



HAL
open science

H2MEMS Project: Resonant MEMS for detection of hydrogen release in radioactive waste disposal facility

Isabelle Dufour, Luis Iglesias Hernandez, Priyadarshini Shanmugam, Jean-François Michaud, Laurent Colin, Daniel Alquier, Dominique Certon, Maria Dolores Manrique-Juarez, Thierry Leichle, Fabrice Mathieu, et al.

► To cite this version:

Isabelle Dufour, Luis Iglesias Hernandez, Priyadarshini Shanmugam, Jean-François Michaud, Laurent Colin, et al. H2MEMS Project: Resonant MEMS for detection of hydrogen release in radioactive waste disposal facility. Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF / IFCS 2022), Apr 2022, Paris, France. hal-03778623

HAL Id: hal-03778623

<https://hal.science/hal-03778623v1>

Submitted on 16 Sep 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

H2MEMS Project: Resonant MEMS for detection of hydrogen release in radioactive waste disposal facility

Invited Talk¹

Isabelle Dufour, Luis Iglesias Hernandez
Université de Bordeaux
Laboratoire IMS UMR-CNRS 5218
Talence, France
isabelle.dufour@ims-bordeaux.fr

Priyadarshini Shanmugam, Jean-François Michaud,
Laurent Colin, Daniel Alquier, Dominique Certon
Université de Tours
GREMAN UMR-CNRS 7347
Tours, France

Maria-Dolores Manrique-Juarez, Thierry Leïchlé,
Fabrice Mathieu, Laurent Mazenq, Liviu Nicu
CNRS-LAAS
Toulouse, France

Luan Nguyen, Sébastien Chenot, Marc Portail
CNRS-CRHEA
Sophia-Antipolis, France

Johan Bertrand
Andra
Chatenay – Malabry, France

Summary— The H2MEMS project aims at developing and optimizing hydrogen sensors based on resonant MEMS for detection of hydrogen release in radioactive waste disposal facility. The principle adopted is based on measuring physical properties of the gas (mass density, viscosity, sound velocity and sound absorption) without requiring any sensitive layer. For this purpose, resonant microcantilevers and CMUT were used.

Keywords— resonant MEMS; CMUT; microcantilever; gas detection; resonant frequency; quality factor; time of flight; viscosity; mass density; sound attenuation; hydrogen detection

I. INTRODUCTION

ANDRA, the French National Radioactive Waste Management Agency, is in charge of finding, implementing and ensuring safe management solutions for French radioactive waste, in order to protect the present and future generations of the risks of nuclear wastes. As part of this mission, ANDRA prepares the industrial phase of the CIGEO project (industrial center for geological disposal). This repository will contain underground facilities designed to store tens of thousands of cubic meters of high-level and intermediate level long-lived radioactive waste. These wastes are mainly issued from the French nuclear power plants. The CIGEO project is intended to confine them for many years with a goal of ensuring a sustainable, safe and reversible storage [1]. One of the key elements of the overall monitoring strategy of geological disposal is the observation and survey of the subsurface installations. The monitoring devices in such context must resist to the harsh environmental conditions existing in a repository, especially levels of radiation that may accelerate sensor material deterioration. Adapting available sensors or developing new sensors is necessary to meet the technical

requirements of the application. This is of particular importance in the case of chemical sensors to increase their durability and to limit the need for maintenance.

In such context, hydrogen release is expected from the radioactive waste disposal facility. It originates from (i) radioactive waste release and (ii) anoxic corrosion of metallic materials. Since hydrogen gas is flammable at concentrations between 4 and 75% vol. in air, monitoring its concentration in this environment is crucial. For this particular application, the H2MEMS project has developed and optimized hydrogen sensors based on resonant MEMS. Resonant MEMS are particularly performant for gas sensing but must be adapted for such a particular application. To achieve this goal, four laboratories, partners of the H2MEMS project, have proposed the use of uncoated sensors.

In fact, the principle adopted in the framework of this project is based on measuring physical properties of the surrounding gas (mass density, viscosity, sound velocity and sound absorption) without requiring any sensitive layer. The absence of the sensitive coating, which is subjected to sorption or redox phenomena in classical chemical sensors, leads to a more reliable and reversible behavior.

II. METHODS

Two kinds of resonant MEMS have been used in the H2MEMS project:

- Silicon and silicon carbide microcantilevers with electromagnetic actuation and piezoresistive or inductive read-out. The details of the manufacturing process for silicon and silicon carbide microcantilevers can be found in [2] and [3], respectively. The typical

¹ This research was conducted thanks to the contest *Programme d'Investissements d'Avenir* of the French Government under the supervision of the French National Radioactive Waste Management Agency (ANDRA).

dimensions of the microcantilevers are: 1mm x 1mm x 10 μ m.

- Silicon nitride capacitive micromachined ultrasonic transducers (CMUT). The fabrication process based on surface micromachining can be found in [4]. The typical dimensions of each membrane of the CMUT are: 32 μ m x 32 μ m x 450nm. Each CMUT is composed of thousands of membranes (the size of the chip is 8mm x 1mm).

When using microcantilevers, the hydrogen detection principle is based on the measurement of both resonant frequency and quality factor variations, which allows to estimate simultaneously the gas mass density and the gas viscosity [5].

In the case of the use of CMUT, it is also possible to achieve hydrogen detection using the measurement of the resonance properties of the MEMS devices [6]. Another innovative way to achieve hydrogen detection using CMUT is the measurement of acoustic wave properties such as time of flight and attenuation. This can be done both in time [7] or frequency domains [8, 9].

