The Optimisation of a resonant gas sensor by using nano-textured surfaces

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ABSTRACT

This paper describes the potential for optimising a resonant gas sensor by using nano-textured surfaces. Initial empirical calculations determined that a device with a nano-textured active layer could have its surface area increased by an order of magnitude when compared to a device with an ideal theoretical smooth surface. These nano-textured surfaces are achieved when using the author's one step DRIE process. By carefully choosing the parameters when using the one step process the underside can be made to mimic porous silicon giving the user this vastly increased surface area on a micro and nano scale.

After explaining how these surfaces are obtained this paper goes on to detail modelling work carried out to demonstrate the possible effects this new textured surface could have on the performance of future resonant gas sensors.

A simple generic resonator is modelled with and without the new surface to give a clear indication of the improvement in signal performance that can be expected from future devices utilizing this new pseudo porous silicon as its active layer.

Keywords: one step DRIE process, bulk silicon machining, resonant MEMS structures, STS, DRIE etching, Silicon on insulator wafers.

1 INTRODUCTION

Resonant structures have been exploited in a number of MEMS (micro electro mechanical systems) applications. Increasingly these devices are realised by using deep reactive ion technology (DRIE) technology and silicon on insulator wafers (SOI). Historically this technique for manufacturing these structures required two steps. The first involved DRIE etching the device into the top layer of the SOI wafer and then a second step using hydrofluoric acid to remove the sacrificial buried oxide layer from under the device releasing it. More recently the authors reported a technique that utilises the same technology to manufacture devices in a single step[1,2,3]. This process harnesses the notching phenomenon[4,5] experienced when etching down to the buried oxide layer present in SOI wafers to release structures.

It has been found that with recipe manipulation of the plasma chemistry it is possible to create a pseudo porous silicon on the under side of devices (see figure 1) when using this one step DRIE process. In keeping with actual porous silicon[6,7] initial empirical calculations have determined that this surface is greater than a smooth service by an order of magnitude. The authors wish to exploit this to manufacture resonating gas sensors with their active layer vastly increased by nano-texturing these surfaces . This would allow for the maximization of any active layer for a gas sensor manufactured using the one step DRIE process. This in turn would allow for devices to be made smaller and due to their increased surface area not to loose sensitivity. This pseudo porous silicon offers the possibility of miniaturizing such sensors whilst still obtaining a detectable signal.

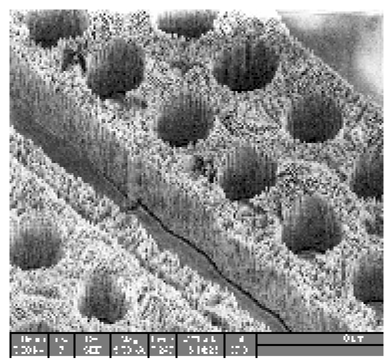


Figure 1 Pseudo porous nano-textured surface

The work detailed in this paper describes how the pseudo porous silicon is manufactured before going on to present preliminary modelling of how it would optimize the output signal for any given device. This preliminary modelling has been carried out assuming the absorbed mono-layer to be carbon dioxide CO_2 as it is such a layer that we are currently using to characterize such devices. In this work the calculations were carried out for a simple generic resonator similar to the one shown in figure 2.

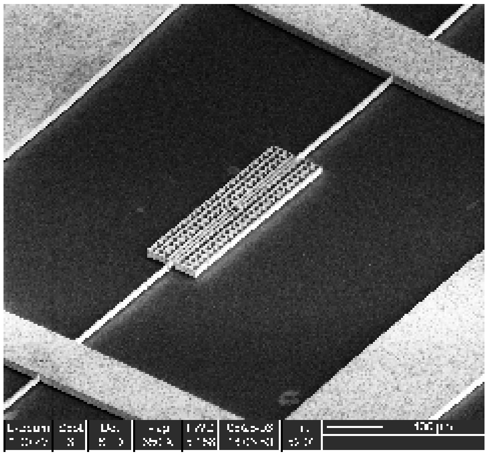
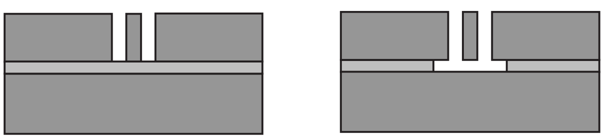


Figure 2 Simple generic resonator

2 MANUFACTURE OF PSUDO POROUS SILICON

Typically when fabricating resonant structures using DRIE and SOI wafers, two etch steps are required. A primary step in which the geometry of the resonator is defined using DRIE etching (step 1), followed by step two where the sacrificial layer is removed by wet etching with hydrofluoric acid (see figure 3).



Step 1: Step 2:

Figure 3 Illustration of the typical two step process used to fabricate MEMS resonant structures.

