

ProTEK PSB as Biotechnology Photosensitive Protection Mask on 3C-SiC-on-Si in MEMS Sensor

N Marsi^{1,2}, B Y Majlis³, F Mohd-Yasin⁴, A A Hamzah³, A Z Mohd Rus^{2,5}

¹Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia

²Sustainable Polymer Engineering, Advanced Manufacturing and Materials Center (SPEN-AMMC), Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia

³Institute of Microengineering and Nanoelectronics (IMEN), Universiti Kebangsaan Malaysia (UKM), Bangi, Malaysia

⁴Queensland Micro- and Nanotechnology Centre (QMNC), Griffith University, 4111 Brisbane, QLD, Australia

⁵Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Email: mnoraini@uthm.edu.my

Abstract. This project presents the fabrication of MEMS employing a cubic silicon carbide (3C-SiC) on silicon wafer using newly developed ProTEK PSB as biotechnology photosensitive protection mask. This new biotechnology can reduce the number of processes and simplify the process flow with minimal impact on overall undercut performance. The 680 μm thick wafer is back-etched, leaving the 3C-SiC thin film with a thickness of 1.0 μm as the flexible diaphragm to detect pressure. The effect of the new coating of ProTEK PSB on different KOH solvents were investigated depending on various factors such as development time, final cure temperature and the thickness of the ProTEK PSB deposited layer. It is found that 6.174 μm thickness of ProTEK PSB offers some possibility of reducing the processing time compared to silicon nitride etch masks in KOH (55%wt, 80°C). The new ProTEK PSB biotechnology photosensitive protection mask indicates good stability and sustains its performance in different treatments under KOH and IPA for 8 hours. This work also revealed that the fabrication of MEMS sensors using the new biotechnology photosensitive protection mask provides a simple assembly approach and reduces manufacturing costs. The MEMS sensor can operate up to 500 °C as indicated under the sensitivity of 0.826 pF/MPa with nonlinearity and hysteresis of 0.61% and 3.13%, respectively.

1. Introduction

The most widely used etching method applicable to the micro-electro-mechanical systems (MEMS) process include steps such as: (a) depositing an etching mask on the wafer such as silicon nitride and silicon oxide, (b) depositing a plurality of patterns in the etching mask regarding the depth of the plurality of trenches, (c) etching the wafer using the etching mask with the plurality of patterns formed, (d) estimating an alignment in photolithography to form an accurate structure and simple fabrication



process, and reducing the fabrication costs [1]. Usually, silicon nitride and silicon oxide materials are used as etch masks in the KOH etching due to high selectivity of the etchant for both materials. For the purpose of bulk micromachining, silicon oxide cannot maintain the layer of etch mask for long hours in the etching process as its etch rate is relatively higher compared to using silicon nitride (~30-70 nm/min) [2].

Silicon nitride has better stability in wet etch due to its lower etch rate compared to silicon oxide. However, the disadvantage involves high costs in terms of deposition of silicon nitride in the overall fabrication process, especially for small samples [2]. The newly developed ProTEK PSB biotechnology photosensitive protection mask as etch mask materials have key advantages over standard photoresists in MEMS application nowadays. This new biotechnology photosensitive protection mask can enhance its performance by reducing the number of process steps and simplifying the fabrication process for small devices, thus impacting overall processing performance. This paper proposes the employment of a newly developed biotechnology photosensitive protection mask called the ProTEK PSB coating as an alternative replacement for silicon nitride and silicon oxide wet etch masks [3].

2. Fabrication Process

The MEMS sensor may be classified through the basic three step fabrication process. The fabrication process involves: (a) fabrication of 3C-SiC diaphragm, (b) fabrication of silicon substrate, and (c) bonding process of MEMS capacitive pressure sensor between diaphragm and substrate which is realized as follows [7]; a 1.0 μm thick 3C-SiC thin film is deposited using Low-Pressure Chemical Vapor Deposition (LPCVD) on 680 μm silicon substrate on a 6-inch diameter of wafer. The 3C-SiC-on-Si was cut to define its geometry into a 2.0 mm x 2.0 mm² square shape. In this project, a cubic silicon carbide on silicon (3C-SiC-on-Si) wafer was employed to produce a movable diaphragm of a capacitive-based pressure sensor for extreme environments due to the superior qualities of SiC at such conditions. The silicon needs to be back-etched to leave only the 3C-SiC thin film to suit the movable diaphragm of the sensor and the process flow as shown in Fig.1. Wet etch protection coating using ProTEX PSB-23 was employed as in Figure 1(d). This process consists of applying a ProTEX PS Primer layer onto a 3C-SiC-on-Si wafer, followed by a spin-coating process of the ProTEX PSB-23 as its photosensitive layer. Results obtained using the new coating depend on various factors such as development time of ProTEX PS primer, final cure temperature, etchant concentration and the thickness of the ProTEX PSB-23 deposited layer used in previous research [4].

