Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 87 (2014) 1533 – 1536

Procedia Engineering

www.elsevier.com/locate/procedia

EUROSENSORS 2014, the XXVIII edition of the conference series

Surface-micromachined Bragg Reflectors Based on Multiple Airgap/SiO2 Layers for CMOS-compatible Fabry-Perot Filters in the UV-visible Spectral Range

M. Ghaderi*, N. P. Ayerden, G. de Graaf, R. F. Wolffenbuttel

Electronic Instrumentation Laboratory, Microelectronics Department, Faculty of EEMCS, Delft University of Technology, 2628CD Delft, The Netherlands

Abstract

In CMOS-compatible optical filter designs, SiO_2 is often used as the low-index material, limiting the optical contrast (n_{Hi}/n_{Lo}) to about 2. Using the air as low-index material improves the optical contrast by about 50%, thus increasing the reflectivity and bandwidth at a given design complexity. The design and fabrication of a 4-layered air-dielectric distributed Bragg reflector (DBR) centered at 400 nm using surface micromachining techniques, is presented here. Fabrication is based on the deposition of poly-Si thin films and subsequent thermal oxidation. Selectively removing the Si layers, produces an air/SiO_2 filter stack according to the optical design. The width of the air-gaps needed in this application is typically smaller as compared to conventional MEMS devices. The number of layers is also higher, while no electrical contact is required. The concept, the fabrication of 4-layer DBRs and preliminary measurement results are discussed in this paper.

Peer-review under responsibility of the scientific committee of Eurosensors 2014

Keywords: Airgap; Bragg reflector; CMOS-Compatibility; UV-visible spectrum.

1. Introduction

Bragg reflectors (DBR) are one of the essential components in Fabry-Perot type micro-spectrometers. The optical contrast between the high and low-index layers determines the spectral resolution and efficiency. However, the choice of available materials for the DBR is limited by the required CMOS-compatibility. Air with a refractive

* Corresponding author. Tel.: +39-15-2789177; fax: +31-15-2785755.
E-mail address: m.ghaderi@tudelft.nl

Peer-review under responsibility of the scientific committee of Eurosensors 2014
doi:10.1016/j.proeng.2014.11.591

index of unity and a very low loss is a perfect choice for the low-index material, improving the optical contrast by about 50% in the UV-Visible range [1]. Daleiden et al. [2] presented an air/dielectric DBR for tunable wide stop-band infrared Fabry-Perot interferometers (FPI). Silicon-airgap FPIs with a single air-gap per DBR were also implemented by [3, 4] for extending the operating range of a micro-spectrometer. However, these methods benefits from the standard silicon micromachining techniques which limit the optical operating range to the infrared. For the visible LED application, the multiple-pair air/GaN DBRs has been also demonstrated by [5] for achieving 98% peak reflectance using electrochemical etching of GaN. Silicon-dioxide and polysilicon thin-films are commonly present in CMOS designs and hence an air/SiO_2 reflector structure is highly appropriate in a fully CMOS-compatible design. The idea and fabrication scheme of this work were already presented [1]. This paper will present preliminary fabrication results and discusses the optical challenges for a reflector design in the visible range.

2. Optical design of an air/dielectric Bragg reflector

A Bragg reflector design consists of a number of high and low index pair of dielectrics, where the optical contrast determines the reflectance of the reflector. Air has all the characteristics that can be expected from a low-index dielectric. The index of refraction is unity and exhibits almost no absorption at the optical range from UV to infrared. This non-absorbing is especially important in the UV range where most of the common optical materials are absorbing, and hence few materials are available to choose. Silicon-dioxide thin films are dominantly used in CMOS processes. With a refractive index of almost 1.5, silicon-dioxide is commonly used as a low index material. However, in this optical design the oxide is used as the high index material giving a contrast of about 1.5 when used with air. This optical contrast is close to highest contrasts achievable using conventional optical materials. For this study, silicon-dioxide films were grown by oxidizing thin layers of poly-Silicon at various temperature. The optical properties of the oxide layers were characterized and shown in Figure 1 (LEFT).

