SELF-ALIGNED POLYSILICON MEMS- REDUCED MASK COUNT SURFACE MICROMACHING

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ABSTRACT

A burst-proof surface micromachined polysilicon resonant pressure sensor is designed, fabricated, and tested. Fabrication is conducted by a versatile 2 mask self-aligned micromachined polysilicon on nitride (SAMPSON) process. As compared to conventional sacrificial oxide based surface micromachining approaches, this fabrication sequence enables rapid fabrication, improves yields, and reduces parasitic capacitances.

INTRODUCTION

To date, polysilicon based surface micromachining techniques have been used to fabricate lateral [1] and vertical resonators. These fabrication techniques typically require 3 or

Figure 1: SAMPSON process flow. Cross sections correspond to cut line AB in Figure 2.

more masking steps for basic designs. In this work, we present a versatile 2 mask self-aligned micromachined polysilicon on nitride (SAMPSON) process. This process results in extremely rapid fabrication, high yields, and low parasitic capacitances.

Due to the self-alignment feature, the SAMPSON process flow can fabricate virtually all conventional lateral and vertical surface micromachined devices with a one mask savings over conventional approaches.

To date, most microelectromechanical (MEM) pressure sensors are fabricated with a sealed vacuum cavity which acts as a pressure reference [2]. Hence, MEM pressure sensors are usually fabricated using costly combinations of wafer bonding and surface or bulk micromachining methods.

In this work, a novel burst-proof pressure sensor is fabricated using only the surface micromachined SAMPSON process flow. This squeeze-film based resonant pressure sensor does not require a sealed vacuum chamber, simplifying processing. Furthermore, the burst pressure limitation is established by mechanical brittleness limits of uniformly

compressed Silicon, rendering the pressure sensor essentially burst-proof.

FABRICATION

The basic SAMPSON process flow, illustrated in Figure 1, begins with an n type silicon substrate. The first step deposits a $1\mu\text{m}$ layer of CVD phosphosilicate glass (PSG), the sacrificial layer, followed by a $2\mu\text{m}$ structural layer of polysilicon. The thickness of the PSG layer defines the spacing of the final device from the substrate.

The structural polysilicon is then patterned and etched. This etch step defines the perimeter of the areas of the final device which are to be attached to the substrate (Figure 2). The thickness of the device is defined by the as-deposited polysilicon thickness.

Figure 2: SAMPSON vertical resonator layout

Next, an anneal and subsequent timed 5:1 BHF etch is performed, removing PSG and undercutting the polysilicon regions as shown in Figure 1i. In this work, the undercut distance was approximately $5\mu\text{m}$, but it can be varied from a few to tens of μm .

Next, $1.3\mu\text{m}$ of CVD silicon nitride is deposited. This is a conformal process, depositing nitride underneath the undercut areas as well as on exposed surfaces.

This conformal lateral deposition is a key concept in any SAMPSON-based process flow. Naturally, SAMPSON-based process flows can use undoped polysilicon, tungsten, or other conformally deposited materials instead of silicon nitride.

Of course, to achieve complete refill of the undercut regions the conformal deposition thickness must equal at least half the sacrificial layer thickness. In this work, the deposition of silicon nitride forms fully refilled insulating supports for our resonators, but thinner layers of silicon nitride can be deposited to form different structure geometries. For example, thin depositions can enable out-of-plane-pivoting polysilicon lever fabrication.

The deposited nitride is now removed by a two fold process, a plasma etch followed by a more selective hot phosphoric acid etch. This leaves areas of silicon nitride which were 'shadowed' by polysilicon areas, in effect self-aligning the nitride support regions (Figure 1iii).

A second and final lithography and polysilicon etch step completes the fabrication process, defining the release etch holes (for membrane resonators) or movable areas (for lateral

resonators). Finally, an HF release prepares the devices for test (Figure 4iv).

FABRICATION DISCUSSION

Figure 2, a low parasitic capacitance bond pad layout, demonstrates a feature of the SAMPSON process flow. Post-release, this layout results in a bond pad comprised of polysilicon on top of an encapsulated PSG layer, offering decreased parasitics as compared to silicon nitride.

In addition to improved yields due to reduced mask counts, the SAMPSON process flow carefully orders etching steps for further yield improvement. This is most obvious for membrane devices. In these layouts the most challenging etch step is performed at the beginning of the process sequence, leaving only the simple release hole etch as the end step. This particular ordering of etch steps has resulted in improved yields for our fabrication runs, allowing identification and rework of poorly defined or etched wafers early on in the process flow.

Figure 3: Electron micrograph of fabricated squeeze-film based SAMPSON resonant sensor.

RESULTS

In [3], a complex bulk micromachining approach was used to form a squeeze-film based vertical resonator, which was then characterized as a pressure sensor. In this work, the much simpler SAMPSON process is used to fabricate squeeze film based resonant pressure sensors (Figure 3).

Figure 4: Measured resonant pressure sensor response.

Compared to the bulk micromachined approach [3], the SAMPSON process offers decreased resonator plate mass and interplate spacing. Decreases in these values result in increased squeeze numbers, increasing the sensor dynamic range. Figure 4 shows the measured frequency² vs pressure response for a fabricated pressure sensor with a 1µm gap. As the figure shows, agreement with the high squeeze number response is excellent.

CONCLUSION

We have introduced the SAMPSON fabrication sequence, a reduced mask count surface micromachining process. The SAMPSON process offers decreased development time, and reduced parasitic capacitances over conventional processes.

A burst-proof squeeze-film based resonant pressure sensor was fabricated using this fabrication technique. The sensor resonant frequency exhibited a 3x change for air pressure ranges from vacuum to 450torr.

REFERENCES

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