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Micromechanical high-doses radiation sensor with bossed membrane and interferometry optical read-out

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Abstract

The silicon-glass MEMS high-doses radiation sensor with *in situ* detection, so far not possible in the field of detection of doses above 10 kGy, has been presented. The sensor consists of a chamber filled with the high density polyethylene (HDPE) and a silicon bossed membrane. The radiolysis product of HDPE increases the pressure inside the chamber causing the deflection of the membrane, which is proportional to the pressure, thus to radiation dose. The sensor has been irradiated with high energy electron beam and shows good detectability for 10-40 kGy. The deflection of the membrane has been detected by optical interferometer.

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Keywords: MEMS radiation sensor, high doses of radiation, bossed membrane, optical read-out, polyethylyne degradation, membrane deflection;

1. Introduction

Measurement of high radiation doses (>10 kGy) by cheap and easy-to-use sensor became urgent and critical in nuclear power plants and other installations where high radiation doses occur [1]. The other issue is the unsolved problem of the *in situ* measurements of a high-dose radiation levels [2, 3]. According to the today's state of art,

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high-doses of radiation (above 10 kGy) may be only estimated *post factum* by a family of passive thermo-, radio- and photoluminescence indicators or hydrogen pressure dosimeters [4]. *In situ* measurements have been up-to-date obtained only for low or medium doses (below 10 kGy) by solid-state MOS based sensors. So, the problem of high-dose radiation measurements is still open and important.

The idea of high-doses MEMS radiation sensor, working in so called destructive mode, has been presented by us in work [5]. In this solution, the pressure generated by H_2, being the effect of radiolysis of HDPE trapped inside the small MEMS chamber with thin silicon membrane, causes mechanical destruction of this membrane. Detection of levels of radiation is done by simple observation of the sensor (by naked eye as well). In this paper, we focus on "proportional" mode in which deflection of a membrane is proportional to the hydrogen pressure, thus to a radiation dose. Moreover, the presented sensor is appointed with a bossed membrane which dimensions are adapted for cooperation with a wireless radio frequency detection system [6].

2. Construction and fabrication

As mentioned earlier the sensor utilizes phenomenon of degradation of some polymers exposed to ionizing radiation. Irradiation releases from the polymer gaseous hydrogen. The pressure of hydrogen deflects thin silicon membrane (Fig. 1). Deflection of the membrane is proportional to the irradiation dose.

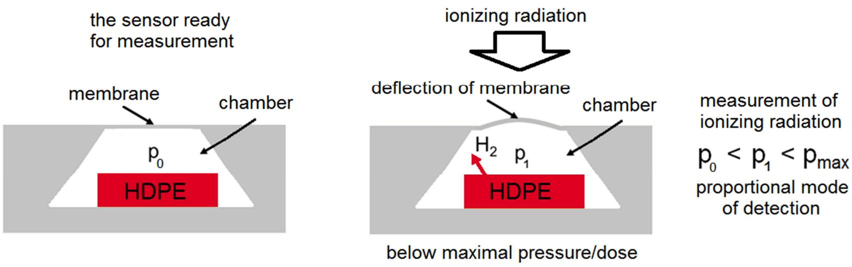

Fig. 1: The proportional mode of operation of the sensor - deflection of membrane is proportional to hydrogen pressure, thus to radiation dose.

The construction of the sensor contains hermetically sealed chamber filled up with a small portion of the HDPE (~ 2 mg), a silicon bossed membrane (5×5×0.08 mm^3), a connecting channel, a joining hole and a channel under the membrane (Fig. 2a). The sensor is made of silicon and glass in a form of anodically bonded sandwich with dimensions of 25×11×1.925 mm^3 (Fig. 2b).