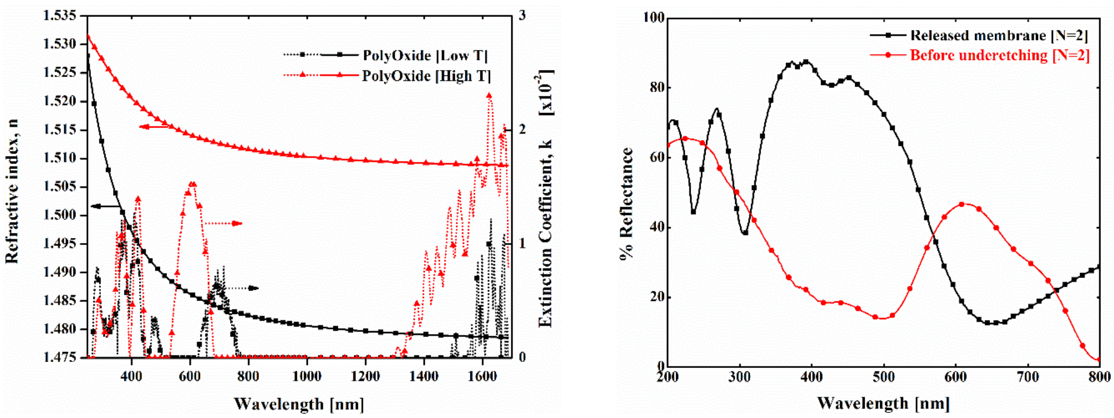

Figure 1. LEFT: Optical characterization of the thermally oxidized poly-silicon layers at 800° C [Low T] and 1000° C [High T] measured by variable angle spectroscopic ellipsometry (VASE), RIGHT: expected reflectance of a double-pair Bragg reflector pre- and post- membrane release.

According to the optical characterization, the oxide film grown at a higher temperature shows slightly higher refractive index, about 1.5%, and hence is more favorable for the high-index application. An optical reflector has been designed based on the refractive index data, and the reflectance of a 4-layered air/dielectric DBR centered at 400 nm is plotted in Figure 1 (RIGHT).

3. Process design and fabrication

Fabrication of a DBR structure based on micromachining techniques has been previously proposed in [1]. A polysilicon layer was deposited in an LPCVD furnace, and an oxide layer was subsequently grown by partial thermal oxidation. The thickness of the remaining (sacrificial) poly-Si layer is designed to be equal to the thickness of the air-film. Successive depositing and oxidizing poly-silicon layers made a layer stack according to the optical design (Table 1).

Table 1. Layer listing of the mirror stack before the membrane release. The non-uniformity of the layers were better than 1 nm and 5 nm over a 4 inch wafer for polysilicon and thermal oxide thin films, respectively.

#	Layer	Thickness [nm]
1	Poly Silicon	100
2	Thermal Oxide	70
3	Poly Silicon	100
4	Thermal Oxide	70

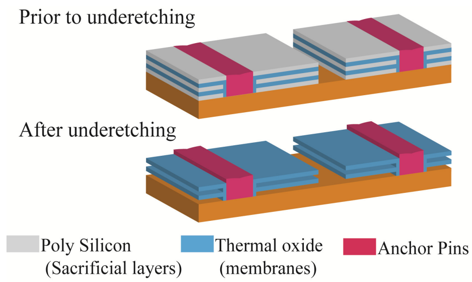

Figure 2. Artistic view of the structures, prior to and after under-etching.

After the layers stacking, the anchor holes were etched through the layers and filled by a thick conformal oxide layer. A set of access holes was patterned and then etched through the layers. Finally, the wafers were sacrificially-etched in a TMAH-based solution. Figure 2 depicts an schematic of the structures before and after under-etching. A doped TMAH solution was prepared by adding silicic acid and ammonium perchlorate into 5% TMAH-water solution [5]. The etch rate of poly-Si increases with temperature [~1-10 μm/hour], whereas the etch rate of the poly-oxide remains about 0.1 nm/hour, giving a selectivity in the order of 10^4. After the etching, the samples were placed into demi water to stop the etching and to dilute the remaining etchant liquid between the membranes. Subsequently, samples were placed in acetone and then in isopropanol bath to remove the water in the gaps and then the samples were dried using CO_2 supercritical drying.

4. Results and Discussion

Several samples containing different geometries with varied etch-hole and anchor distances were prepared, and the sacrificial layers were etched while the temperature of the etching bath was kept at 50° C without any stirring. Different samples were taken out of the etch bath during the under-etching to examine the partially under-etched structure. Each sample went through the sample preparation steps and dried using critical point drying (CPD) technique. After two hours of sacrificial layer etching, the membranes were released over a length of about 8 μm, giving a sacrificial etch rate of 4 μm/hour at 50° C.

