists for translating a certain physical sensing effect into assessable electric sensing signal. For a MEMS pressure sensor, the input pressure induced deflection or mechanical stress of the sensing diaphragm can be directly output by the signal transduction of a capacitor or a piezoresistor, respectively. Differently, a bio/chemical sensor normally possesses one more (i.e. two) transduction interfaces. At the first interface, specific adsorption/binding is implemented to firstly translate the bio/chemical information into certain physical phenomenon (e.g. heat generation, mass, electric current, mechanical stress or vibration, optical light, etc.) [1, 2]. Then at the second interface, the generated physical effect can be further translated into electric output in the similar way of the physical sensor. In order to improve the bio/chemical sensors for high-resolution detection of ultra-low concentration bio/chemical molecules, efforts have been made in our group to independently optimize the two interfaces for higher sensitivity and selectivity.

To improve specific gas (or vapor) adsorption performance at the first interface, nano sensing film with large surface-area needs to be loaded on the sensitive location (i.e. near the free end) of the cantilever. The nano sensing film should consist of nanostructure with similar nano-size to the targeted gas molecule. In the nanostructure, specific sensing-group should be densely grown. More importantly, the sensing film would be better directly grafted or *in situ* grown on the sensing location of the cantilever for sensitivity uniformity of batch fabrication. We have developed serial such sensing materials that are addressed as follows. (1) Mesoporous-silica is used as sensing film as it features controllable pore size (in the range of 2-10nm). Specific sensing group can be modified at the inner walls of the pores for sensing functionalization. To further enlarge the surface area, nanoparticles of the mesoporous-silica is developed that shows enhanced sensitivity to pesticide residues. Figure 1 schematically shows the sensing nanomaterial on cantilever for pesticide detection. To obtain highly uniform sensing performance of batch fabricated cantilever gas sensors, a “one pot” method is developed to directly grown the mesoporous sensing film at the end of the silicon cantilever. During the solvent vaporized, the nano pores are formed and, simultaneously, the sensing groups are in-wall constructed. (2) Hyper-branched polymer is directly grown on the cantilever surface via an  $A_2 + B_4$  layer-by-layer route, where  $A_2$  and  $B_4$  are complementary interacting groups which undergo coupled linking. After dense sensing groups modified on tops of the polymer branches, the resonant cantilever sensors exhibits 5ppb resolution to DMMP vapor. Moreover, the “fewer roots but more branches” construction helps to depress noise from stiffened spring effect of the cantilever. (3) Aggressive graphene sheets are re-constructed into porous-layered stack to explore function on gas adsorbing and sensing. Gold nanoparticles

are *in situ* grown on graphene-oxide by chemical reduction. After the hybrid nano-film is loaded on cantilever, the hierarchical nanostructure is formed with the Au nanoparticles isolated in between the adjacent graphene sheets. The sensing group modification can be implemented on either the gold or the graphene for trace-level ammonia sensing.

At the second interface of the resonant cantilever sensor, the resonating Q-factor should be as high as possible for fine resolution to the adsorbed mass. Higher resonant modes of microcantilever, such as the 2<sup>nd</sup> bending, the 1<sup>st</sup> torsion and the 2<sup>nd</sup> torsion ones, have been explored and employed to significantly improve Q-factor. With optimal resonant mode, resonant cantilever sensors have shown detection limit of a few femto-gram gas and 1ng/mL antigen in immune-sensing. On the other hand, high Q-factor resonance in solution is also pursued for real-time biologic detection in liquid environment. We develop a cantilever which resonates in in-plane mode to decrease resisting force from liquid, thereby, obtaining Q of 250 in aqueous solution. With the cantilever sensor, tens of ppb mercury-ion in water can be detected for heavy-ion pollution monitoring (see Figure 2).

Intensive attentions have also been paid to chemical sensing or biological detection. For chemical sensing, for example, low-concentration homologues of TMA, DMA and MMA can be identified by solving dual-cantilever arrayed signals. For rapid repeat detection of bacteria or fast change detection target (e.g. from *E coli* to *Bacillus Anthracis*), a chelating-bond breaking and re-linking technique is developed to the cantilever for rapid re-immobilization of immune micro-sensors.

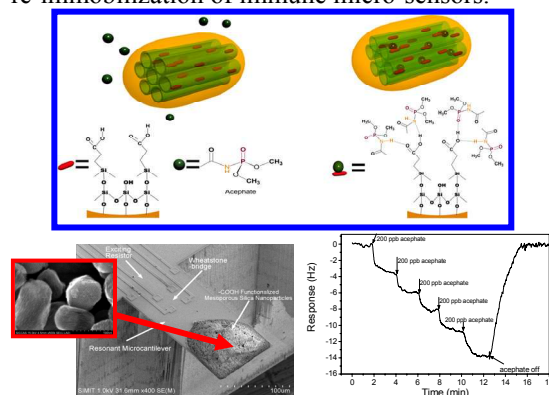


Figure 1. Sensing scheme, SEM images and sensing response of mesoporous-silica nanoparticles loaded on a resonant cantilever for detection of pesticide residue.

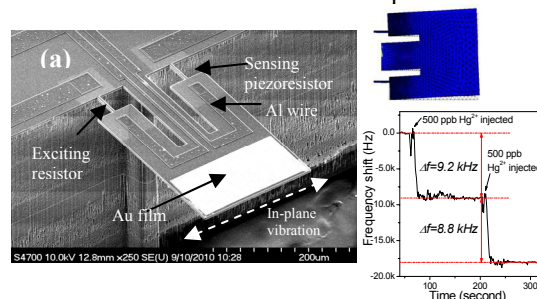


Figure 2. High-Q cantilever with in-plane resonant mode for ppb-level  $Hg^{2+}$  ion detection in water environment.

#### References:

- [1] T. Burg, M. Godin, S. Knudsen, et al, *Nature*, 446 (2007): pp. 1066–1069.
- [2] G. Shekhawat, S. Tark, V. Dravid, *Science*, 311 (2006): pp. 1592–1595.