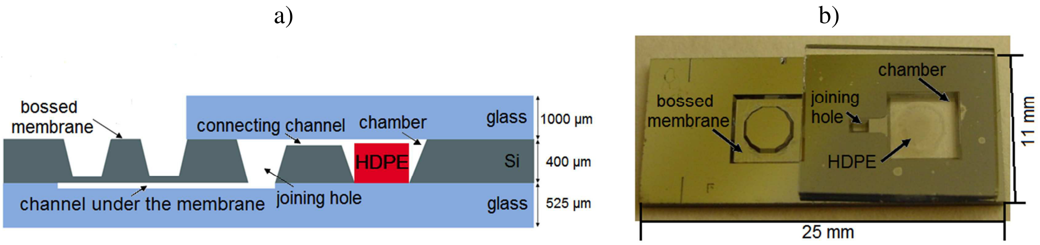

Fig. 2: The MEMS high doses radiation sensor: (a) cross-sectional view; (b) sensor at a glance.

The fabrication process utilizes wet etching in tetramethylammonium hydroxide (TMAH) in (100) silicon wafer, in order to make a connecting channel, deep wet etching in potassium hydroxide (KOH) to make a bossed membrane, a chamber and a joining hole in the same procedure. The hydrogen fluoride (HF) etching of a glass wafer has been used to make a channel under the membrane. The back side glass and silicon wafers are anodically bonded in 450°C, at 600 V. HDPE is precisely placed inside the chamber and the second anodic bonding of top side glass cover is done in pure nitrogen in 300°C, at 1200 V (Fig. 3). The second bonding is provided in a decreased temperature process and is the key process of the fabrication.

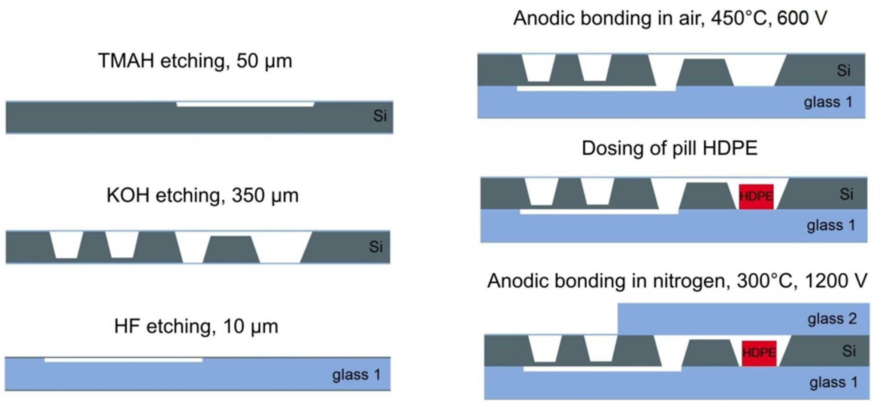

Fig. 3: The fabrication of the sensor – main technological steps.

3. Results

Deflection of membrane induced pressure changed from 0 to approximately 190 kPa has been measured by interferometric method.

After that, calculations were done (FEM modeling) to confirm the experimental data. We obtained good agreement here, as shown in the Fig. 4a.

Following, true structure of sensors (with HDPE inside) were irradiated by high energy beam of electrons with variable doses (5–40 kGy) and membrane deflection of irradiated sensors, was measured by interferometric method (Fig. 4b).

