A Novel Ultra-miniature catheter tip pressure sensor fabricated using silicon and glass thinning techniques

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Abstract: A novel subminiature pressure sensor for blood pressure measurement has been fabricated. The device is only 250 microns wide and 70 microns thick. It is 1.1 mm in length. The sensor is housed in a guide-wire lead for use in measuring coronary artery blood pressure. The device has a 5 micron thick silicon diaphragm and senses pressure using a 1/2 bridge piezoresistive network. Glass is processed to provide depressions above the sensing area as well as above the connection area of the device. A full-thickness silicon wafer is processed using standard micromachining techniques. V-Groove notches are micro-machined on the top surface of the silicon to provide locators/guides for the lead-wires. Diaphragm windows are patterned on the back of the silicon wafer and the wafer is etched down to form the 5 micron diaphragm, using electro-chemical etch-stop techniques. The Glass and Silicon wafers are aggressively cleaned prior to bond. The glass and silicon wafers are then precisely aligned to better than 10 microns and bonded using anodic bonding techniques.

The glass/silicon wafer sandwich then has the silicon thinned from 400 microns to 37 microns using both grinding and polishing. Then the full-thickness glass wafer is etched in HF to a thickness of 37 microns as well, for a composite 74-micron thick structure. The wafer is then diced to form the micro-mechanical structure.

INTRODUCTION

One of the challenges of invasive monitoring of the body is in making parts small enough to allow them to fit into the targeted environment. One such application is in the small arteries of the heart. Here the arteries start at 2 to 3 mm external diameter and rapidly bifurcate into progressively smaller arteries in the sub-millimeter range. A catheter that occupies more than 1/2 the area of the vessel under study will have detrimental impact on accuracy of the measurement. Because of these concerns, a pressure sensor has been fabricated in a guide-wire to allow accurate measurements of pressure in the Coronary arteries. The guide wire is 0.355 mm in diameter and requires a sensing element that can be housed with lead-outs, housing, and encapsulation in that diameter.

The completed guide-wire is shown in Figure 1. The diaphragm size is 280 microns X 130 microns. The wire is constructed with a helical sheath for flexibility except at the tip and around the sensor itself. Here a stainless-steal housing with a machined-in lumen for the sensor is used. Three 25 micron leads are connected to the sensor to allow measurements from 2 piezoresistive-sensing elements. A simplified cross-section of top-view of the device is shown in Figure 2.