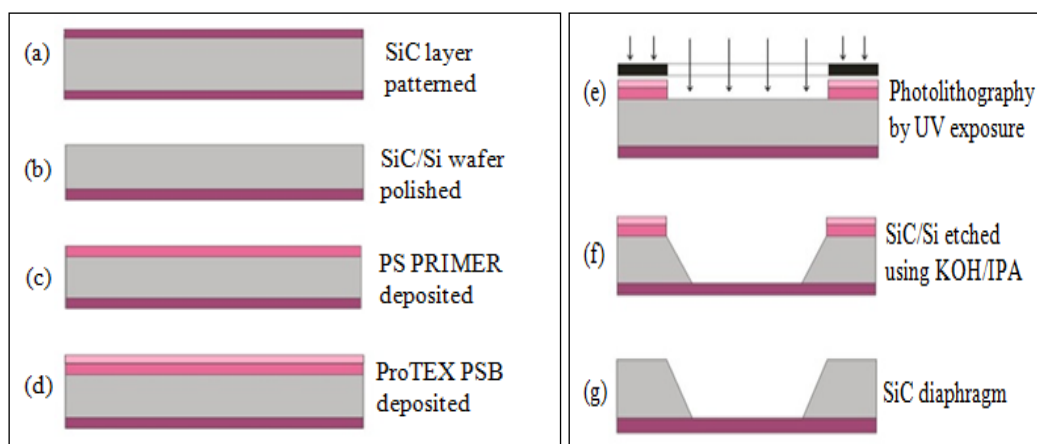


Figure 1. Process flow for the fabrication of the diaphragm

The first layer of the new biotechnology photosensitive protection mask which is ProTEK PS Primer coating was deposited on the silicon substrate with a spin-coat speed of 1000 rpm for 60 seconds. The second layer of ProTEK PSB coating is applied on the wafer with a spin-coat speed of 3000 rpm for 60 seconds. The exact chemical composition of the ProTEK PSB coating and its primer layer are listed in Table 1 [5].

Table 1: Chemical composition of ProTEK PSB and its primer [5]

Material	Chemical name	Composition (%)
ProTEK PSB-23 coating	2-(1-Methoxy)propyl acetate	50-60
	(Propylene glycol monomethyl ether acetate, PGMEA)	
	Ethyl acetoacetate	15-25
	Photoacid generator	1-10
	Sensitizer	<1-5
	Polymer solids	5-25
PS Primer	Propylene glycol n-propyl ether (PnP)	35-45
	Catalyst	<1
	Coupling agent	1-5
	Surfactant	<0.1
	Water	55-65

Afterwards, the new biotechnology photosensitive protection mask is exposed using the photolithography process in order to pattern the diaphragm for approximately 300 seconds through a photomask, as shown in Fig.2(a). The ethyl lactate (EL) is used to develop the ProTEK PSB mask by immersing it into an EL bath for 30 seconds until the geometric pattern from the photomask is copied onto the 3C-SiC-on-Si substrate. Fig.2(b) shows that ProTEK PSB and its primer has been exposed and developed into ethyl lactate (EL) and then etched in Potassium Hydroxide (KOH) to leave the 3C-SiC thin film. Finally, ProTEK PSB and its primer are removed using io-4000 polishing and 180 nm slurry as lubricant.

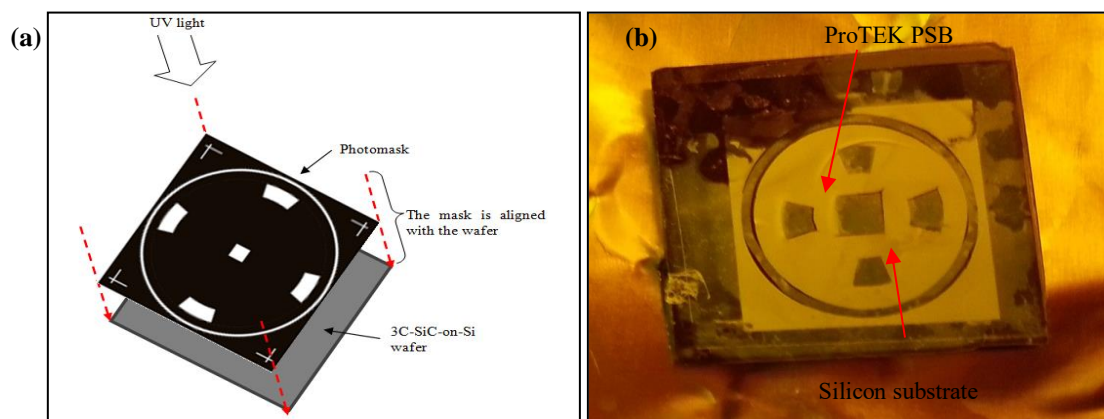


Figure 2. (a) The external markers used for mask aligner, (b) ProTEK PSB coating after developed in ethyl lactate

