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Towards a modular, versatile and portable sensor system for measurements in gaseous environments based on microcantilevers

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Abstract

Microfabricated silicon cantilever sensor arrays represent a powerful platform for sensing applications in physics, chemistry, material science, biology and medicine. The sensor response is mechanical bending due to absorption of molecules. In gaseous environment, polymer-coated microcantilevers are used as electronic nose for characterization of vapors, resulting in cantilever bending due to polymer swelling upon exposure. Medical applications involve fast characterization of exhaled patient's breath samples for detection of diseases, based on the presence of certain chemicals in breath. We present a portable, compact, modular microcantilever setup, which uses a micropump for aspiration and a bluetooth interface for remote data acquisition.

Keywords: Microcantilever; array; electronic nose; chemical sensor; breath test sensor; wireless sensor

1. Introduction

Micromechanical detection of chemical processes using microcantilever sensor arrays has been established in recent years as a powerful technique for detection of volatile gaseous analytes and biomolecules.[1-3] Adsorption and/or recognition of molecules on the surface of microcantilevers functionalized with receptor layers results in bending of the microcantilevers due to the formation of surface stress. In the application as an artificial nose[4] each microcantilever of a sensor array is coated with different polymer layer. Upon exposure to a volatile gaseous analyte, the polymer layer swells leading to a bending of the microcantilever. From the bending pattern of typically eight microcantilevers in an array, a response characteristic of the volatile gaseous analyte is measured, allowing to recognize the analyte using principal component techniques. The sensor can be easily purged by exposing it to a flow of dry nitrogen gas. The major advantages of microcantilever array sensors are their small size, high sensitivity and fast response time,[1] as well as their broad range of applicability as the functional coating can be selected according to the desired application, e.g. for chemistry, food and fragrance industries, for quality and authenticity assessment, and for biosensing.[2,3] The microcantilever deflections are usually measured using the optical beam deflection technique utilizing microfabricated vertical-cavity surface-emitting lasers (VCSELs),[2,4] requiring a

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measurement setup of the volume of about 1 dm^3. Practical application of the sensor setup demands further miniaturization and ease of usage, especially for medical purposes, e.g. as rapid diagnostic tool.[5] We show in this article some opportunities to construct a more compact version of a portable, miniaturized microcantilever-array based sensor system with wireless data transmission.

2. Experimental setup

An electronic nose–type sensor setup consists of the following key elements:

- reliable sample handling system providing reproducible and repeatable samples for measurement,
- sensor with transducer that yields reproducible, repeatable and robust responses,
- readout system for the sensor response,
- data acquisition, evaluation and interpretation.

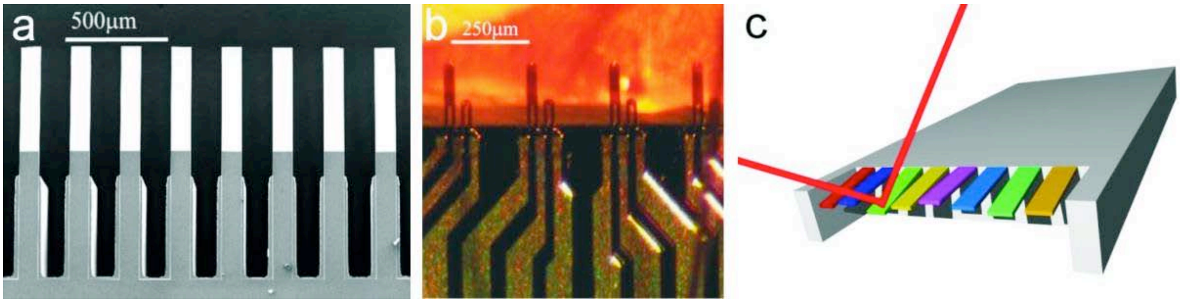

Fig. 1. (a) Array of silicon microcantilevers for optical readout (IBM Research GmbH, Rüschlikon, Switzerland); (b) array of piezoresistive microcantilevers (P. Vettiger, CSEM Neuchâtel, Switzerland); (c) schematic of readout of bent microcantilevers using optical beam deflection.

We use silicon microcantilever arrays (Fig. 1a), whereby the bending response due to swelling of a polymer layer upon exposure to volatile vapors is read out optically via beam deflection.[2,4] To avoid bulky optics, we started to use piezoresistive microcantilevers[6] (Fig. 1b). Upon exposure to volatile vapors the cantilever start to bend in a way characteristic of the diffusion properties of the vapor into the polymer layer and a bending pattern results (Fig. 1c). Handling of solvent vapor or medical breath samples[5] proceeds via aspiration of the air sample at controlled rate and volume using a syringe pump, or in the miniaturized setup a micropump (Fig. 2a) based on a piezoactuated membrane pump interconnecting the air sample bag and the microcantilever measurement chamber. Dedicated measurement electronics and a bluetooth or universal serial bus interface (Fig. 2b) transfers data to a remote portable computer running data display and evaluation software. The schematic of the experimental setup is shown in Fig. 2c.

Fig. 2. (a) Battery-operated micropump system for pumping a sample of exhaled breath from a medical breath sample bag into the microcantilever measurement chamber (model mp5 from Bartels Mikrotechnik, Dortmund, Germany); (b) Bluetooth interface on top of the portable, compact and wireless measurement setup; (c) schematic of the wireless data acquisition and measurement setup.

