PRESSURE SENSING USING LTCC TECHNOLOGY

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Abstract: This paper deal with the design, manufacturing and measurement of optical pressure sensors produced using Low Temperature Co-fired Ceramic technology. There is brief overview of measurement methods used for pressure sensor interrogation. Benefits and problems regarding measurement methods are discussed. Pressure transducers are based on the change of the light spectrum reflected from the Fiber Bragg Grating integrated in the sensor. Low Temperature Co-fired Ceramic structure with membrane was used for the forming of a pressure transducer. Samples of fiber optic sensors are calibrated using reference pressure measurement and characteristics of the sensors are measured. Pressure sensors for different pressure ranges were measured and tested.

Keywords: Low Temperature Co-fired Ceramic, pressure sensors, Fabry-Pérot resonator, Fiber Bragg Grating

1 INTRODUCTION

In past decades Low Temperature Co-fired Ceramic (LTCC) technology became more popular in many applications. This technology is commonly used in packaging, high frequency modules and sensors. Sensing is growing area of possible applications of LTCC technology. Main advantages of LTCC technology is thermal stability up to 350 °C, chemical resistance, mechanical parameters similar to alumina ceramics, low thermal coefficient of expansion and many others. For use in industrial pressure sensors is LTCC suitable candidate. [1]

Pressure sensors are one of the most common sensor types available on the market. Optical pressure sensors compared to the other types of pressure sensors have advantages like immunity to electromagnetic interference, they are suitable for explosive environment, interrogation unit can be far from the sensor and with one interrogation unit can be evaluated large number of sensors. Disadvantage of the optical sensing can be higher price of some interrogation units. Cost of the interrogation unit often limits use of the optical sensor only for special application [2][3][4].

There are many types of ceramic pressure sensors based on different principles of sensing [5][6]. Pressure sensors based on LTCC are widely used, employing a variety of sensing methods based on the mechanical transducers like membranes. The most common method of pressure sensing is using piezoresistive elements with resistors in bridge configuration [7]. Other frequently used methods are based on the piezoelectric, capacitive or inductive structures.

Most pressure sensors use membranes, which deflects under applied pressure. The material of the membrane can vary depending on the demands of the environment and reliability. Properties of the membrane in terms of deformation under the pressure are defined by the physical dimensions of the membrane and by the material properties.

2 MEASUREMENT METHODS

The most common principle of pressure sensing around atmospheric pressure is using deformation elements such as membrane, which deflects under applied pressure. The deflection is converted to the change of electrical or other quantity easy to measure. Pressure sensors are divided into three groups based on the reference pressure on the other side of the membrane. In this paper is described differential pressure sensors with cavity pressure equal to the pressure of one atmosphere. There are many methods of optical detection of membrane deflection.

2.1 INTENSITY BASED MEASUREMENT

The simplest method of measuring membrane displacement under pressure is measurement of light power reflected from the surface of the membrane. For this method is used reflective membrane placed close to the end face of optical fiber. Dispersion loss of the light signal depends on the distance between reflective mirror and optical fiber. This type of interrogation is very simple, cheap and fast. Disadvantage is the need in attenuation calibration of the detected light signal on the optical path of the signal. This attenuation can vary under different environmental conditions and is hard to compensate.

2.2 MEASUREMENT USING FABRY-PÉROT RESONATOR

Using Fabry-Pérot (FP) resonator for measuring deflection of the membrane is very similar to the first measuring method with difference in evaluation of the reflected light signal. In FP resonator is analyzed spectrum of the reflected light signal from the FP resonator. Basic principle of sensing including spectral characteristics are in the figure 1.

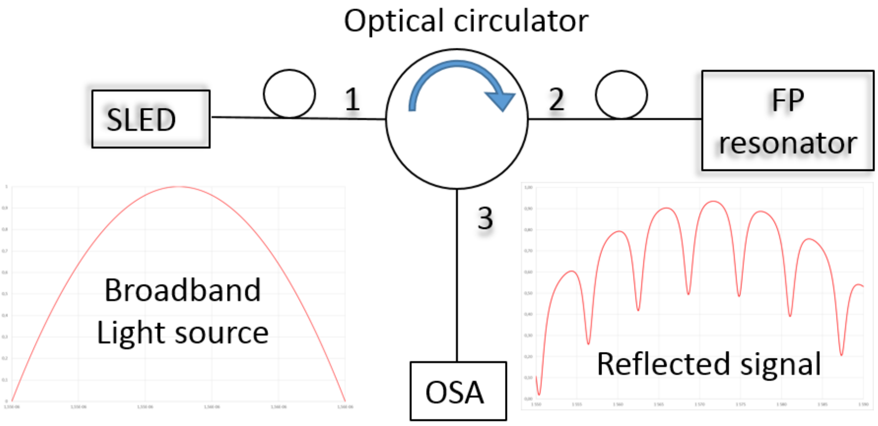

Figure 1: Measurement setup for evaluation of the length of FP resonator [8]