Fig.3 shows the reaction of the new ProTEK PSB thin film biotechnology photosensitive protection mask. There are several reactions between the ProTEK PSB coating and its primer after deposited. After pre-baking, the samples in Fig.3(a) were immersed into the KOH solvent (55% wt, 80°C) for the etching process as referred [6]. Around 5 minutes, the exposed patterned photosensitive protection mask of ProTEK PSB coating started to react as shown in Fig.3(b), while the unexposed pattern maintained its performance as the etch masks materials in the KOH solvent provides an alternative to the conventional etch masks. This new ProTEK PSB biotechnology photosensitive protection mask reduces the number

of process steps by simplifying its process flow though the elimination of the deposition and patterning for small samples, resulting in reduced fabrication costs. After 30 minutes, the bulk etching of the silicon wafer is realized as shown in Fig.3(c). In Fig.3(d), observations were done in terms of stability of ProTEK PSB in 2 hours. A highly hydrophobic surface was observed, meaning that the stability of the ProTEK PSB coating in the KOH solvent was achieved. The samples of 3C-SiC-on-Si were successfully etched using ProTEK PSB as shown in Fig. 4.

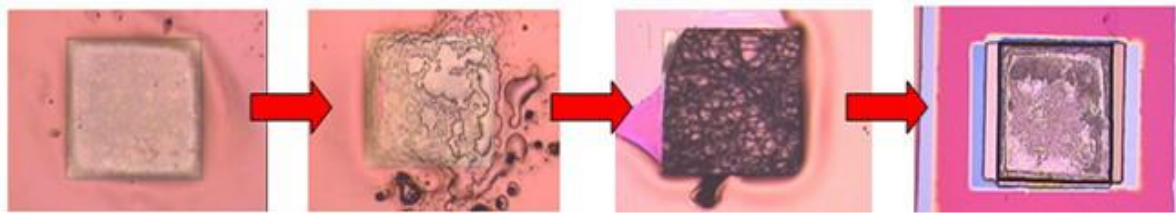


Figure 3. Reaction of ProTEK PS Primer and ProTEK PSB as a new biotechnology photosensitive protection mask when immersed into KOH for etching process (a) ProTEK PSB Primer and ProTEK PSB were deposited, (b) The wafer was immersed into the KOH solvent, thus the exposed pattern of ProTEK PSB coating started to etch, (c) after 30 minutes, the exposed 3C-SiC-on-Si wafer started to etch, (d) in 2 hours, the pattern was etched completely.

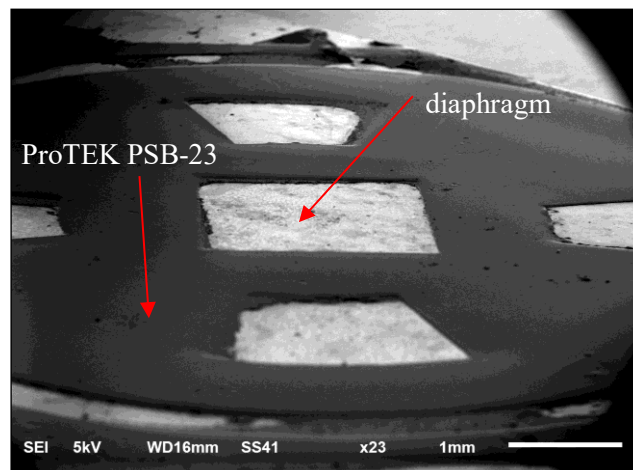


Figure 4. The pattern of the MEMS capacitive pressure sensor using ProTEX PSB-23

3. Theoretical and Experimental set-up

Fig.5 shows the experimental set-up of the MEMS capacitive sensor encapsulated in the stainless-steel housings as shown in Fig.6 as referred in our energy proceeding publication [7]. Experimental tests were carried out to investigate the device's performance detection dependence of capacitance on pressure and temperature. The experimental evidence on sensitivity and linearity of the significant correlations of MEMS sensor involves the response between the diaphragm and substrate parts.

