Released all-porous-silicon microstructure for spectrometer applications

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All-porous-silicon microstructures have been released with in-situ controllable current density to achieve low residual stress and out-of-plane stress gradient in the porous silicon (PS) films. Optical transmission of large area released PS structures was investigated through both Fourier-transform infrared spectroscopy (FTIR) and modelling in the near infrared and mid infrared wavelength range.

1. Introduction

Microelectromechanical systems (MEMS)-based tuneable Fabry-Perot filters have been developed within various infrared thermal imaging bands [1-3]. For such filters, released distributed Bragg reflectors (DBR) are needed to achieve narrowband transmission with high signal-to-noise ratio and a controllable wavelength. Usually they are fabricated through releasing multilayer materials which form alternate quarter wavelength thick layers of high refractive index and low refractive index. However, this method requires multistep deposition/etching with limited choice of suitable materials in terms of desired refractive index and micromachining compatibility.

Alternatively, through controlling the anodisation current density and HF electrolyte concentration in the formation process of porous silicon, modifying film properties such as porosity, refractive index and optical thickness can be easily achieved. Multilayer PS based distributed Bragg reflectors [4, 5] and optical filter based on released PS [6] have been fabricated, however, the MEMS device performance was limited by the non-uniform porosity and tendency to oxidise (ageing of the PS film), especially in released thick porous silicon devices. Through N_2 annealing, oxidation in ambient air of PS films is eliminated and the PS films become robust enough to apply standard photolithography [7], therefore allowing complex and scalable PS-MEMS structures to be fabricated. Methods to tune the residual stress and stress gradient by varying the current density during anodisation have been investigated to achieve a flat surface profile of the released PS microstructures having reduced out-of-plane stress gradient [8].

In this work, suspended PS plate microstructures with a large area of up to 0.36 mm^2 have been released, which show promise as a platform for an optical spectrometer. Fourier transform infrared spectroscopy (FTIR) was utilised to measure the transmission of the released PS structure. A transmission spectra model based on released single layer and multilayer PS was built for comparison and analysis. The study shows the opportunity to build large size, transmission controllable PS based optical spectrometers.

2. Results and discussion

PS films were fabricated with room temperature anodisation in a 15% HF/ethanol solution, on moderately doped p-type (100) silicon wafers with resistivity of 0.08-0.12 Ω·cm. The current density during anodisation was decreased from 20 mA/cm^2 to 8 mA/cm^2 over the film forming process, which was designed to compensate the

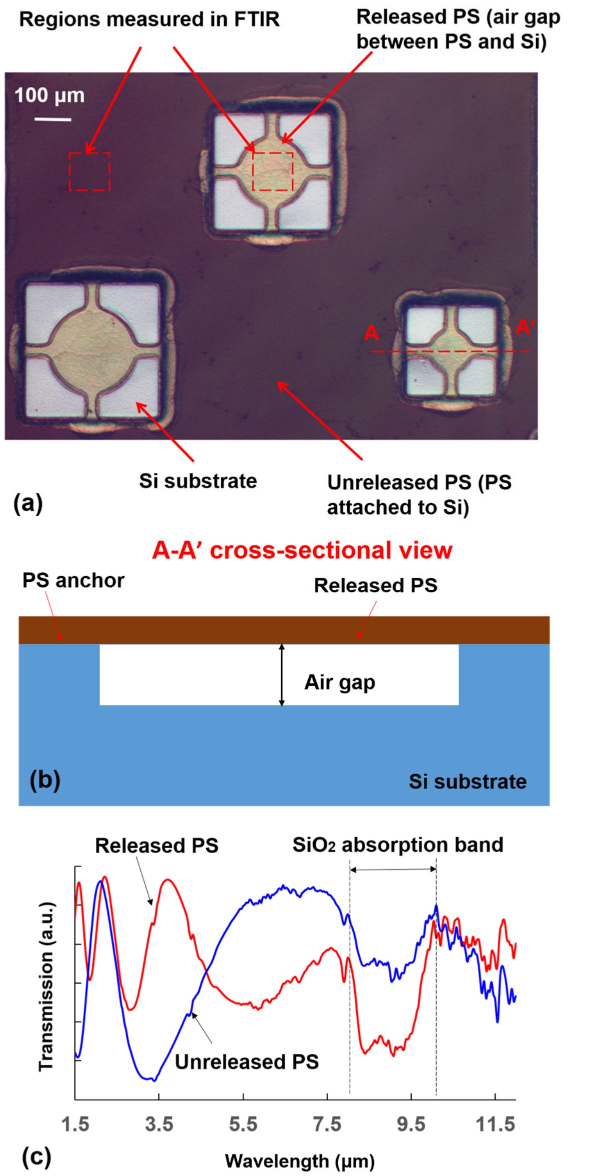

Figure 1: Transmission of released and unreleased PS microstructures. (a) Optical micrograph of released suspended PS plate microstructures; (b) Cross-sectional schematic of A-A' in (a); (c) transmission spectra measured by FTIR, with air gap of 2.9 µm.