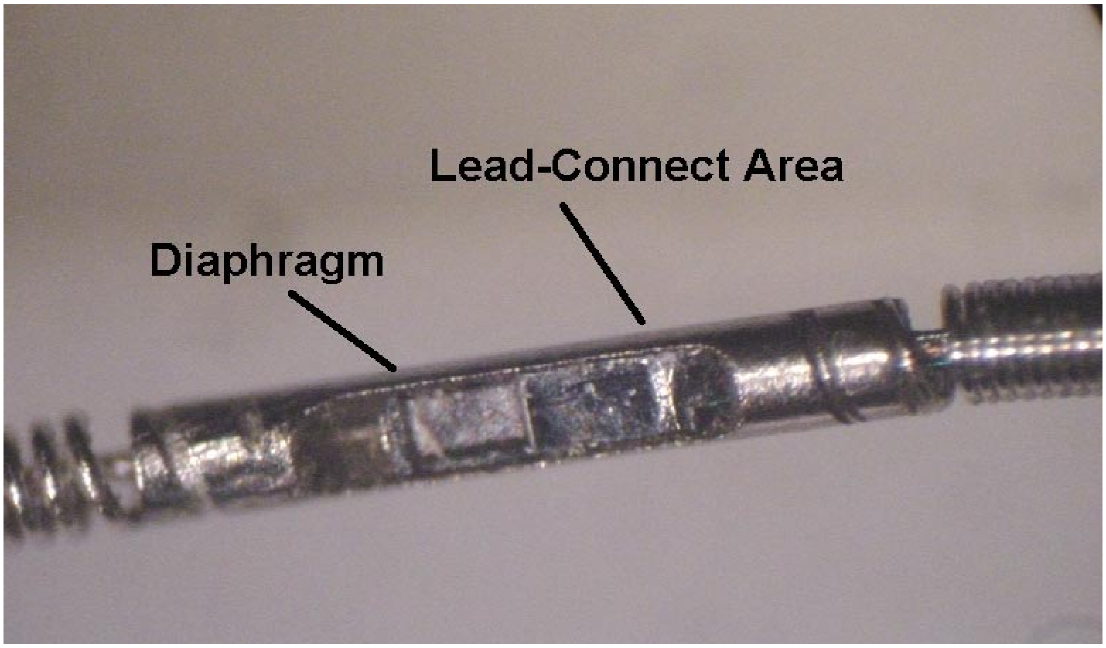

Figure 1. Completed SmartWire Guidewire Pressure Transducer

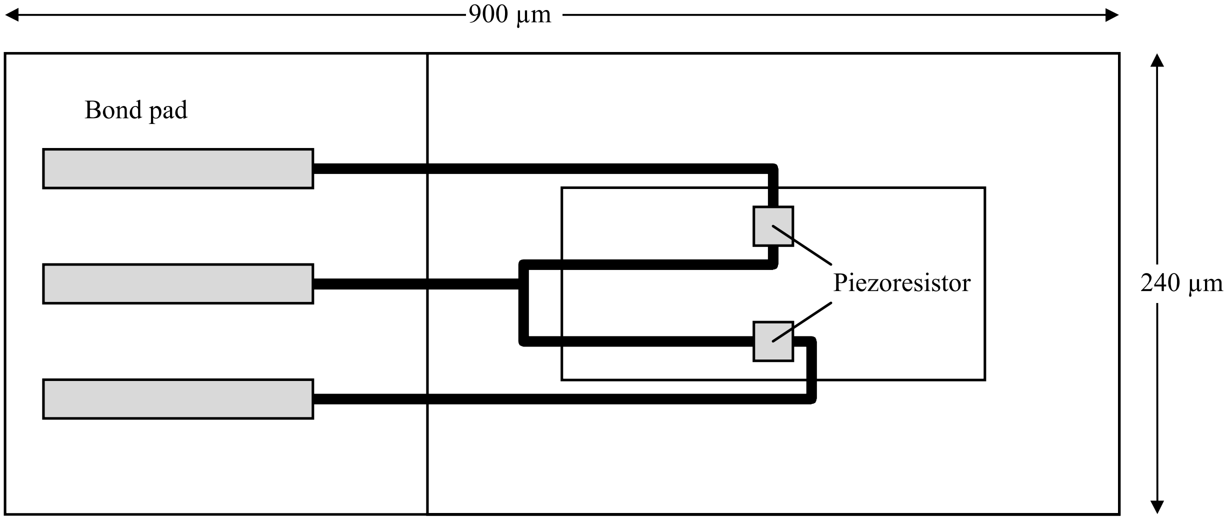

Figure 2. Schematic diagram of sensor showing external dimensions

DESIGN

A number of design constraints were established at the outset. These included having the lead-outs and the sensing surface on opposite sides of the die, having a sealed cavity to provide a reference pressure incorporated on chip, and having the pads designed for easy alignment and attachment of the leads. The chosen configuration is shown schematically in Figure 3. In this case, V-grooves on the top-side of the wafer provide for lead-out alignment. Further, because of pad design, the wires can successfully be recessed by 30 to 50% of their actual height.

