Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 388-389

An Optomechanical Pressure Sensor Using Multi-Mode Interference Couplers

Dooyoung Hah, Euisik Yoon, and Songcheol Hong

Department of Electrical Engineering, KAIST, 373-1 Kusong-dong, Yusong-gu, Taejon, 305-701, Korea
Phone : +82-42-869-5421, Fax : +82-42-869-8560, E-mail : hady@cais.kaist.ac.kr

1. Introduction

Most of pressure sensors reported are based on either capacitance or piezoresistance change by pressure. They have good performance, but are very sensitive to electromagnetic radiation. Optomechanical pressure sensors are alternative solutions, especially in electromagnetically active environments. There have been some reports of optomechanical pressure sensors using a Mach-Zehnder interferometer(MZI)[1]-[3]. Most of previous optomechanical pressure sensors have thick membranes, so that their areas are large(above 40mm^2). In this work, we use a thin p$^+$ Si membrane to reduce device size, and instead of an MZI, use multi-mode interference(MMI) couplers, which, we believe, have lower loss and is smaller than an MZI.

2. Design and Simulation

The schematic diagram of the proposed sensor is depicted in Fig. 1. MMI couplers are designed to divide input light into two equal-power output. One arm of an input MMI coupler is on the membrane, and the strain induced to this membrane by pressure change varies refractive index of waveguide layers. This photo-elastic effect can be written as

$$\Delta(\frac{1}{n^2})_i = p_{ij}S_j \qquad (1)$$

where n is refractive index, p is photo-elastic coefficient, and S is strain. The strain also causes change of light path length. Output power of an output MMI coupler is determined by the two kinds of effects described above. Waveguide layers are designed as a single-mode striploaded type of a triple layer SiO_2-SiN_x-SiO_2 system(Fig. 2). The refractive index measured by an ellipsometer and the thickness of each layer are written on Fig. 2. The lengths of an MMI coupler and an arm are 3mm and 5mm, respectively , and the total length of active section is 11mm, which is smaller than the previous sensors using an MZI(several centimeters). We have made a thin membrane by using p$^+$ Si as an etch stop layer in anisotropic Si etchant(EDP). The thickness of the p$^+$ Si layer is designed to be 4μm in a mild tensile stress. The roughness of p$^+$ Si surface is measured to be below 100Å(measured by an AFM and about 1/100 of the wavelength of He-Ne laser). The dimension of the membrane is $5.9\times500\times500$ μm^3, which is very small compared to previous sensors without p$^+$ Si etch stop layer. Simulated characteristics of the sensors of various membrane size is shown on Fig. 4. Two steps are included in this simulation. Firstly, the deflection and the strain of the membrane according to the pressure are calculated by means of the analytical and the numerical method. Then, the light propagation through whole device is simulated by means of the normal mode theory with the calculated strain at the previous step. The simulated sensitivities of the sensor of 500×500 μm^2 membrane and 400×400 μm^2 membrane are 20.0ppm/Pa in the range of 50kPa and 8.22ppm/Pa in the range of 100kPa, respectively. There is almost no response in 200×200 μm^2 case in the range of 100kPa. The values of p_{11} and p_{12}, the photo-elastic coefficients used in this simulation are 0.121 and 0.270, respectively[4].

3. Fabrication and Results

Fabrication starts with boron diffusion to form a p$^+$ Si membrane layer. The lower cladding layer SiO_2 is made by thermal oxidation(3000 Å) and sputtering deposition(1.2 μm). Backside SiO_2 formed in this thermal oxidation is used as a mask in bulk Si etching. Because thermal oxide has much larger residual stress than sputtered SiO_2, the formation of the lower cladding layer is separated into two steps. The core layer SiN_x is deposited by RPCVD. The upper cladding layer SiO_2 is deposited by sputtering. The waveguides are formed by means of RIBE with Cr mask and wet etching. A front-back aligner is used for align the waveguide and the membrane. After window opening of backside SiO_2, anisotropic etching of bulk Si in EDP at 110℃ is performed for the membrane formation and the etching is stopped at the p$^+$ Si layer. Fig. 3 shows the SEM image of one arm of an MMI coupler and a membrane. A He-Ne laser(λ=6328 Å) is used as a light source and the light is injected to the sensor via objective lens. The measured result is shown on Fig. 5, comparing with simulated result. Measured sensitivity is 11.98 ppm/Pa in the dynamic range of 50kPa. The difference between measured and simulated result may caused by the difference between simulation and real device parameters.

4. Conclusion

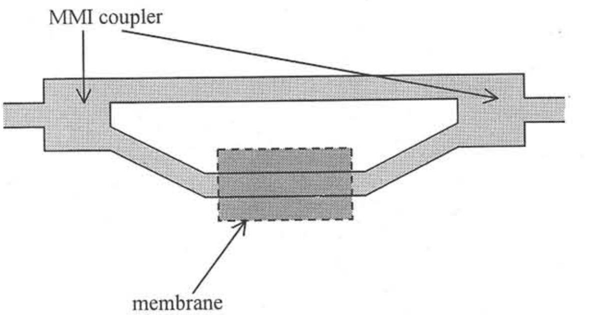
An optomechanical pressure sensor using MMI couplers with 4μm-thick p+ Si membrane is fabricated. The dimension of membrane is $5.9\times500\times500$ μm^3. The total length of the active section is 11mm. The characteristic of the device is measured with a He-Ne laser and compared with simulation results. Measured sensitivity is 11.98 ppm/Pa in the dynamic range of 50kPa.

