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Proceeding Paper

Performance Analysis of FEM Simulated LTCC Diaphragm [†]

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Abstract: In this study, low temperature cofired ceramic (LTCC) based circular diaphragm design was considered for the Fabry–Pérot Interferometer (FPI) pressure sensor application. Characteristics of LTCC based circular diaphragm was analyzed by FEM analysis. Thickness of LTCC diaphragms were selected 50 µm, 75 µm and 100 µm with the diameter of 3 mm, 4 mm and 5 mm, respectively. Our results showed that sensitivity and frequency response of this structure can be designed flexibly by adjusting the parameters of the ceramic diaphragm size including radius and thickness. The key contribution of this work is to study the LTCC diaphragm with different size for future works.

Keywords: LTCC diaphragm; FEM; performance analysis

1. Introduction

MEMS (Microelectromechanical system) pressure sensors have been extensively studied and used for different applications. Miniaturization, fabrication cost and high performance are the some of the advantages of them over macro size pressure sensor counterpart [1,2]. Working principle of diaphgram based MEMS sensor includes deformation of diaphragm after applied external pressure and measurement of capacitance or resistance due to this deformation [3,4]. Sensitivity and naturel frequency of the diaphragm are the important parameters in terms of mechanical performance of sensor and thus, it should be considered for design of pressure sensor. These parameters are simply calculated by using material properties and geometrical parameters of diaphragm [5–7]. As it mentioned above, diaphragm material selection is the critical issue in addition to the shape or geometry optimization to improve the mechanical performance of micro-fabricated pressure sensors. Although single crystal silicon (Si), polysilicon (PolySi), graphene, Si_3N_4 are the common diaphgram materials [8], LTCC (low temperature co-fired ceramic) is a good candidate as a diaphgram for the high temperature applications of (FPI) Fabry–Pérot Interferometer pressure sensor [9,10]. However, there are limited number of studies in literature regarding LTCC based FPI sensor fabrication. One of these study proposed and experimentally demonstrated the performance of the square diaphragm that has a length, width, and thickness of 10 mm, 10 mm, and 100 µm,respectively for high-temperature applications [10].

In this study, LTCC based circular diaphragm design was considered for the FPI pressure sensor application. Characteristics of LTCC based circular diaphragm was analyzed by finite element method. Sensitivity, resonance frequency and static deflection of the diaphragm are analyzed and evaluated for MEMS based LTCC diaphragm performance. Thickness of LTCC diaphragms were selected 50 µm, 75 µm and 100 µm with the diameter of 3 mm, 4 mm and 5 mm, respectively. The performances of diaphragms that were obtained using ANSYS are were compared with analytically results. Our results showed that sensitivity and frequency response of this structure can be designed flexibly by adjusting the parameters of the ceramic diaphragm size including radius and thick-

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ness. The key contribution of this work is to show performance of the circular LTCC diaphragm with different size for future works of LTCC based sensor design and fabrication for different pressure sensor application at high temperature.

2. Materials and Methods

2.1. Low Temperature Co-Fired Ceramic (LTCC)

LTCC has been generally used anodic bonding of Si wafer for more compact 3D device integration/packaging process [11–14] and it is a good alternative to glass and TGV (Through Glass Via) substrate owing to its good material properties and low resistance inner wirings that embedded inside the layers [15]. It is a multilayer ceramic substrate that consists of an alumina–cordierite ceramic powder and Na_2O-Al_2O_3-B_2O_3-SiO_2 glass powder [15]. Material properties of LTCC substrate was reported from previous study in literature [16].

2.2. LTCC Diaphragm Design

In this study, naturel frequency and sensitivity of circular LTCC diaphragms are investigated by finite element method (FEM) and results are compared with theoretical calculations. For a flat circular diaphragm with a clamped edge, the center deflection caused by pressure is analytically expressed as [17]

$$\omega(r = 0) = \frac{Pa^4}{64D} \tag{1}$$

where P is pressure, a is diaphragm radius and D is the flexural rigidity of diaphragm. Frequency response is another important parameter and it is given for a circular diaphragm with a clamped edge as below [17]

$$f = \frac{10.2}{2\pi}\sqrt{\frac{E}{12(1 - v^2)\rho}}\frac{t}{a^2} \tag{2}$$

Here, t is thickness, E is the Young's modulus, and ρ is the density of diaphragm. Nine different design was used for the FEM analysis. Thickness of LTCC diaphragms were selected 50 μm, 75 μm and 100 μm with the diameter of 3 mm, 4 mm and 5 mm, respectively.

