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Development of Flexible and Printed Carbon Nanotube-Based Gas Sensors for In-vitro Food Digestion Models

S. Vasquez[1], MA. Costa Angeli[1], P. Lugli[1,3] and L. Petti[1,2]

[1]Faculty of Engineering, Free University of Bozen-Bolzano, Piazza Domenicani 3, Bolzano 39100, Italy
[2]Competence Centre for Plant Health, Free University of Bozen-Bolzano, Piazza Universitá 1, Bolzano 39100, Italy
[3]Competence Centre for Mountain Innovation Ecosystems, Free University of Bozen-Bolzano, Piazza Universitá 1, Bolzano 39100, Italy

Abstract: The gut microbiota plays a pivotal role in breaking down indigestible carbohydrates, resulting in the production of various gases, including ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), and hydrogen sulfide (H_2S). These gases, alongside other fermentation byproducts, offer valuable insights into the effects of different diets on gut health. NH_3, for instance, can reflect changes in dietary protein, which is linked to gastrointestinal diseases and potential toxicity. Conventional methods for analyzing gut fermentation typically rely on costly and complex techniques such as high-performance liquid chromatography (HPLC) or gas chromatography-mass spectrometry (GC-MS). Here, we present a more efficient, less invasive approach by developing chemiresistive carbon nanotubes-based gas sensors that can continuously monitor fermentation byproducts in real time within the Simulator of the Human Intestinal Microbial Ecosystem (SHIME) model. This research follows a structured approach to sensor development, focusing on the design, optimization, and testing of the sensors suitable for the harsh, humid, anaerobic, and acidic conditions of the in vitro gastrointestinal tract. Different fabrication methods—including dispense printing, screen printing, and inkjet printing—were examined to create custom electrodes and conductive networks of single-walled carbon nanotubes (SWCNTs). The sensors were successfully integrated into the SHIME® model to monitor gas production during microbial fermentation over a two-week period. The findings demonstrated that the sensors accurately tracked gas production patterns, providing valuable insights into how diet influences gut microbiota. This study highlights the importance of real-time, in-line gas sensor technologies in advancing the understanding of gut health and microbial fermentation dynamics through a systematic sensor development approach tailored to the unique demands of food digestion models.

Corresponding author:
S. Vasquez
svasquezbaez@unibz.it
Sensing Technologies Laboratory (STL)
Website: https://sensingtechnologies.groups.unibz.it/