Acknowledgements

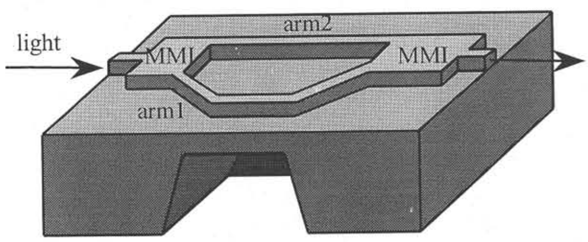
This work is partially supported by Ministry of Information and Communication, and by Korea Science and Engineering Foundation, OERC-1997G0202

References

1) K. Benaissa and A. Nathan: IEEE Trans. Electron Devices, vol. 43, pp. 1571-1582, 1996
2) K. Hoppe, L. U. A. Andersen, and S. Bouwstra: Transducers, pp. 590-591, Stockholm, 1995
3) C. Wagner, J. Frankenberger, and Peter P. Deimel: IEEE Photon. Technol. Lett., vol. 5, pp. 1257-1259, 1993
4) G. N. De Brabander, J. T. Boyd, and G. Beheim: IEEE Photon. Technol. Lett., vol. 6, pp. 671-673, 1994



(a)



(b)

Fig. 1 Schematic diagram of an optomechanical pressure sensor using MMI couplers. (a) top view (b) cross-sectional view

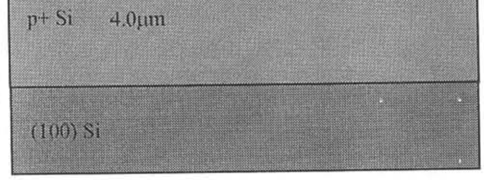


Fig. 2 Designed waveguide layer system.

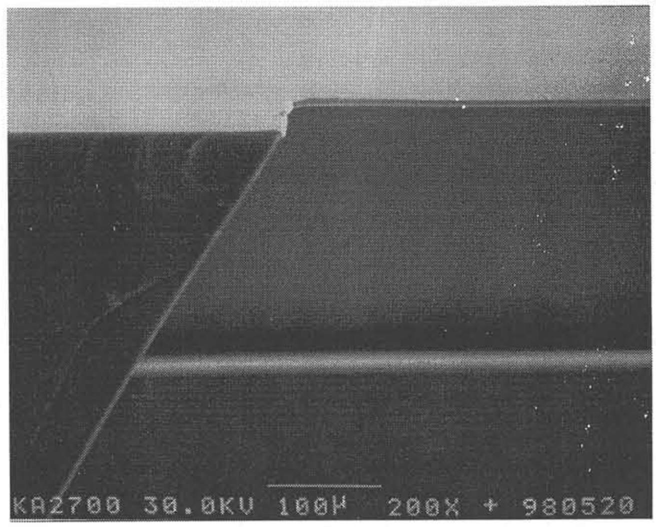


Fig. 3 SEM picture of fabricated sensor.

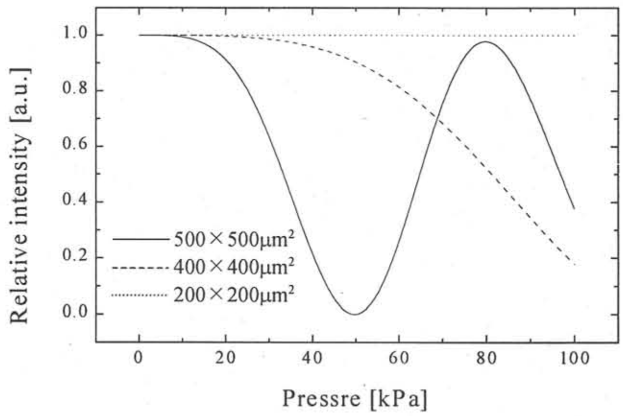


Fig. 4 Simulated characteristics of the sensors of various membrane sizes.

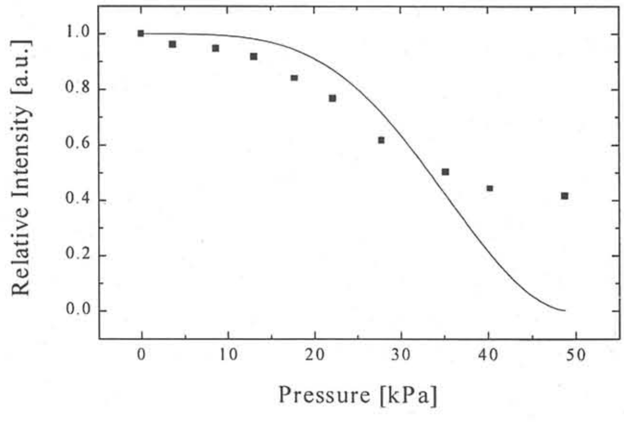


Fig. 5 Simulated(solid line) and measured(squares) data of the sensor.