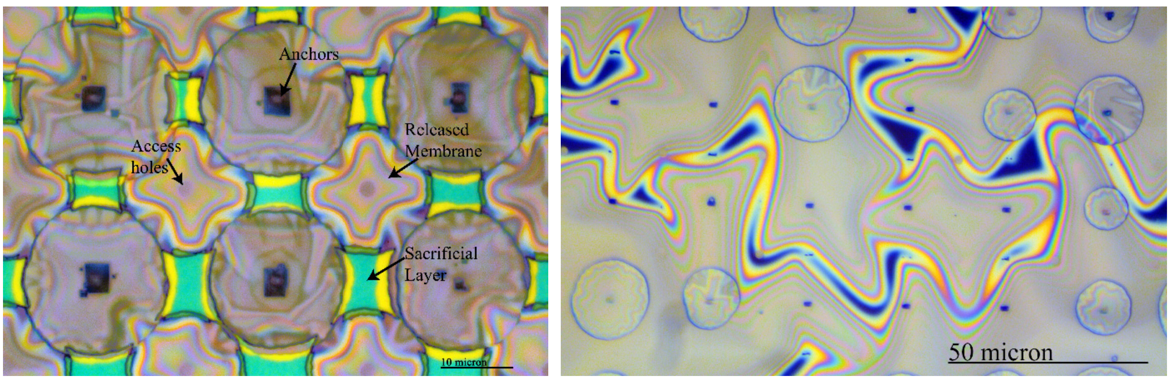

Figure 3. Optical microscope images of LEFT: partially released membranes after two hours of under-etching in doped-TMAH solution (50° C), RIGHT: Fully released membranes after 3 hours of etching in doped-TMAH solution.

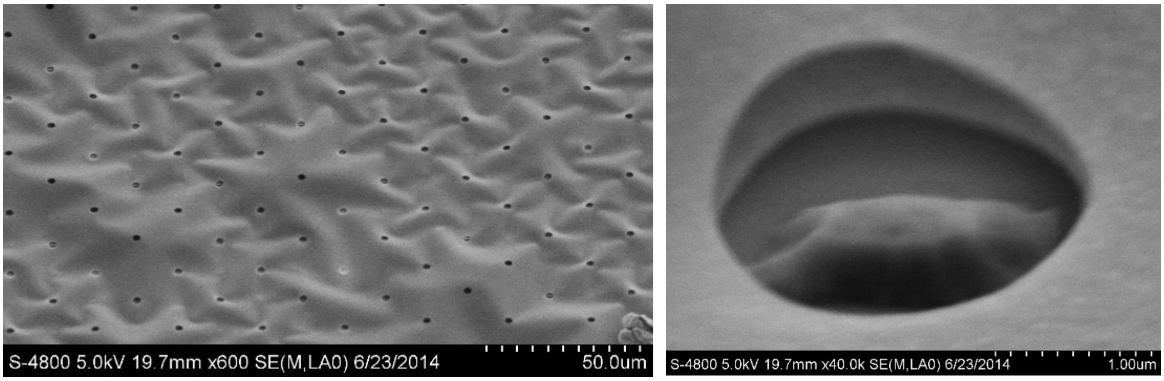

Figure 4. LEFT: 45° tilted SEM image of the large-area fully-released membrane. RIGHT: 45° tilted SEM image of an access-hole/anchor-pin, the double oxide layers are recognizable.

Some waviness in the released thin films can be seen from the fringe patterns (Figure 3) and also from the 45° tilted SEM photos (Figure 4). This non-uniformity in the films degrades the optical performance of the device for the intended UV-visible spectrum and is expected to be partly due to the partial etching of the anchor-pins during the membrane release-etch and is subject to further investigation.

5. Conclusion

The fabrication of several double ultrathin air-dielectric freestanding membranes was reported this paper. The doped-TMAH solution showed a very high selectivity to the thermal oxide layers and membranes survived after prolonged etching steps. The critical point drying effect was also found to be very promising in drying and release of the ultrathin membranes. Further research is directed to an improved understanding of the under-etching of very narrow channel and improved process uniformity.

Acknowledgment

This work has been supported by the Dutch technology foundation STW under grant DEL.11476. The samples were fabricated in the Dimes technology center and the Kavli nanolab, Delft.

References

[1] M. Ghaderi and R. F. Wolffenbuttel, "Design and fabrication of multiple airgap-based visible filters," 2014, pp. 913005-913005-8.

[2] J. Daleiden, V. Rangelov, S. Irmer, F. Römer, M. Strassner, C. Prott, *et al.*, "Record tuning range of InP-based multiple air-gap MOEMS filter," *Electronics Letters,* vol. 38, p. 1270, 2002.

[3] T. Enomoto, M. Suzuki, T. Iwaki, H. Wado, and Y. Takeuchi, "Infrared absorption sensor for multiple gas sensing. Development of a Fabry-Perot spectrometer with ultrawide wavelength range," *Electronics and Communications in Japan,* vol. 96, pp. 50-57, 2013.

[4] M. Tuohiniemi, M. Blomberg, a. Akujärvi, J. Antila, and H. Saari, "Optical transmission performance of a surface-micromachined Fabry–Pérot interferometer for thermal infrared," *Journal of Micromechanics and Microengineering,* vol. 22, p. 115004, 2012.

[5] D. Chen and J. Han, "High reflectance membrane-based distributed Bragg reflectors for GaN photonics," *Applied Physics Letters,* vol. 101, pp. -, 2012.