High doses wireless radiation sensor using electromagnetic transducers

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***Abstract*— This communication reports the last results obtained on the development of a wireless passive chipless sensor for high doses radiation monitoring. The sensor is based on polymer out-gazing inside a micro-chamber coupled with electromagnetic pressure transducer. Previous results on test structures have validated the principle of polymer out-gazing under nuclear radiation. An hermetic sealed prototype including the micro-chamber and the pressure transducer is reported here for the first time. This sensor has been fabricated successfully. Experimental results are reported and discussed.**

Keywords—passive electromagnetic sensors ; nuclear radiation sensor ; Hydrogen pressure dosimetry

I. INTRODUCTION

The dosimetry is one of the crucial techniques that are needed to provide personal safety and facilities security in the areas of high radioactivity (10kGy – 10 MGy) as nuclear power plants or powerful experimental research infrastructures (LHC, XFEL or ITER project) [1]. Up to now, standard electronic dosimeters are based on the silicon diodes or on field effect transistors which limit the measured dose value up 10kGy (higher dose levels lead to the device saturation). Higher dose measurements (up to 1 MGy) may be based on the variation of physic-chemical parameters of materials (see, e.g., the Polymer Alanine Dosimetry, the Radio-photoluminescent Dosimetry, the Hydrogen Pressure Dosimetry or the Thermo-Luminescent Dosimetry [2-3]). However, complex post-treatments and continuous measurement are often required in practice. Moreover, in case of nuclear reactors the access to the radioactive zones is limited. Up to now existing sensor solutions do not perform the continuous monitoring of the radioactivity as they do not allow in-situ readout.

The solution for overcoming this issue may be to use the recently developed innovative concept of passive (battery less) sensors remotely interrogated by radar reader. Such sensors incorporate a small (millimeter sized) micro-resonator designed at ultra-high frequency (few ten of GHz) and an antenna. The variation of the resonant frequency of the resonator due to the changing of the physical quantity of interest, such as temperature, pressure or humidity [4-7], may be wirelessly detected by the radar.

We exploit here the known property of Hydrogen-Pressure Dosimeters (HPD) for which the polymer material dehydrogenates under nuclear irradiation [8]. The transducer principle is described in Figure 1. The irradiation will generate the out-gazing (hydrogen) of the polymer inside a micro-chamber. The resulting overpressure leads to the deflection of a silicon membrane which modifies the resonant frequency of the RF resonator [4, 9, 10].

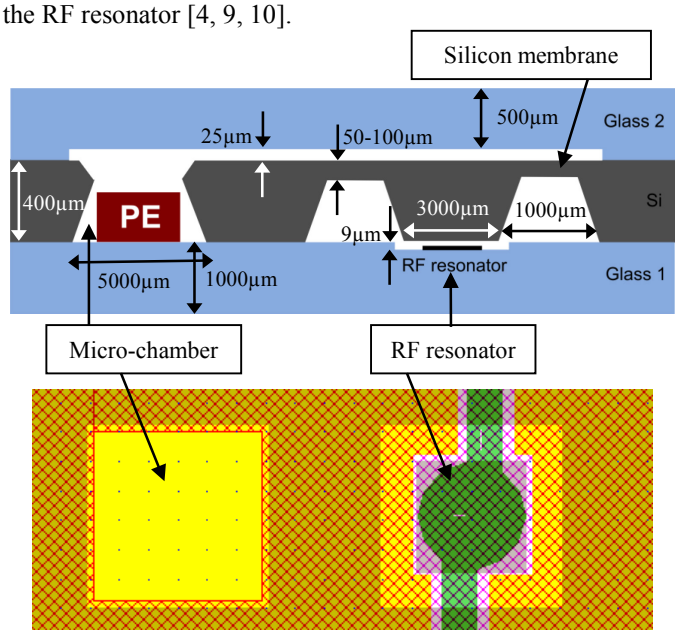

Figure 1. Cross section and mask view (glass 1 & Si) of complete sensor

Previous results obtained from preliminary test structures (see Figure 2 and Figure 3) indicate that a membrane deflection of 0.3µm/mg$_{HDPE}$/kGy after the irradiation (6MeV focused e-beam providing by electron accelerator) was possible [9-10]. In this paper an hermetic sealed small prototype (2cm square) including the micro-chamber and the pressure transducer is reported for the first time. This sensor has been fabricated successfully. Experimental results are reported and discussed.