Sensitivity is defined as the slope of the calibration curve given by Equation (1), whereas ΔC is the changing of capacitance and ΔP is the changing of pressure [8]. If the pressure-capacitance relation is linear, the sensitivity is constant for all values of input. The sensitivity of the nonlinear instrument depends on the pressure quantity. Both linear and nonlinear curves are important to evaluate its sensitivity by interfering and modifying the pressure value.

$$\text{sensitivity} = \lim_{\Delta \rightarrow 0} \frac{\Delta C}{\Delta P} \dots\dots\dots \text{Equation (1)}$$

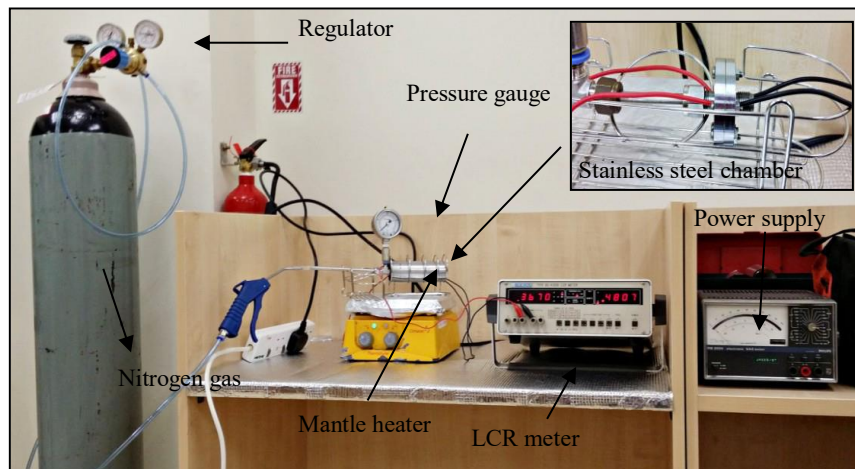


Figure 5. The experimental set-up of the MEMS capacitive pressure sensor

Linearity can be determined if the relationship between input and output can be expressed by equation (2) in the form of linear equation. The slope of the line is known as the gradient and is represented by m in the equation. The point at which the line crosses the C-axis is the c in the equation where m and c are constants, then the instrument is said to possess linearity [9]. The instruments which do not possess linearity may be linear over a range of usage.

$$\text{Capacitance} = (m)\text{Pressure} + c \quad \text{..... Equation (2)}$$

4. Results and discussion

Surface conditions were observed using a scanning electron microscope (SEM) image to inspect the effect of undercut edge and adhesion strength on ProTEX PSB-23 layer coated on the 3C-SiC-on-Si substrate as mask patterns of the MEMS capacitive pressure sensor diaphragm. It is found that the use of 6.174 μm thickness of ProTEX PSB offers some possibility of reduction of the processing time compared to using silicon nitride etch masks in KOH (55%wt, 80°C) as shown in Fig.6. The ProTEX PSB-23 coating reveals good adhesion to 3C-SiC-on-Si substrate, no degradation with etching rate of 1.2 $\mu\text{m}/\text{min}$ for 8 hours, and smooth surface roughness about 20.74 nm were obtained without damaging the sidewall microstructure. Taken together, we indicated that the use of the ProTEX PSB-23 coating instead of the silicon nitride etch mask shows advantages in processing time, adhesion and smooth surface.

The preliminary experiment of the MEMS capacitive sensor was demonstrated for operation at temperatures ranging from room temperature (RT) at 27 °C to 300 °C and 500 °C. The MEMS capacitive sensor was determined using capacitance response. In Fig.7, the preliminary measurement indicated that for the experiment at 27 °C, the sensitivity of the MEMS capacitive sensor is 0.774 pF/MPa with nonlinearity and hysteresis of 0.67%. At 300 °C, the sensitivity decreased by 2.1 pF/MPa (0.515% decreased from RT) while at 500 °C, the sensitivity decreased at 0.826 pF/MPa with nonlinearity and hysteresis of 0.61% and 3.13 pF/MPa, respectively. This is due to the fact that the diaphragm is more sensitive to temperature changes.