3. Results and Discussion

LTCC diaphragm deflection with different size under pressure was obtained by ANSYS software and then compared with analytical results. Firstly, displacement of diaphragm was simulated (Figure 1). Figure 2 shows the comparison of theory and FEM results of center displacement for the 100 μm thick diaphragm with a diameter of 3 mm, 4 mm and 5 mm as a function of pressure. It can be seen that theory and FEM results are consistent. Sensitivity was obtained by dividing diaphragm deformation to applied pressure and these results are summarized as in Table 1. These results indicated that sensitivity increases with the size of diaphragm (diameter) as expected from the Equation (1) ($\omega \propto a^4$). Similarly, sensitivity decreases as a function of diaphragm thickness due to a proportion of $\omega \propto 1/t^3$ between the center deflection and diaphragm thickness.

Table 1. Sensitivity (nm/kPa).

	t (μm) = 50		t (μm) = 75		t (μm) = 100	
Diameter (mm)	**Theory**	**FEM**	**Theory**	**FEM**	**Theory**	**FEM**
3	88.79	88.00–88.29	26.31	26–26.17	11.10	11.12
4	280.62	278.33–279.00	83.15	82.33–82.56	35	34.90
5	685.1	680–681.2	203	201–201.8	85.6	84–84.6

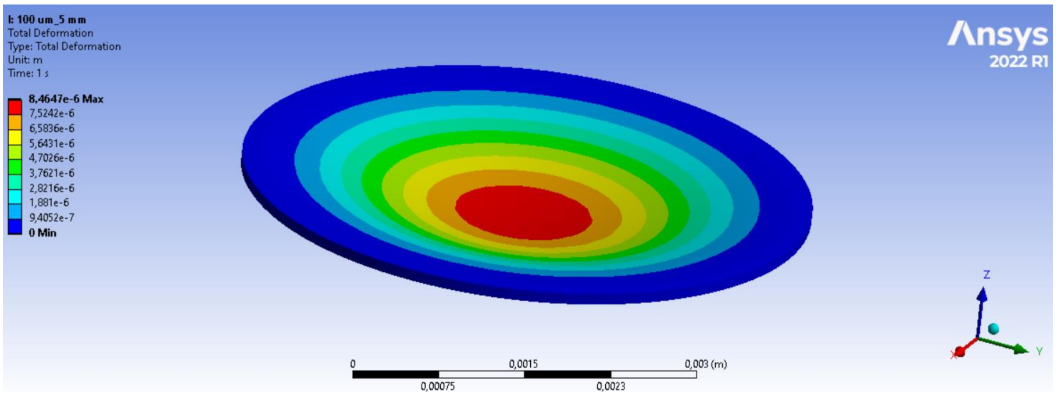

Figure 1. FEM result of center deflection for 100 µm thick diaphragm with a diameter of 5 mm under 100 kPa pressure.