While DRIE typically gives a high quality etch in bulk silicon, the etching of SOI wafers can lead to problems when the plasma reaches the buried oxide layer. A charging phenomenon known as 'notching' [8,9] occurs and an undercut or 'notch' is formed in the silicon trench sidewalls (see figure 4). When using the two step DRIE process notching is a problem workers try to eliminate. This is achieved by altering plasma chemistry or by employing additional equipment. It should be noted that is often not a trivial task even with additional equipment.

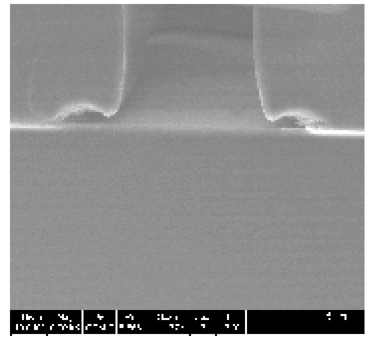


Figure 4 Features etched in a bulk and SOI wafers using DRIE etching

Initial exploration of the notching phenomenon was investigated by Ayon[10] and Ranglow[11]. Recently the authors have reported exploiting this notching effect to realise actual devices eliminating the requirement for a hydrofluoric acid wet etch step. It is known that the notching effect is aspect ratio sensitive (requiring narrow trenches to release the device) and simple design rules determined by Docker et al must be followed to successfully use the technique to manufacture one step released devices. Typically when using the process these design rules also ensure the device is released by a more controlled notch. See figure 4.

For generating devices with the peudo silicon surfaces the plasma chemistry is altered to give a more serve notch creating the desired nano textured surface on the underside of a device. Figure 3 shows a trench etched under these conditions and demonstrates two small areas of the pseudo porous silicon parallel with the top surface of the wafer. If two trenches had been etched next to each other a freestanding beam would have been created between them with the new nano–textured surface covering the entirety of its underside. The reader should refer back to figure 1 where the underside of a complete mass from a resonator released in this way can be seen. The textured surface can be seen in detail.

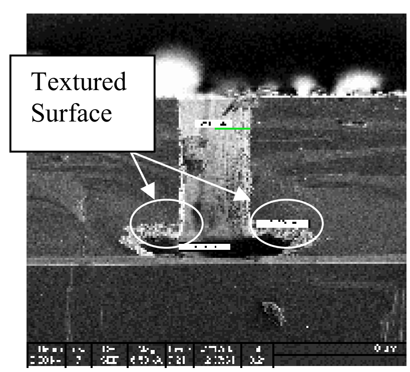


Figure 3 Type of notch used to manufacture pseudo porous silicon

The same design rules are still applicable to these new nano-textured devices and designs can also still be manufactured surrounded by large cleared areas[2] and the technique that indicates when the device is released[3] can still be exploited.

3 MODELLING OF PSUDO POROUS SILICON

In order to determine the potential impact of nano structured surface upon the performance of the resonator described in fig 2 as a mass balance gas sensor we have analysed the structure as a simple lateral lumped mass resonator and determined the resonators mass detectivity D[Hz Kg^{-1}]. We assume that the frequency of the resonator is given by;

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{2Ehw^3}{l^3 m}} \qquad (1)$$

Where f0 is in Hz, E is the modulus of the beam, l is the length of the beam, h is the thickness of the released silicon layer, w is the width of the beam, m is the total mass of the beam. The mass detectivity D is then simply given as:

$$\frac{\partial f_0}{\partial m} = -\frac{f_0}{2m} \qquad \textbf{(2)}$$

The theoretical mass of the CO2 monolayer was calculated by taking the weight of a mole of CO2 and dividing it by Avogadro's number to obtain the mass for an individual molecule. It was then assumed that a single molecule would occupy $1\text{x}10^{-19}\text{m}^2$ on the active surface of the device. By dividing the active area by the area a single molecule would occupy and multiplying by the mass of a single molecule the mass of a complete mono layer covering the active layer was determined.

4 RESULTS

For the resonator shown here and taking in to account the waffle nature of the mass, we obtain a resonant frequency of f_0=67kHz and a detectivity D of 2.4×10^{13} Hz kg^{-1}. Again taking into account the waffle nature of the mass we estimate that the mass of an adsorbed monolayer of CO_2 would be 8.0×10^{-15} kg, giving a shift in frequency of approximately 0.2Hz.

The effect of the nano structured silicon surface will increase the adsorbed mass by perhaps an order of magnitude, which would give the modified device a detectivity of 2.4×10^{14} Hz kg^{-1} and an associated CO_2 mono layer frequency shift of 2Hz. This is a useful increase in detectivity that can be used for increased sensitivity or higher bandwidth data acquisition.

5 CONCLUSIONS

To conclude we have shown that by careful control of the dry release etching process we can create a nano textured surface that could have a significant impact upon the sensitivity of resonant gas sensors. We have further shown that the processing technology can yield useful resonating structures.

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