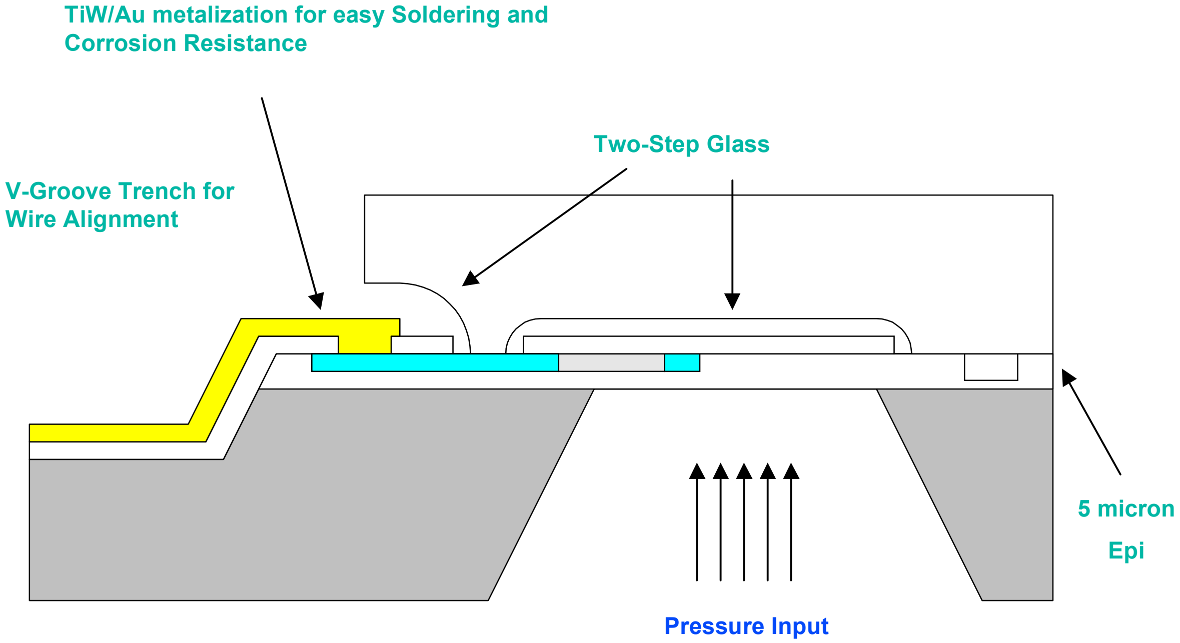

Figure 3. Cross-section of the Pressure sensor. Leads are connected in the trench area to the left of the figure. The top glass is etched to form a sealed cavity as a reference pressure.

The cap is a glass cap. This choice was made to allow for a simple metalization because the glass can be anodically bonded to the silicon wafer. It also allows two steps in the glass, one over the diaphragm area and one over the pad area. Further it allows easy visualization of the circuit area prior to dicing the wafer and facilitates easy alignment of glass to silicon prior to bonding.

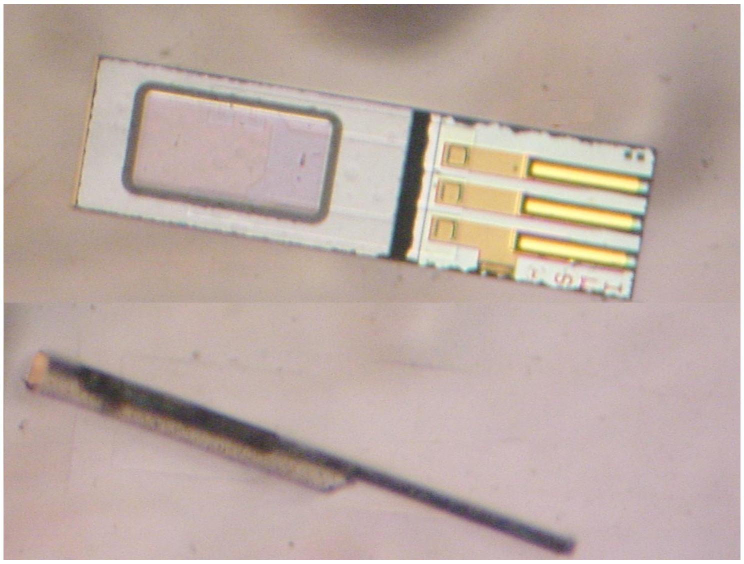

Figure 4. Diced sensor looking at the top of the silicon and the side-view of the sensor showing the glass cap (bottom left) and the thin silicon as diced.

