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# Wireless Hydrogen Pressure Dosimeter for Nuclear High Dose Monitoring

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**Abstract**— This communication reports the very first experimental results on an original wireless, chipless and passive (battery-less) sensor for monitoring high doses of nuclear radiation. The micro-sensor combines a miniature hydrogen pressure dosimeter with a passive microwave resonator. The pressure response is derived from  $S_{11}$ -parameter measurement using vacuum and atmospheric pressure conditions. After e-beam irradiation (20kGy) the resonant frequency shift of the resonator ranges between 0.12%/kGy and 0.42%/kGy while the hydrogen pressure inside the cavity varies from 20mbar/kGy to 90mbar/kGy. No significant frequency shift is observed when using sensors during 6 months. These results demonstrate that a good hydrogen hermetic seal was fabricated during the manufacturing process of the constitutive micro-cavity.

**Keywords** – Hydrogen pressure dosimeter, wireless passive chipless sensor

## I. INTRODUCTION

The safety of nuclear infrastructures may involve the monitoring of many parameters in harsh environments with high radiation levels, high temperature and high pressure conditions. If technological solutions exist for manufacturing transducers, the electronics of the reader is not appropriate in such extreme environments. Well-known solutions consist of connecting the transducer to the reader by using long cables or by performing *ex-situ* remote sensing. However cables or wires may be difficult to implement in practice while *ex-situ* measurements are not applicable for on-line monitoring. Wireless, chipless (without integrated circuit) and passive (battery-less) sensors could be a very convenient solution for the remote sensing of physical parameters in harsh environments. Applying the electromagnetic transduction principle many microwave and millimeter-wave sensors have been manufactured at LAAS-CNRS, such as pressure, temperature and strain sensors, as well as a radar-based solution for the wireless and long-range sensors interrogation (see, e.g., [1-5]). Very recently the authors have proposed a new concept of wireless, chipless and passive dosimeter which overcomes the limitations of state-of-the-art dosimeter [6-7]. As a matter of fact, conventional wired electronics dosimeters (silicon diodes or field effect transistors) allow measuring nuclear dose values only up to few ten of kGy while passive dosimeters (e.g., photo-luminescence, thermo-luminescence or hydrogen pressure dosimeters) require the post-treatment of measurement

data [8-9]. In this communication, we report the very first experimental results on an original wireless, chipless and passive (battery-less) sensor for monitoring high doses of nuclear radiation.

## II. SENSOR DESCRIPTION

The working principle of the proposed sensor is based on the dehydrogenation of polymer material under nuclear irradiation [6-7]. This irradiation generates the outgazing of the polymer placed inside a hermetic micro-cavity (see Figure 1). The resulting overpressure leads to the deflection of a silicon membrane which modifies the resonant frequency of a microwave or millimeter-wave resonator. From the tracking of the resonant frequency the variation of the radiation doses can be derived. The technological process for manufacturing such Hydrogen-Pressure Dosimeters (HPD) is described in [6]. It uses one silicon wafer anodically bonded between two glass wafers for fabricating the micro-cavity and the microwave resonator. The micro-cavity is partially filled with polyethylene and the pressure of nitrogen inside the cavity is around 500 mbar. For illustration purpose the fabricated sensor is shown on Figure 2. The thickness of the silicon membrane is here of 50 $\mu$ m.

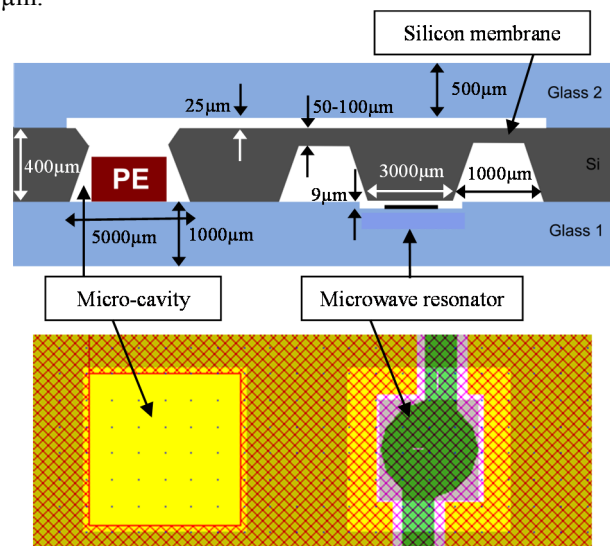


Figure 1 : Cross section and mask view (glass 1 & Si) of the sensor. The acronym PE stands for PolyEthylene