Modulation of the light signal intensity is caused by interference of incident light from mirrors at each end of the resonator. Distance between these two mirrors defines the length of the FP resonator. Positions of the light intensity minimums depend on the mirror spacing and are defined by equation 1. For any given length of the resonator there are resonant wavelengths according to the interference between two counter propagating light waves in the resonator. On the broadband spectrum, there is a visible power modulation according to this interference. The position of these peaks and valleys are determined by the simplified equation:

$$L = \frac{\lambda_1 \lambda_2}{2(\lambda_1 - \lambda_2)} \tag{1}$$

Where L is the length of the resonator and λ_1, λ_2 are the positions of resonant wavelengths in the spectrum.

2.3 MEASUREMENT USING FIBER BRAGG GRATINGS

The next method of measurement is based on the shift of the central wavelength reflected from the Fiber Bragg Grating (FBG). FBGs are widely used in telecommunications as a band-pass filters in signal multiplexing. Measurement setup for the FBGs is also based on the evaluation of the reflected signal from the sensing element. The schematic of the setup for pressure measurement with FBG is shown in **Figure 2**.

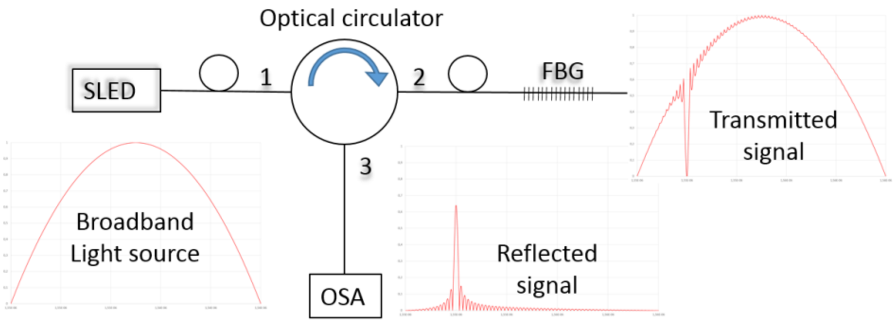

Figure 2: Measurement setup for interrogation of the FBG pressure sensor [8]

The structure of the FBG is created by alternating changes in refractive index of the fiber core (defined as the grating period - Λ). Reflected and transmitted light changes with a physical change of the optical fiber with grating. This effect is described by the equation:

$$\lambda_B = 2n_e \Lambda \tag{2}$$

Where λ_B is the wavelength reflected by the grating, n_e is the effective refractive index of the optical fiber core.

3 PRESSURE SENSOR DESIGN

The sensors described in this paper were designed as the differential pressure sensors. Measurement range of the sensors starts from atmospheric pressure up to 3 bars. All sensors were designed to have damage threshold approximately 2 times higher than upper measurement range. All sensors were referenced to the atmospheric pressure.

The main part of each sensor is a membrane, which is deformed under the applied pressure. The main limitation in the sensor design is the thickness of the membrane. Minimal thickness of the membrane after firing process is given by the thickness of a single green sheet. In the case of material DP951 is the minimal thickness (*t*) of the membrane is around 50 µm for the sheets with lowest thickness. Green tapes with thickness 100 µm after firing process were used in the experiments. There are also other parameters influencing the mechanical behavior of the membrane: material constants (Young's modulus - *E*, Poisson's ratio - *γ*) and dimensions of the membrane (radius - *a*, thickness - *t*). Deflection of the membrane under applied pressure can be calculated using the following equation:

$$d = \frac{3\, P_0\, r^4 (1-\nu^2)}{16\, E\, t^3} \tag{3}$$

Pressure sensors with different thickness of the membrane were manufactured for different pressure ranges. The sensor design and threshold pressure were simulated in ANSYS for verification of the mechanical behavior of the membrane.