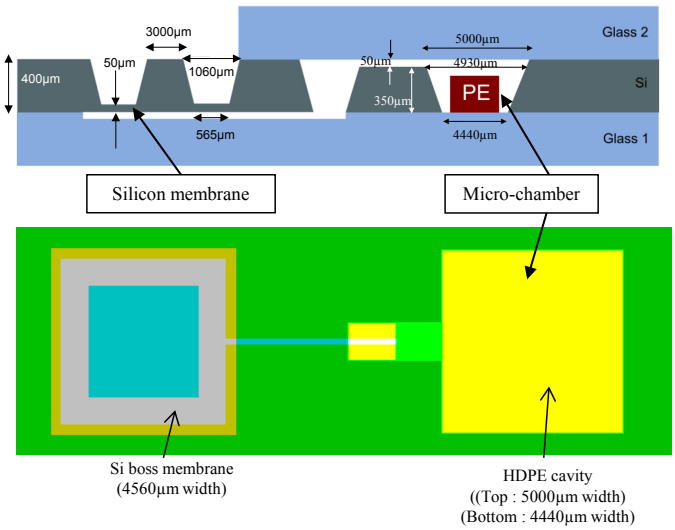

Figure 2. Cross section (top) and layout (bottom) of the first test structure

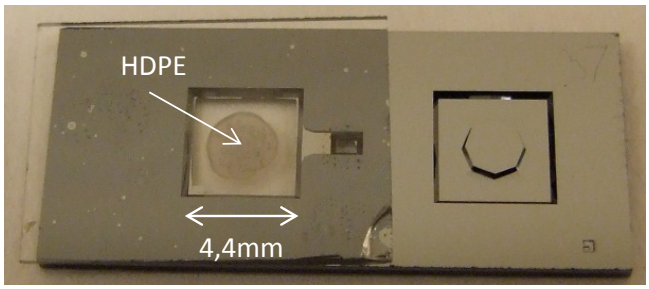

Figure 3. Photograph of test structure

II. Characterization of the Hermetic Sealing of the Micro-Chamber

In order to characterize the hermetic sealing of the micro-chamber under hydrogen over-pressure, membrane deflection after irradiation has been recorded during one month. Figure 4 shows the experimental results obtained for 2 different samples. A gradual diminution of the pressure inside the micro-chamber is not apparent. The variations of membrane deflection are randomly distributed and generally lower than ±5%. These variations can be attributed to the membrane deflection measurements reproducibility (± 0.2µm) which uses mechanical profiler with very low weight applied on the tip. Consequently, hermetic sealing is sufficiently good (after 1 month) for providing the same pressure (±5%) inside the micro-chamber.

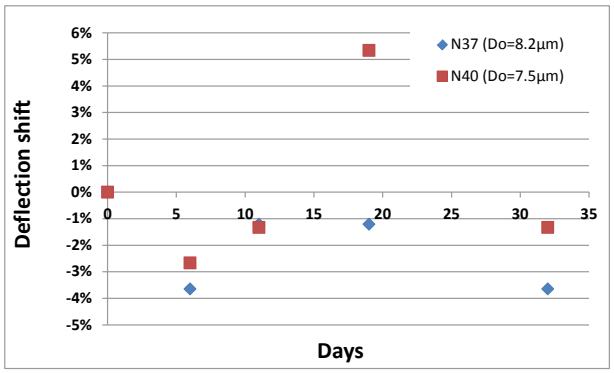

Figure 4. Membrane deflection shift versus time after nuclear irradiation
Do denotes the deflection at initial time

III. Sensor Prototype

The main steps of sensor fabrication are described in the following where 4 inches wafers are used. The RF resonator is first fabricated inside a glass cavity (Figure 5). The micro-chamber and the silicon membrane of the pressure sensor are then defined in high resistivity silicon wafer (Figure 6), following by a bonding with the previous glass wafer (Figure 7). This stack is diced in order to obtained individual cells. The micro-chamber is then filled with polymer and finally sealed by a second glass wafer (Figure 9). A cavity is formerly realized in this second glass wafer in order to provide a connection between the micro-chamber and the silicon membrane (Figure 8). A fabricated sensor prototype is shown in Figure 10.