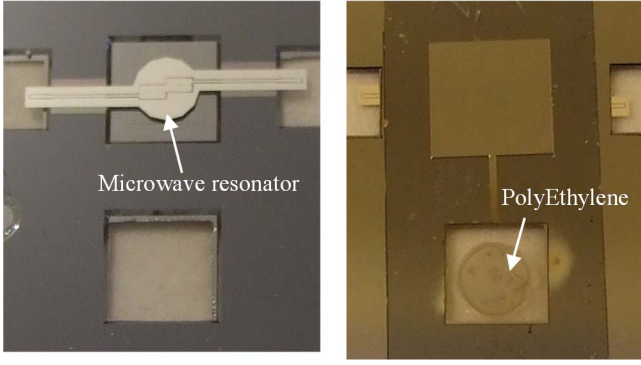


Figure 2: The fabricated sensor (top views). Back side view before HDPE filling & Glass2 bonding (left) and top side view after HDPE filling & Glass2 bonding (right)

### III. PRESSURE MEASUREMENTS

Before nuclear irradiation the pressure sensor has been calibrated through the measurement of the  $S_{11}$ -parameter using Suss-MicroTec MPC-150 chamber for vacuum and atmospheric pressure conditions (see Figure 3). The resonant frequency shift provided by various sensors when a pressure of 1 bar is applied on the silicon membrane is reported in Table 1. The sensitivities ranges from -5.9% per bar to -3.6% per bar. The accuracy on the resonant frequency measurement is found to be  $\pm 40$ MHz (or  $\pm 0.15\%$ ) at 26 GHz.

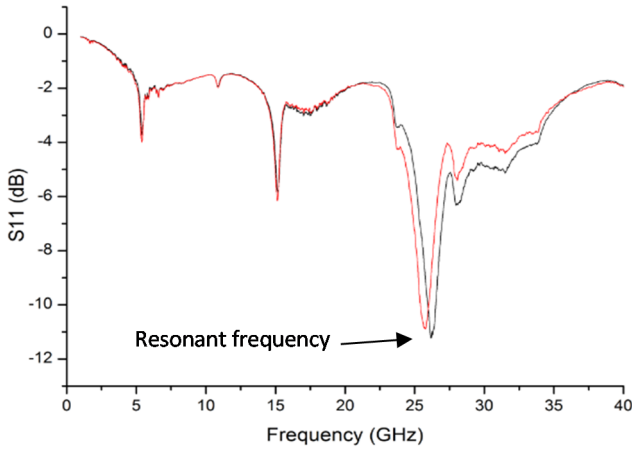


Figure 3: Measured  $S_{11}$ -parameter versus frequency for atmospheric (in black, 1 bar) and vacuum (in red) pressure conditions.

	Sensor N21-1	Sensor N21-2	Sensor N21-6	Sensors N21-9
Freq. shift	- 3.6%	- 4.6%	- 5.9%	- 5.9%

Table 1: Measured resonant frequency difference (in %) between atmospheric (1 bar) and vacuum pressure conditions.

The hermetic seal of the micro-cavity has been checked from the measurement of the sensor resonant frequency after two days in vacuum pressure condition. A good seal is required as the eventual nitrogen leak by the micro-cavity causes the

decrease of the differential pressure applied on the silicon membrane, increases the membrane-to-resonator distance and results in the undesirable variation of the resonant frequency with time. The results shown in Table 2 indicates that the resonant frequency does not significantly change after 47 hours and consequently a good hermetic seal was achieved during the manufacturing process of the sensors' micro-cavities.