3. Results and discussion

Figure 3 shows raw data acquired using eight microcantilevers in an array coated with layers of different polymers (Table 1). A micropump was used to apply subsequent cycles of exposure to ethanol vapor (500 ppm in nitrogen) and dry nitrogen purging gas.

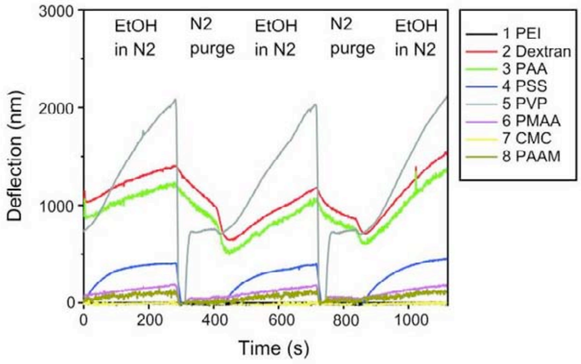

Fig. 3. Cantilever sensor array test measurement using ethanol vapor in dry nitrogen. The abbreviations in the legend denote the different polymers deposited by inkjet spotting onto the cantilevers.

Figure 4 shows five measurements of a patient's exhaled air sample in a row with intermediate purging steps of the cantilever sensors. The time-dependent deflection traces from a healthy person (Fig. 4a) and a person suffering from halitosis (bad breath) clearly differ from each other. The time-dependent cantilever bending responses in 5 consecutive injections have been found to be very reproducible.

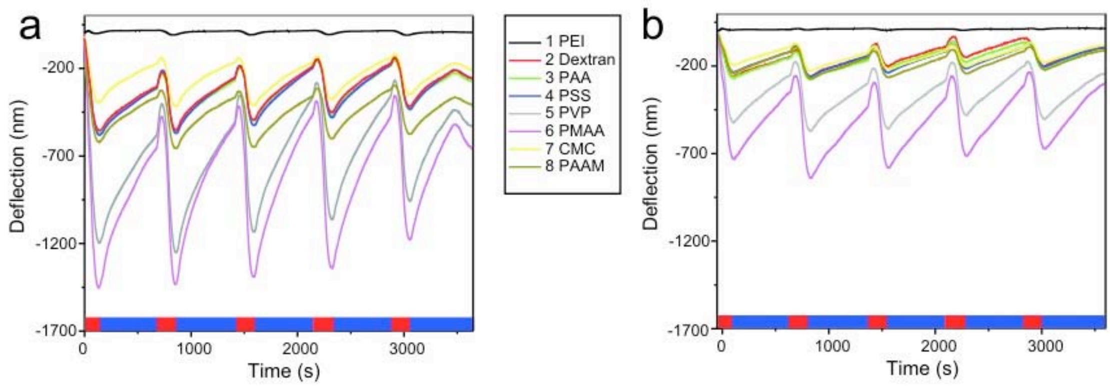

Fig. 4. (a) Cantilever deflection traces from an exhaled air sample of a healthy person; and (b) from a person with halitosis. The red intervals indicate injections of breath sample (5 mL/min for 2 minutes), while the blue intervals represent the purging steps with dry nitrogen gas (1 mL/min for 10 minutes).

Fig. 5 shows an evaluation of medical exhaled breath samples obtained from persons suffering from halitosis and breath samples from healthy control persons. The principal component analysis (PCA) representation reveals that people suffering from bad breath can be clearly distinguished from the healthy control persons. In many cases the class of substances responsible for halitosis are sulfur-containing compounds, which can be reliably detected using cantilever sensors.[3]

Table 1. Polymer coatings

Cantilever	Abbreviation	Aqueous solution for deposition of the polymer layer (1mg/mL)
1	PEI	Polyethylenimide (branched) solution
2	Dextran	Dextran solution from *Leuconostoc* spp.
3	PAA	Poly(acrylic acid sodium salt) solution
4	PSS	Poly(sodium 4-styrenesulfonate) solution
5	PVP	Polyvinylpyrrolidone solution
6	PMAA	Poly(methacrylic acid, sodium salt) solution
7	CMC	Carboxymethylcellulose sodium salt solution
8	PAAM	Poly(allylamine hydrochloride) solution

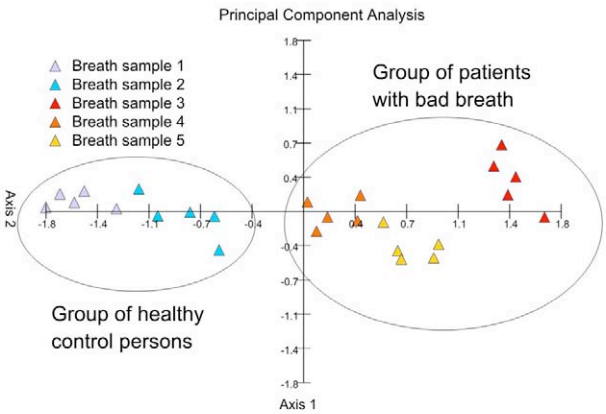

Fig. 5. Principal component analysis plot of the exhaled breath study on persons with halitosis and on healthy control persons.

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