III. DISCUSSION

For the dedicated application of radioactive waste disposal facility, selectivity is not a real concern and a major specification as only hydrogen concentration may change significantly in such radioactive environment. However, within the H2MEMS project, discrimination between different gas mixtures using resonant MEMS without sensitive coating has been studied. The discrimination has been achieved, using either the microcantilever based sensors or the CMUT based sensors, by combining the measurement of two physical properties of the surrounding gas [5, 9, 10]: either the mass density and the viscosity, or the time of flight and attenuation. This has been demonstrated using four different binary gas mixtures at different concentrations (Figures 1-2).

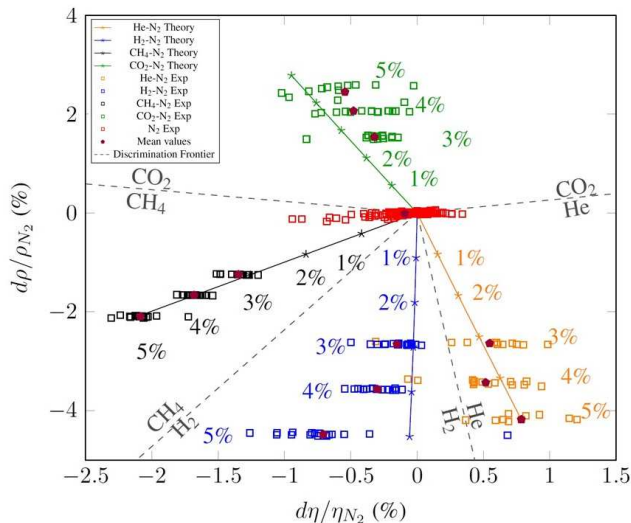


Fig. 1. Discrimination of different gases with the simultaneous measurements of mass density and viscosity using microcantilevers.

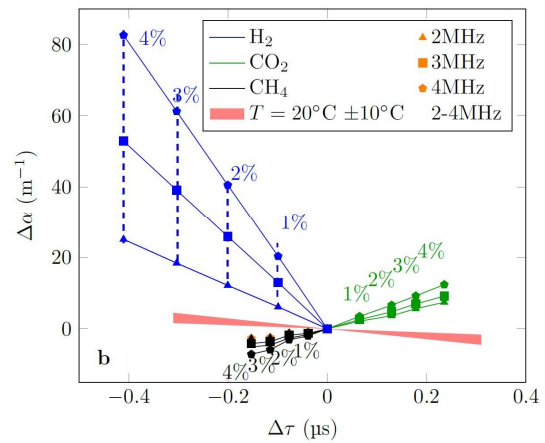


Fig. 2. Discrimination of different gases with the simultaneous measurements of time of flight and attenuation using silicon nitride CMUT.

IV. CONCLUSION AND PERSPECTIVES

Reliable detection of hydrogen has been achieved using either microcantilevers or CMUT. To go further for the targeted application, similar tests have to be done with materials more appropriate to harsh environment such as silicon carbide or diamond. Moreover, dedicated electronics has to be developed for this harsh environment.

REFERENCES

- [1] <https://international.andra.fr/>
- [2] M.T. Boudjiet, J. Bertrand, F. Mathieu, L. Nicu, L. Mazonq, T. Leichlé, S.M. Heinrich, C. Pellet; I. Dufour, "Geometry optimization of uncoated silicon microcantilever-based gas density sensors" *Sensors and Actuators B*, Vol. 208, 2015, pp. 600-607.
- [3] P. Shanmugam, "Design, fabrication and characterization of micro resonant systems for hydrogen detection in the radioactive environment" PhD thesis, Univ. Tours, December 2021
- [4] J. Heller, A. Boulme, D. Alquier, S. Ngo, D. Certon, "Performance Evaluation of CMUT-Based Ultrasonic Transformers for Galvanic Isolation," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, Vol. 65, 2018, pp. 617-629.
- [5] L. Iglesias, M.T. Boudjiet, I. Dufour, "Discrimination and concentration measurement of different binary gas mixtures with a simple resonator through viscosity and mass density measurements", *Sensors and actuators B*, Vol.329, 129184, 2021.
- [6] L. Iglesias, P. Shanmugam, J.F. Michaud, D. Alquier, D. Certon, I. Dufour, "Proof of concept and preliminary results of gas detection by measuring the admittance at the resonance and anti-resonance of an uncoated CMUT", *Frontiers in Mechanical Engineering*, March 2020, Volume 6, Article 14.
- [7] P. Shanmugam, L. Iglesias, J.F. Michaud, D. Alquier, I. Dufour, L. Colin, D. Certon, "Broad Bandwidth air-coupled micromachined ultrasonic transducers for gas sensing", *Ultrasonics*, 2021, Volume 114, Article 106410.
- [8] L. Iglesias, P. Shanmugam, J.F. Michaud, D. Alquier, D. Certon, I. Dufour, "Hydrogen selective gas sensor based on attenuation measurement of acoustic wave using uncoated CMUT", *MEMS 2021 on line* (On-line instead of Munich, Germany), January 25-29th 2021. 4 pages.
- [9] L. Iglesias, P. Shanmugam, J.F. Michaud, D. Alquier, D. Certon, I. Dufour, "Gas discrimination by simultaneous sound velocity and attenuation measurements using uncoated capacitive micromachined ultrasonic transducers", *Scientific Reports*, accepted Nov 2021.
- [10] L. Iglesias, "Resonant microsystems for hydrogen gas detection without functionalized coating" PhD thesis, Univ. Bordeaux, September 2020