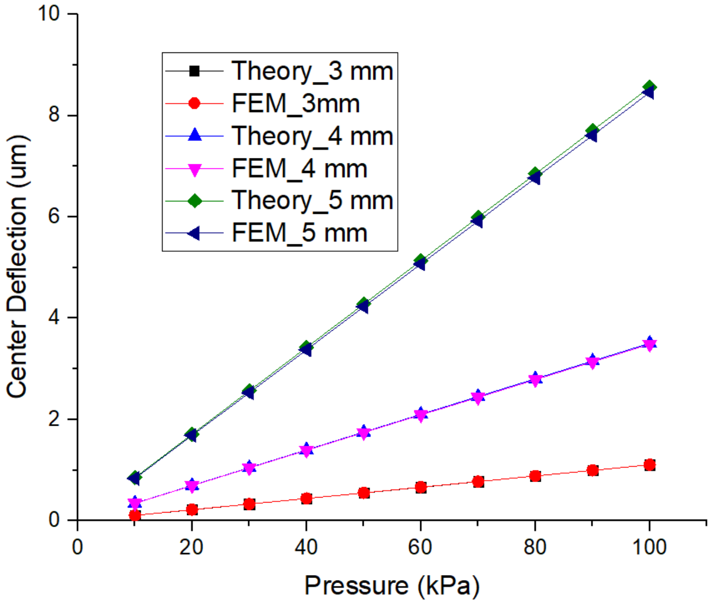

Figure 2. Center deflection of 100 µm thick diaphragm with a diameter of 3 mm,4 mm and 5 mm under pressure between 10–100 kPa.

The effects of diaphragm thickness and radius to the naturel resonant frequency were also studied by using FEM analysis and results are presented in Table 2. Figure 3 shows the FEM result of resonant frequency for 75 µm thick diaphragm with diameter of 4 mm.

As it known from Equation (2), naturel frequency decreases as function of radius and proportion to the thickness of diaphragm. FEM results are very consistent to theoretical results as expected.

Table 2. Comparison of FEM and theoretical naturel frequency (kHz) results of LTCC diaphragm for different thickness and diameter.

	t (µm) = 50		t (µm) = 75		t (µm) = 100	
Diameter (mm)	**Theory (kHz)**	**FEM (kHz)**	**Theory (kHz)**	**FEM (kHz)**	**Theory (kHz)**	**FEM (kHz)**
3	61.78	62.00	92.67	92.89	123.56	123.32
4	34.75	34.89	52.13	52.34	69.50	69.67
5	22.24	22.32	33.36	33.49	44.48	44.64

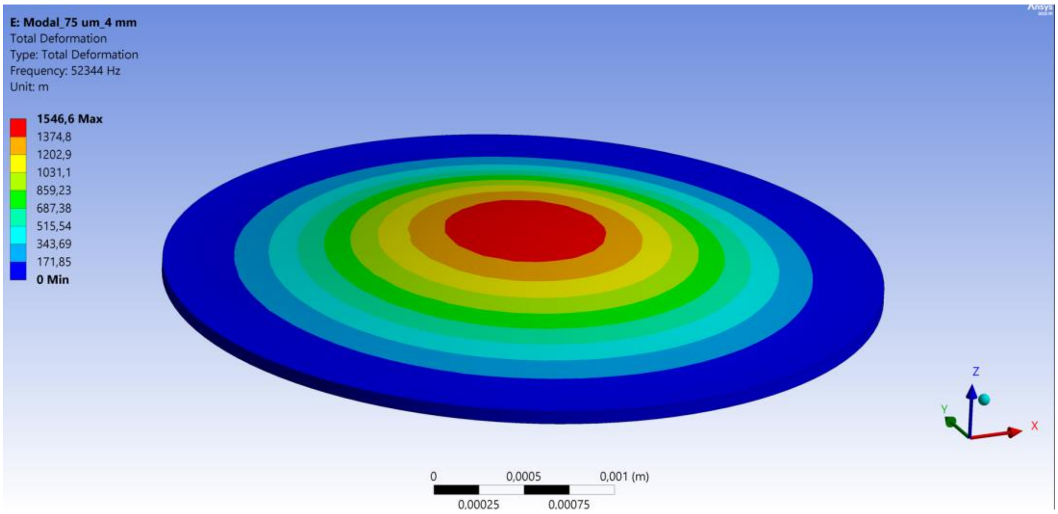

Figure 3. FEM result of resonance frequency for the 75 μm thick diaphragm with diameter of 4 mm.

4. Conclusions

In this work, the effect of diaphragm thickness and radius on sensitivity and naturel frequency for circular LTCC diaphragms proposed and studied. It was evaluated using a finite element model (FEM) analysis and results were then compared to analytical results. The main purpose of this study is to provide preliminary results for the future works of LTCC based diaphragm design and fabrication for high temperature applications. Future work of this study is performance analysis (numerical and analytical) of LTCC diaphragm with different geometry (circular, square, hexagon, etc.).

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