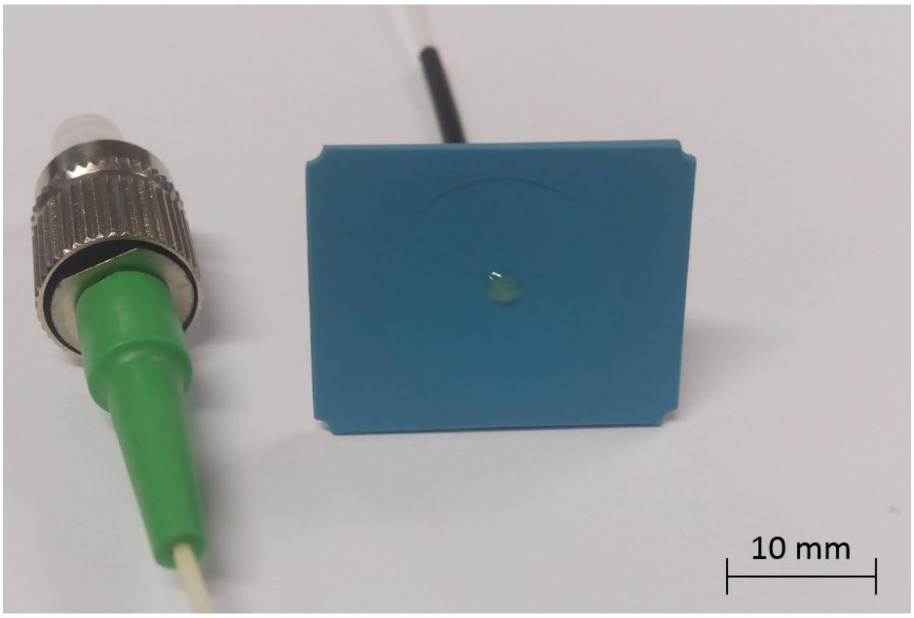

Figure 3: Optical pressure sensor without housing

Sensors based on the FBGs measures induced stress in the FBG caused by the ceramic membrane under applied pressure. In case of FBG sensors the fiber is attached to the membrane using adhesive. Optical pressure sensor without metal housing is shown in **Figure 3**. During the manufacturing process FBG is fixed to the membrane with pre-applied strain. In case of sensor design in this paper, the compressive stress from the pressure load is applied to the FBG, therefore, reflected central wavelength of the FBG will shift to the lower wavelengths with applied pressure.

4 EXPERIMENTA MEASUREMENT

Custom interrogation unit was used for the measurement of produced optical sensors. This interrogation unit has absolute accuracy of measured wavelength 1 pm with resolution of 0,1 pm in range of 7 nm. Automated measurement was set using electronic pressure valve, pressure chamber and interrogation unit connected to the PC with National Instrument Data acquisition unit. Measured data are shown in figure 4. Central wavelength (cwl) reflected from FBG has linear dependence on applied pressure.

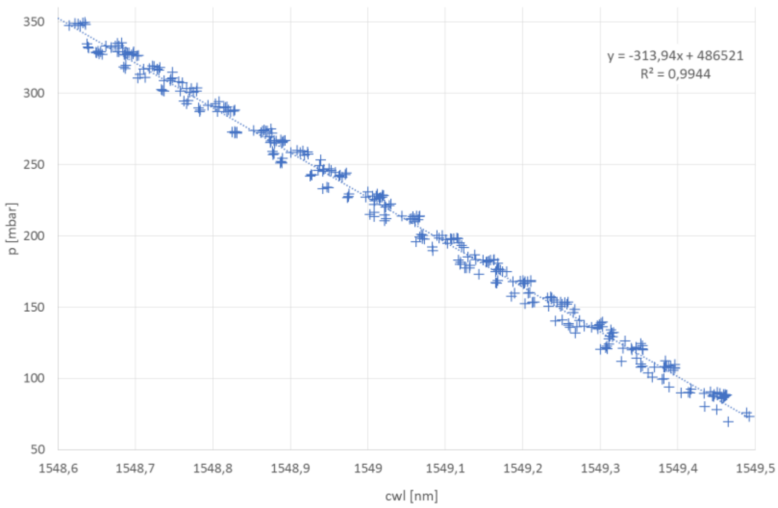

Figure 4: Calibration curve for optical pressure sensor

Optical sensors presented in this paper exhibit good linearity over the designed measurement range. For FBG sensor this is achieved by the preloading of the FBG and the designed small range of the motion of the membrane in the sensor.

This gives that the theoretical sensitivity of the sensors with the same membranes and the same interrogation unit is 0,6 % for the FBG based sensors.

5 CONCLUSION

Design and measurement methods of optical pressure sensors are presented in this paper. For sensor body is used LTCC ceramics and all of the sensors are based on the optical interrogation methods. Experiments showed the possibility of manufacturing the optical pressure sensors in LTCC technology in combination with fiber optics. This combination brings unique properties of the sensors in terms of use in the hazardous environments and high sensitivity. Sensitivity of the FBG pressure sensors is around 3 nm/bar and accuracy ±0,3 %. In comparison sensors based on the FP resonator exhibit higher accuracy and sensors based on the FBGs are more resistant to the environmental influences such as vibrations and are easier to interrogate.

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