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Fully Integrated Sensor Platform for Remote Respiratory Biomarker Monitoring

Simon Schlapansky[1], Federico Burisch[1], Ryan Rusch[1], Andreas Güntner[1]
[1]Human-centered Sensing Laboratory, Department of Mechanical and Process Engineering,
ETH Zürich, Switzerland
schlsimo@ethz.ch

Summary:

Space exposes astronauts to extreme environmental conditions, which can induce significant physiological changes. While current systems primarily track basic vital signs, prolonged missions will necessitate monitoring complex physiological changes. This work introduces a fully integrated sensor platform for selective detection of molecular breath biomarkers. Depositing highly sensitive porous nanoparticle gas sensing films directly onto microelectronic circuitry provides access to low power, miniaturized sensor systems suitable for portable or wearable applications.

Keywords: Astronaut health monitoring, Breath analysis, Wearables, Chemoresistive sensors, Nanoparticles

Background, Motivation and Objective

Astronauts face extreme environmental stressors in space, including microgravity, radiation, disrupted circadian rhythms, and altered diets. [1] These factors induce significant physiological changes, affecting metabolism [2], the microbiome [3] and the musculoskeletal system [4]. Current health monitoring aboard the ISS relies on intermittent, crew-intensive sampling methods (e.g. blood tests, microbiome swabs), which are unsuitable for long-duration missions.

To address this, real-time, non-invasive monitoring technologies are needed. [5] Wearable sensors offer continuous, autonomous tracking but are currently limited to basic vitals. [6] Extending this to molecular level biomarkers, however, requires novel sensor platforms. Breath analysis offers a unique, non-invasive approach to access real-time information of metabolic, musculoskeletal and microbiome-related changes.[7]

While past technologies like NASA's PUMA [8] and ESA's RSS [9] focus on basic gases (CO_2, O_2), breath contains a vast array of informative volatile organic compounds (VOCs) in the ppb–ppt range. Acetone, for instance, reflects fat metabolism and nutritional state [10]; isoprene correlates with muscle activity and circadian rhythm. [2,4] Commercial sensors, however, often lack the necessary selectivity to detect these analytes.

Recent advances in nanotechnology, on novel semiconducting metal-oxide (SMOx) sensors, such as silicon-doped WO_3 and palladium-doped SnO_2, allow sensitive, and selective detection of acetone and isoprene in breath at ppb levels. [10,11] To realize their potential for space applications, further system integration into portable, low-power platforms is needed.

Description of the New Method or System

Results

In this work, we present a miniaturized chemoresistive sensor platform incorporating molecule-selective sensors fabricated via flame aerosol deposition. This approach enables the formation of nanoparticle-based sensing films directly on commercial micro-hotplate substrates with high spatial precision.

The sensing films are deposited within the active area of the interdigitated electrodes (d = 300 µm), as verified by SEM imaging (Figure 1b). A shadow mask is employed to shield the contact and heater pads, ensuring clean deposition exclusively in the sensing region. Flame aerosol deposition, driven by thermophoresis, results in the formation of highly porous, nanostructured films. These structures are subsequently mechanically stabilized through post-deposition annealing and wire-bonded onto leadless chip carriers.

The employed micro-substrates consist of a suspended membrane with an integrated micro-heater that precisely controls the temperature of the sensing film. Thanks to an optimized chip design, the heaters maintain high thermal efficiency, operating at temperatures up to 300 °C with a power consumption of only ~60 mW.

A custom-designed circuit board has been developed to interface with the sensors, enabling precise control and readout of their electrical response. Sensor performance is evaluated under well-controlled exposure to gas mixtures with variable relative humidity levels using a calibrated gas mixing setup. The test conditions are tailored to mimic exhaled breath under different physiological states. This allows us to assess sensor selectivity, sensitivity, and stability toward key breath biomarkers under realistic conditions.

Such a miniaturized sensor platform has the potential to not only transform health management in space but also on earth by enabling continuous, non-invasive and decentralized monitoring of biochemical markers with molecular precision.

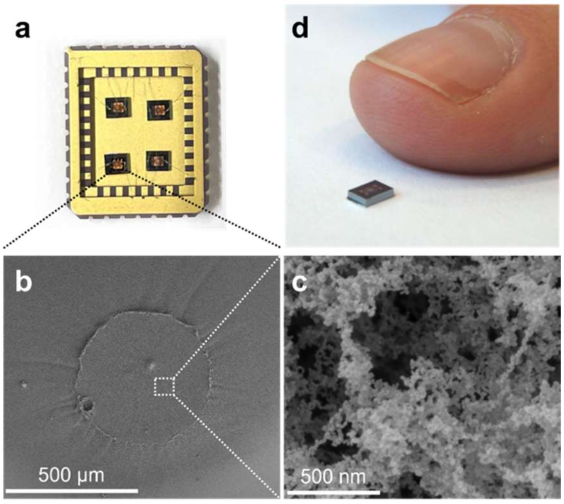

Figure 1. (a) Sensor package wire-bonded to a chip carrier after deposition of a flame-made and in situ annealed Pd-doped SnO_2 film. SEM confirms (b) the accurate sensing film deposition onto the designated area with interdigitated electrodes and indicates (c) the highly porous film architecture. (d) The total size of one microsensor is around 2x2 mm. Figure reproduced from [12].

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