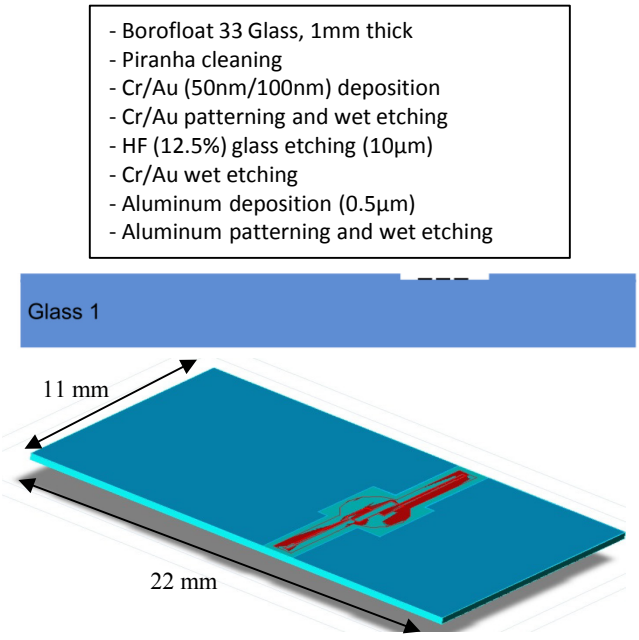

Figure 5. Process done on Glass1 wafer

- High resistivity (> 3kΩ.cm) silicon, 400µm thick, double side polished
- Si_3N_4 LPCDV deposition (100nm thick)
- Si_3N_4 top side patterning (micro-chamber) and RIE etching
- TMAH wet silicon etching (50-100µm)
- Si_3N_4 removing (HF 50%)
- Si_3N_4 LPCDV deposition (100nm thick)
- Si_3N_4 back side patterning (micro-chamber & membrane) and RIE etching
- TMAH wet silicon etching (350-300µm)
- Si_3N_4 removing (HF 50%)

Figure 6. Process done on silicon wafer

- Anodic bonding (450°C, 600V, vacuum)
- Dicing

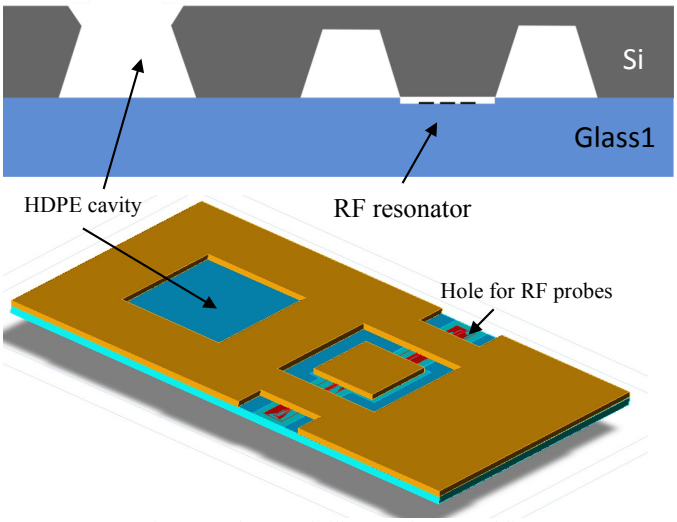

Figure 7. Glass1 and silicon wafers assembling

- Borofloat 33 Glass , 500µm thick
- Piranha cleaning
- Cr/Au (50nm/100nm) deposition
- Cr/Au patterning and wet etching
- HF (12.5%) glass etching (25µm)
- Cr/Au wet etching
- Dicing

Figure 8. Processdone on Glass2 wafer

- HDPE filling (2mg) inside Glass1/Si chamber
- HDPE annealing (180°C, 15min, vacuum)
- Glass2 anodic bonding (300°C, 1200V, N_2 1 bar)

