In-situ monitoring
of high doses of radiation

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Motivation

Chernobyl (at left) and Fukushima (at right) nuclear power plants after nuclear accidents.

High radiation > 100 kGy doses in short term.

* International Nuclear Safety Center
Motivation

Scientific / Industry facility

Radiation level - low, but long-term dose high > 20 kGy.
High radiation doses "measurements" - state of art:

> 20 kGy **only non-direct measurements** by:

- **alanine dosimeters:**
  - range of measurement up to 1 MGy

- **photoluminescent dosimeters:**
  - range of measurement up to 1 MGy

- **thermoluminescent dosimeters:**
  - range of measurement up to 1 MGy

- **hydrogen pressure dosimeters:**
  - range of measurement up to 10 MGy
Non-direct measurement

absorbed dose above 20 kGy

radiation source

classic dosimeter(s)

radiation-proof container

transport to the laboratory
Non-direct measurement

- Classic dosimeter(s)
- Transport
- Laboratory
  - Reading + analysis = result (estimation of dose)

Result: several hours to months
Wanted: new method of measurements of high-doses of radiation above 20 kGy

Problem: no sensors
Hydrogen pressure dosimeter - principle of the work

**principle using from 1950’s**

high dose radiation

\[ \text{transport} \quad \Delta p \quad \text{HDPE} \]

glass container with HDPE

- High Density Polyethylene (HDPE)

- \( H_2 \)

Laboratory

break the bottle

measurements by Bourdon gauge
Our goal

principle using from 1950’s

glass container with HDPE

V ~ 100 cm³

new MEMS sensor for continues measurements

HDPE

H₂ \( \Delta p \)

miniaturization

V ~ 10 mm³

www.memslab.pl
Our new MEMS sensor - principle

prior to irradiation

thin membrane

Si

\( p_0 \)

glass

HDPE

\( p_0 = \text{introductional pressure (after sealing)} \)
after irradiation

Irradiated HDPE degrades and releases atomic hydrogen

\[ p_1 - p_0 = \Delta p = f \text{ (dose)} \]
Our new MEMS sensor - principle

Single membrane sensor

$p_1 < p_{\text{max}}$

proportional mode of detection possible

below maximal pressure/dose

deflection of membrane

"Cascade" membranes sensor

$p_2 > p_{\text{max}}$

membrane of known mechanical properties discriminates doses

destruction of membrane

over maximal pressure/dose
Technical realization
Single membrane proportional sensor

![Diagram of the technical realization of a single membrane proportional sensor](diagram.png)

- **Cross-section view**
  - Microchannel
  - Membrane
  - Sealing by anodic bonding under controlled pressure $p_0$

- **Planar view**
  - HDPE container
  - Membrane $S_1$

Dimensions:
- 1.1 mm glass
- 0.4 mm Si
- 1.1 mm HDPE
- 15 mm
- 9 mm HDPE container

Scheme not in scale
Technical realization
“Cascade” membranes threshold sensor

Planar view

Cross-section view

HDPE container $S_1$ $S_2$ $S_3$

Scheme not in scale

1.1 mm glass
0.4 mm Si
1.1 mm HDPE
Si

24 mm

9 mm
Fabrication - process

double-side deep wet etching in KOH 80°C, 10M KOH

first anodic bonding in N₂ 450°C, 1000 V

placing of solid HDPE pill

second anodic bonding in N₂ 300°C, 1200 V
MEMS sensors at a glance

Single membrane sensor

"Cascade" membranes sensor

container with HDPE

Several tens of sensors have been successfully fabricated.
Irradiation

- Linear accelerator: 6 MeV
- Beam spot: ~3 mm
- Sample
- Chuck-holder
- Total dose: $20 \text{ kGy} < x < 120 \text{ kGy}$
Results of irradiation

Single membrane proportional sensor

sensor before irradiation  
sensor after irradiation

25 mm$^2$ and 30 µm thick membrane – deflected @ 10 kGy dose

deflected membrane

Sensors have been fabricated in MEMS lab facilities at Wrocław University of Technology.

Sensors have been tested in National Center for Nuclear Research in Otwock / Świerk
Data processing toward sensor

![Graph showing the relationship between pressure [kPa], deflection of the membrane [μm], and dose of radiation [kGy].]
Results of irradiation

"Cascade" membranes threshold sensor

sensor before irradiation    sensor after irradiation

25 mm² / 30 µm thick membrane – destroyed at 26.8 kGy dose
Data processing toward sensor

4 independent low dose sessions

- ■ model
- △ experiment

- dose of ionizing radiation [kGy]
- surface of the membrane [mm²]
Short interim summary:

- MEMS miniature sensors for detection of high doses of ionizing radiation have been fabricated and tested.
- Doses up to 120 kGy have been successfully detected.
- High radiation doses 10 – 120 kGy in situ detection by small MEMS sensor have been shown for the first time.
- “Cascade” membrane sensor as dose threshold sensor is ready-to-use!
Single membrane sensor - proportional operation mode

- Radiation source
- In situ sensor
- Remote detection
- Reading + result
- Safe area

Remote detection
Radar remote detection based on LAAS technology

Modification of EM coupling between resonator and silicon membrane
- High sensitivity to membrane displacement (Air gap: 1µm to 10µm)
Radar remote detection based on LAAS technology

Air gap (2, 3, 6, 8, 10, 30µm)

Q ≈ 10

Simulation

Silicon 400µm

≈ 1GHz /µm

Experiment

Silicon 400µm
Radar remote detection based on LAAS technology

Interrogation distance:
- 3 m (pressure sensor)
- 30m (Antenna loaded with impedance) → >> 30m expected
Radar remote detection based on CNRS-LAAS (Toulouse, France) technology

- RF probe access
- High resistivity Silicon (400µm thick)
- Pyrex
MEMS high-dose radiation sensor

DOSIMEMS Project „Passive, wireless MEMS dosimeter for the high radiation dose monitoring”, financed by the European Commission under the Seventh Framework Programme FP7, MNT-ERA.NET.

Responsible for development of the sensor technology
DOSIMEMS project - participants

- Poland
- France
Sensors of high doses of radiation – potential application

"Cascade" membranes threshold sensor

+ simple eye control

Single membrane proportional sensor

+ remote control

Radar

Optical
Sensors of high doses of radiation – potential application

Monitoring of high doses of radiation after the disaster in harsh environment.

- S - radiation sensor

- damaged reactor

- polluted area
Monitoring of high doses of radiation acting on the reactor covers – safety „caps”.

working reactors / industry facility
Sensors of high doses of radiation – potential application

Monitoring of doses coming from nuclear waste disposal.

leakages

nuclear waste disposal

ground

door
Sensors of high doses of radiation – potential application

High radiation coexist with another treats

- High temperature
- High electromagnetic / magnetic field
- Explosion risk
- Poisonous gases

Sensor and sensing head are:
- resistant against high temperature (up to 300 ºC)
- EX standard ready
- wireless
More information in papers


• M. Olszacki, M. Matusiak, I. Augustyniak, P. Knapkiewicz, J. Dziuban, P. Pons and E. Debourg, Measurement of the high gamma radiation dose using the MEMS based dosimeter and radiolisys effect,, 24th *Micromechanics and Microsystems Europe Conference*, September 1-4, 2013 Hanasaari Finland, p. 33-36,
Acknowledgments
MEMSlab Team

MEMSlab team of Faculty of Microsystem Electronics and Photonics of Wrocław University of Technology – picture taken in the 14th century Castle, Ryn, Poland