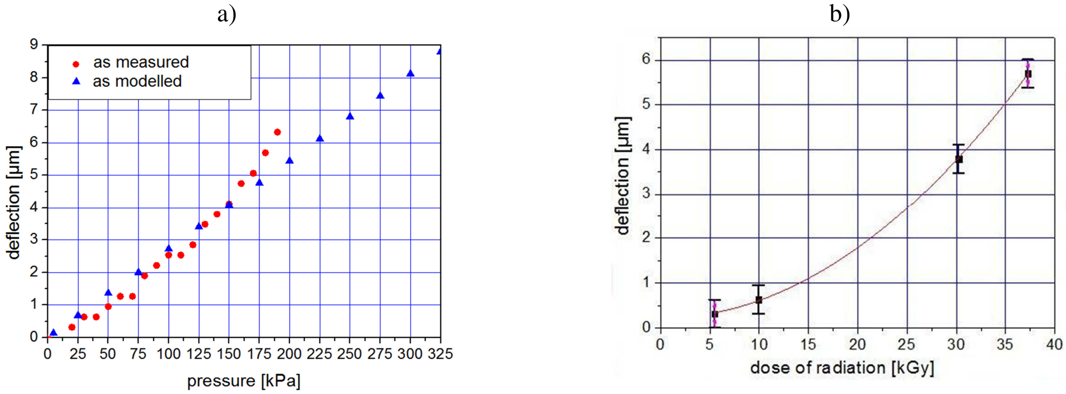

Fig. 4: Sensor response for (5×5×0.08 mm^3) membrane: (a) deflection as a function of pressure inside the chamber; (b) deflection as a function of radiation dose.

Additionally, a pressure value existing in the HDPE chamber after irradiation has been measured by indirect method (Fig. 5a). Test structure has been closed inside special chamber with window, precise pressure sensor and regulator. Compressed air has been precisely applied into the chamber till silicon membrane had become flat. Flat membrane manifest the differential pressure is equal to zero. This non-destructive method has been applied to measure pressure inside tests structures after each of four irradiation sets.

This experiment indicated very high pressure of hydrogen existing inside irradiated sensor (Fig. 5b), much higher (about ten times) than those related in the literature [7]. Experiments indicated that hydrogen pressure generated under irradiation is high enough to ensure proper wireless interrogation as described in [6].

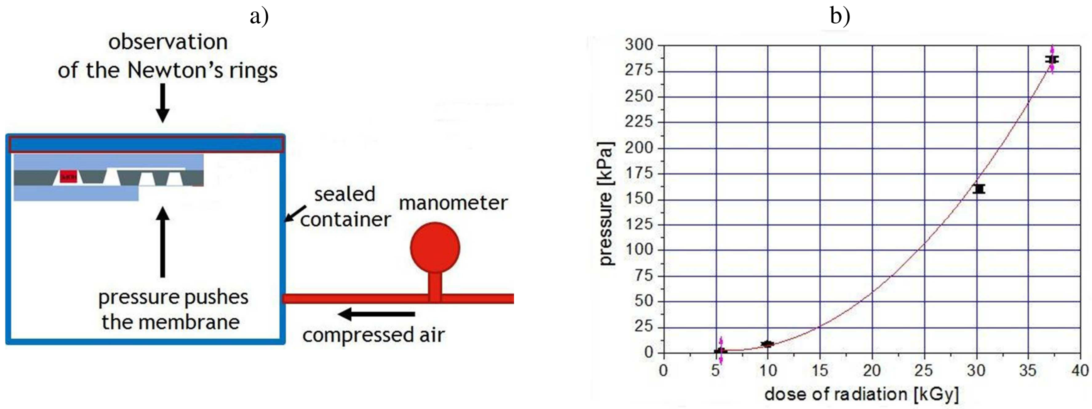

Fig. 5: Differential method for measurement of pressure inside the sensor after irradiation: (a) scheme of the measurement set-up; (b) pressure inside the sensor as a function of dose of radiation.

4. Summary

The silicon-glass MEMS high-doses radiation sensor has been presented. The sensor consists of a chamber filled with HDPE and a silicon bossed membrane. The radiolysis product of HDPE, mostly the hydrogen, increases the pressure inside the chamber causing the deflection of the membrane, which is proportional to the pressure, thus to radiation dose. The sensor has been irradiated with high energy electron beam.

The sensor shows good proportional detection of doses of radiation in the range 10–40 kGy. The pressure inside the chamber of the sensor is unexpectedly high (up to 300 kPa). It shows that radiolysis of HDPE in micro-scaled MEMS sensor is much more effective in comparison to macro-scaled solutions.

To achieve the range of the sensor for higher doses of radiation, it is necessary to design a sensor with a thicker membrane.

This solution opens the way toward creation of family of high dose radiation MEMS sensors for *in situ*, real-time measurements in harsh and dangerous conditions in which no another sensor could be applied.

Acknowledgements

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