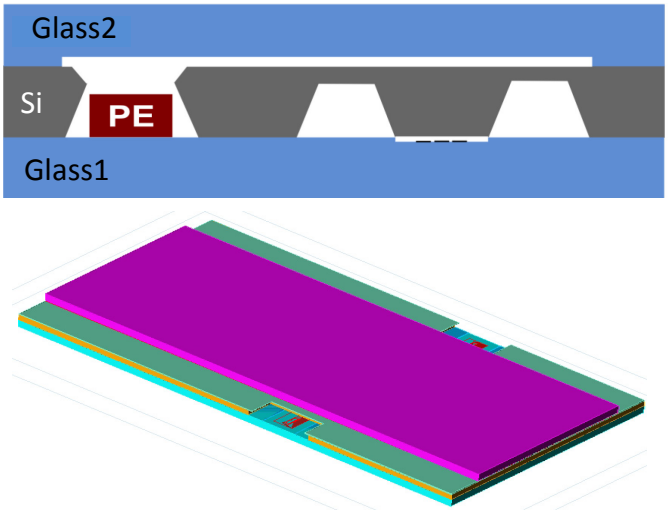

Figure 9. HDPE filling and Glass2 bonding

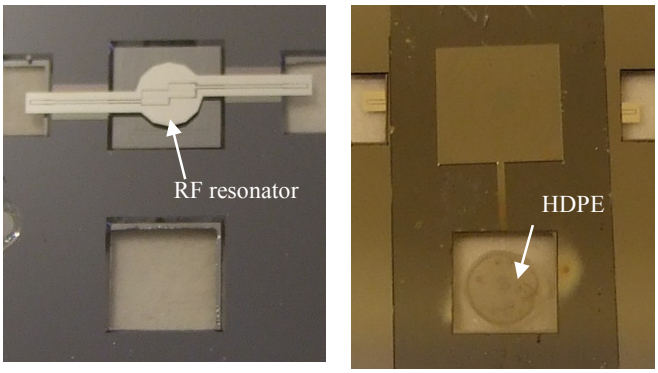

Figure 10. Sensor view. Back side view before HDPE filling & Glass2 bonding (left) and top side view after HDPE filling & Glass2 bonding (right)

Before the irradiation, the S-parameters of the sensor have been recorded using Suss-MicroTec MPC-150 chamber under atmospheric pressure and under vacuum. Figure 11 shows an example of S11-parameter for a sample with 90µm thick silicon membrane. As vacuum is applied on bottom side of the

membrane, the resonant frequency decreases (from 26.1GHz to 25.6GHz) that is consistent with a decrease of the distance between the RF resonator and the silicon membrane. The resonant frequency is then shifted with sensitivity around 2%/bar.

After 24h in vacuum, no resonant frequency modification is recorded confirming that the hermetic sealing is good for 1 day long. The evaluation of this sealing for a longer period (one week) is in progress. If the results are convincing, the sensor will be irradiated and characterized after irradiation.

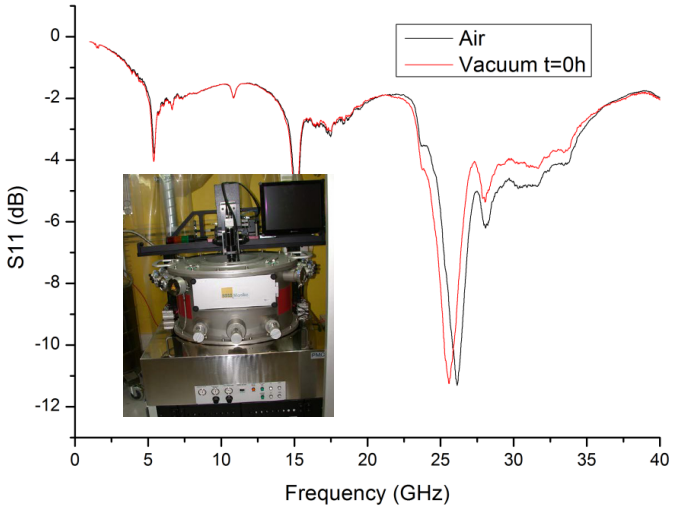

Figure 11. S_{11} sensor parameter under atmospheric pressure & vacuum

IV. Conclusion

Previous results have shown the validation of the polymer outgazing inside a micro-chamber under irradiation, using a test structure that allows the measurement of a membrane deflection submitted to over-pressure. In this communication we have shown that the hermetic sealing of the micro-chamber over 1 month on the test structures used for polymer outgazing is acceptable. The technological fabrication of the complete sensor has been described. As expected when a pressure is applied on the membrane, the resonant frequency is shifted. The sensitivity is about 2%/bar. This sensor will be irradiated and characterized in order to experimentally validate that the pressure inside the micro-chamber has changed.

Acknowledgements

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