	Sensor N21-1	Sensor N21-2	Sensor N21-6	Sensor N21-9
Freq. shift	0.08%	0.21%	0.09%	- 0.02%

Table 2 : Measured resonant frequency variation (in %) for 4 fabricated sensors after 47 hours with vacuum pressure condition.

### IV. MEASURED PERFORMANCES OF THE HYDROGEN-PRESSURE DOSIMETERS

The Hydrogen-Pressure Dosimeters have been irradiated using 6MeV focused e-beam providing by electron accelerator with doses of 20kGy. The obtained resonant frequency shift is reported on Table 3 for various sensors. The measurement sensitivities ranges from -0.42% per kGy to -0.12% per kGy.

	Sensor N21-1	Sensor N21-2	Sensor N21-6	Sensor N21-9
Freq. shift	- 3%	- 8.4%	- 2.5%	- 5.1%

Table 3 : Measured resonant frequency shift (in %) after e-beam irradiation (20kGy)

The pressure inside the micro-chamber resulting from the outgazing of the polyethylene can be derived from Table 1 and Table 3. The results are reported in Table 4. The sensitivities are between 20mbar/kGy and 90mbar/kGy. These encouraging results are consistent with those obtained in [6] (50mbar/kGy) using specific test structures based on silicon membrane deflection.

	Sensor N21-1	Sensor N21-2	Sensor N21-6	Sensor N21-9
Pressure in the micro-cavity	0.8 bar	1.8 bar	0.4 bar	0.8 bar

Table 4 : Pressure inside the micro-cavity after e-beam irradiation (20kGy). These results are derived from results reported in Tables 1 and 3

In order to check that the seal of the micro-cavity is hermetic to hydrogen, the resonant frequency of sensors has been measured during several months after e-beam irradiation (Figure 4). After few days the frequency shift is found to be very small (no more than  $\pm 0.15\%$ ) and consequently, the sensors sensitivities reported in Table 3 are still applicable.

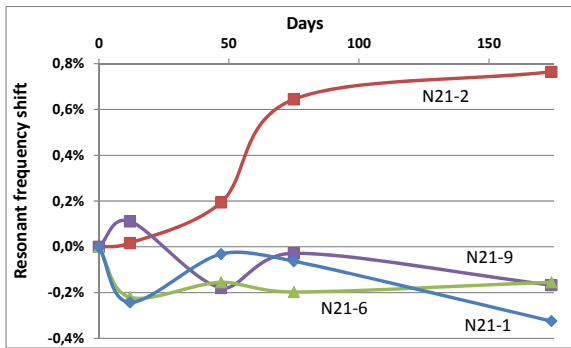


Figure 4 : Measured resonant frequency shift (in %) versus time after e-beam irradiation for 4 sensors

From Figure 4 it can be observed that the undesirable frequency shift is small after six months for 3 sensors (Sensors N21-1, N21-6 & N21-9). This results demonstrates that a good long-term hermetic seal was achieved during the manufacturing process of the micro-cavities.

## V. CONCLUSIONS

For the first time, high dose nuclear radiation dosimeters with wireless capabilities are presented. The sensor is composed of a miniature hydrogen pressure dosimeter and a passive microwave transducer. The good hermetic seal of the constitutive micro-cavities is crucial and is achieved 6 months after nuclear irradiation. The irradiation sensitivity of proposed sensors is measured for 20kGy e-beam dose and the pressure generated by the hydrogen outgazing inside the sensors' micro-cavity can be derived.

A large range of pressure is achieved by the proposed sensors. The observed dispersion in the sensors' performances are probably due (1) to the lack of reproducibility in the hydrogen outgazing of the polyethylene which was used in this first experiment and, (2) to the complex mechanical behavior of non-conventional bossed silicon membrane.

Research are now focused on design optimization and reliability studies of the three transducers used in the sensor (hydrogen outgazing, bossed membrane, microwave resonator).

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