out-of-plane porosity gradient induced stress gradient [8] and achieve a flat PS microstructure surface. The resulting film has a thickness of t=2.5 µm and porosity P=77%. After anodisation, the PS was annealed at 600 ^{o}C in nitrogen for 48 min, resulting in a robust film with high resistance to alkaline developer over the entire surface [9]. After annealing, established processes consisted of repeated patterning, RIE and electropolishing, followed by critical point drying, were implemented to release suspended PS plate structures with diameters range from 100 µm to 300 µm (circular) [10] or side length of 300-600 µm (square). The air gap height between the released PS and Si substrate can be controlled through electropolishing duration, and was designed to range from 2.5 µm to 8 µm in this work.

FTIR measurement was carried out with a PerkinElmer Spotlight i200 microscopy system, which can accurately locate the measurement region within an area of 100 µm diameter. As shown in Fig.1 (a), suspended PS plate microstructures of different sizes were released with an airgap of 2.9±0.4 µm between the released PS and Si. The cross-sectional view of the released PS microstructures is shown in Fig. 1(b). FTIR transmission was measured from the near infrared to mid infrared range (1.5-12 µm) in both released PS regions and unreleased PS regions; the spectra are shown in Fig. 1(c). A clear change of transmission peak positions between the spectra of released PS and unreleased PS was observed, indicating optical resonance resulting from the air gap cavity plays an important role in tuning the transmission peaks.

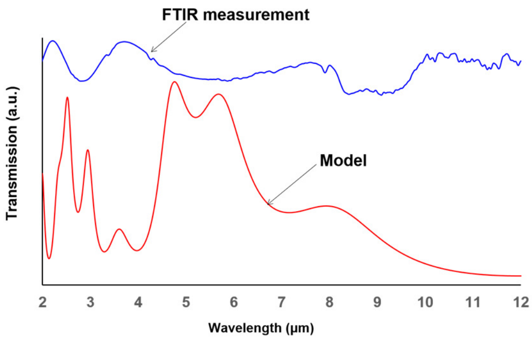

Figure 2: FTIR measurement and model of released single layer PS microstructure transmission spectra. Air gap of 2.9 µm.

To further understand the transmission of released PS structures, the FTIR measured data was compared with modelling results as shown in Fig. 2. The model was built based on a PS/air/Si/air structure, with PS film of porosity 77% and an airgap of 2.9 µm. The measured data showed similar transmission peak variations to the model, however with peak positions at different wavelengths. This could be due to non-flat structures; further topological studies are required to understand the flatness of these structures.

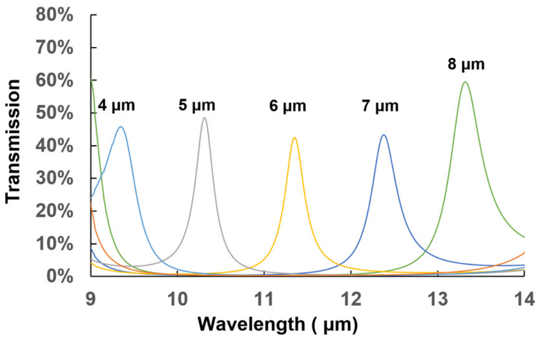

Figure 3: Modelled transmission of multilayer PS DBR filters with airgap ranges from 4 µm to 8 µm.

Investigation is ongoing through refinements of setup and background spectrum in FTIR to improve the measurement and signal/noise ratio. However, the work shows a pathway to release large size suspended PS plate microstructures, which provides the opportunity for fabricating multiplayer PS structures to work as DBR filters for an optical spectrometer.

The performance of a modelled narrowband filter based on a 3-layer PS DBR is shown in Fig.3. This model does not include the SiO_2 absorption which exists and needs to be eliminated in future structures. With the ability to fabricate multiplayer PS [11] and release large size PS microstructures with different air gaps, complex PS based Fabry-Perot filters should be achievable.

3. Conclusion

Large size (area up to 0.36 mm^2) suspended PS plate microstructures were released, and FTIR transmission was measured and compared with a model. The work provides a pathway for released complex PS filter fabrication, indicating the possibility of PS infrared thermal imaging applications.

Acknowledgements

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