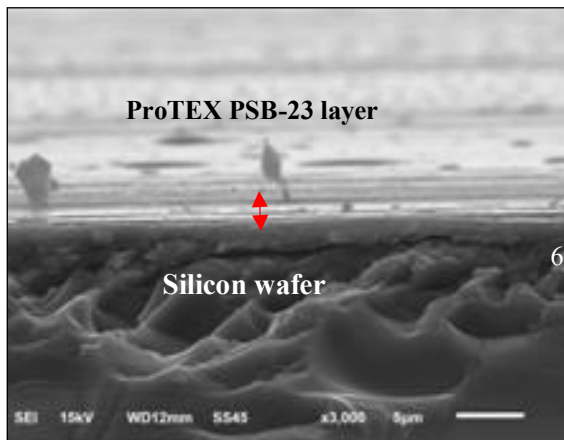


Figure 6. The SEM image of a 6.174 μm ProTEX PSB-23 layer

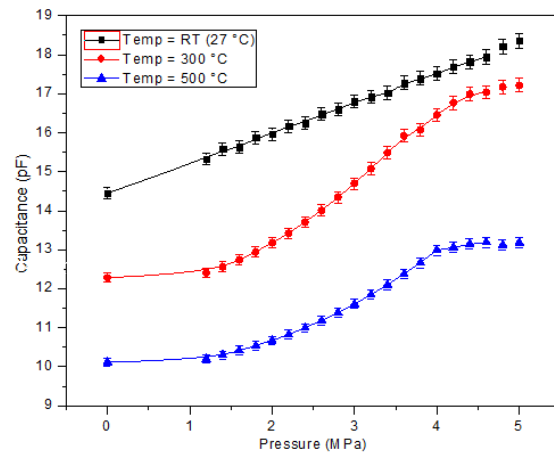


Figure 7. The preliminary experimental results of the MEMS sensor with different temperatures at 27 °C, 300 °C and 500 °C

5. Conclusion

In conclusion, the use of ProTEK PSB-23 biotechnology photosensitive protection mask coating and its primer provides the most effective etching condition for small samples, allowing the forming of an accurate structure, a simpler fabrication process and reduction of costs. This work also deals with the fabrication of the MEMS capacitive sensor, offering an alternative to the conventional etch mask for bulk micromachining processes. It also shows that by using the methodology process, the MEMS capacitive sensor is capable to withstand up to 5.0 MPa under stable sensor operations with good performance of sensitivity and linearity of various temperatures.

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References

- [1] Dalvi-Malhotra J, Brand G J and Zhong X F 2007 Use of Silane-based Primer on Silicon Wafers to Enhanced Adhesion of Edge-protective Coatings During Wet Etching, *Proc. SPIE*, pp. 6462
- [2] Daniel J V, Shao X, Yess K, Fowler S, Trichur R K, Planje C and Tang T 2010 Novel Polymeric Protection Coatings for Hydrofluoric Acid Vapor Etching during MEMS Release Etch, *IMAPS Device Packaging Conference*, pp.76-80
- [3] Dalvi-Malhotra J, Zhong X F, Planje C, Brand G and Yess K 2008 A Spin-on Photosensitive Polymeric Etch Protection Mask for Anisotropic Wet Etching of Silicon, *Journal of Micromechanics and Microengineering*, vol 18(2), pp. 1-8
- [4] Marsi N, Majlis B Y, Hamzah A A and Mohd-Yasin F 2014 Characterization of ProTEX PSB Thin Film as a Photosensitive Layer for MEMS Capacitive Pressure Sensor Diaphragm Based on SiC-on-Si Wafer *Key Engineering materials*, Vols. 594-595, pp. 1083-1086
- [5] Ab Rahim R, Bais B, Majlis B Y and Sugandi G 2013 ProTEK PSB Coating as an Alternative Polymeric Protection Mask for KOH Bulk Etching of Silicon, *Microsystem Technologies*, vol 19(6), pp. 905-914
- [6] Marsi N, Majlis B Y, Mohd-Yasin F and Hamzah A A 2014 The Fabrication of Back Etching 3C-SiC-on-Si Diaphragm Employing KOH + IPA in MEMS Capacitive Pressure Sensor *Microsystem Technologies*, Vol. 21(8), pp. 1651-1661
- [7] Marsi N, Majlis B Y, Hamzah A A and Mohd-Yasin F 2015 High Reliability of MEMS Packaged Capacitive Pressure Sensor Employing 3C-SiC for High Temperature *Energy Procedia*, Elsevier, Vol. 68, pp. 471-479
- [8] Abdul Mokti M I and Abd Rahim I 2012 Siimulation Study of Sensitivity Performance of MEMS Capacitive Bending Strain Sensor for Spinal Fusion Monitoring, *Modelling and Simulation in Engineering*, Hindawi, vol 2012, pp.1-11
- [9] Tabarestani M S and Ganji B A 2012 Analytical Analysis of Capacitive Pressure Sensor with Clamped Diaphragm *International Journal of Engineering*, Vol.26(3), pp.297-302