The active sensing area is formed with standard KOH etching techniques. The main variant on this is that the wafer is thinned down after the glass is bonded to the silicon so that the apparent sidewall edge is radically reduced. The actual cross-section of the sensor and die is shown in Figure 4.

Resistor Layout Considerations Because of the need for a very narrow structure, analysis of the optimum geometry and layout for resistors was preformed using conventional Finite-Element modeling software. The rectangular diaphragm shape means that there is no stiffening of the narrow dimension of the sensor by the perpendicular dimension, unlike the conventional square diaphragm. Peak stress of equal and opposite magnitudes are observed at the center and edge of the rectangular diaphragm. However for ease of routing the resistors, the chosen location of the resistor pair is on the outside edge of the diaphragm, using tangential and perpendicular resistors.

PROCESS SEQUENCE

The sensor is fabricated on 400 micron thick p-type <100> starting material with a thin epitaxial layer. N+ regions to provide contact to the substrate are diffused into the Epi. P+ and P- layers are Implanted and then a KOH etch is used to form the V-groove recesses in the pad area. The wafer is then oxidized and contact is made thru the oxide to the P+ regions. The Wafer flow thru the foundry part of the operation is shown in Figure 5. The wafers are then metalized, a pattern is aligned for the back cavities and the wafers are then electro-chemically etched. The diaphragm thickness is determined by the epitaxial thickness. Wafers then undergo a second metalization of PtSi/Ti/W/Au and the Pad metal is defined into the V-groove areas. Wafers are then probed and the sensitivity of the wafers are at select points. A final top-surface lithography and etch are done to define the anodic bond surface. The silicon wafers are processed thru a sulfuric-peroxide clean and an HF dip as the final clean prior to bond.

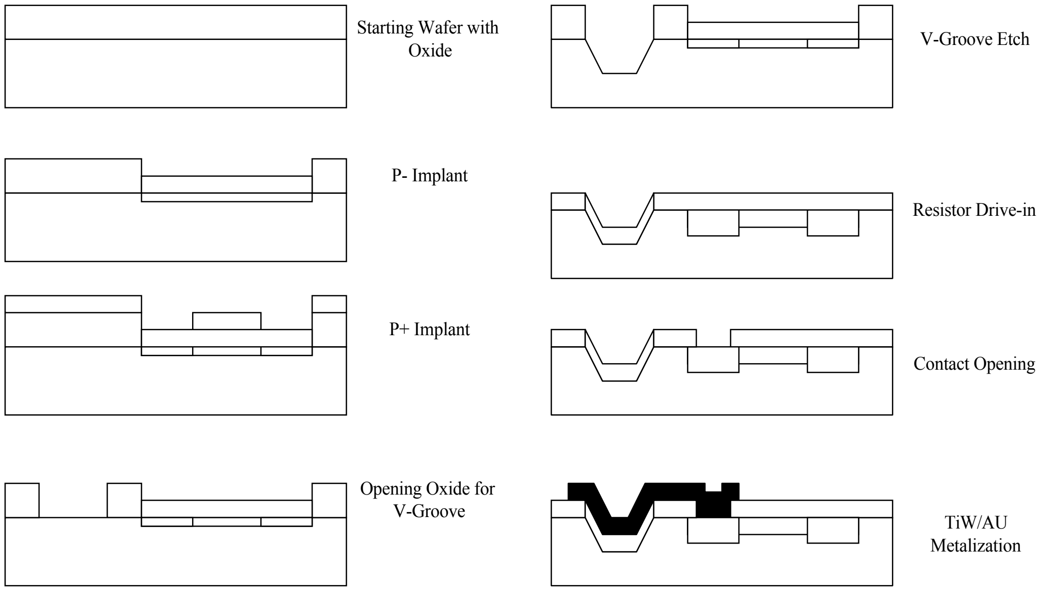

Figure 5. Top-side Sensor process

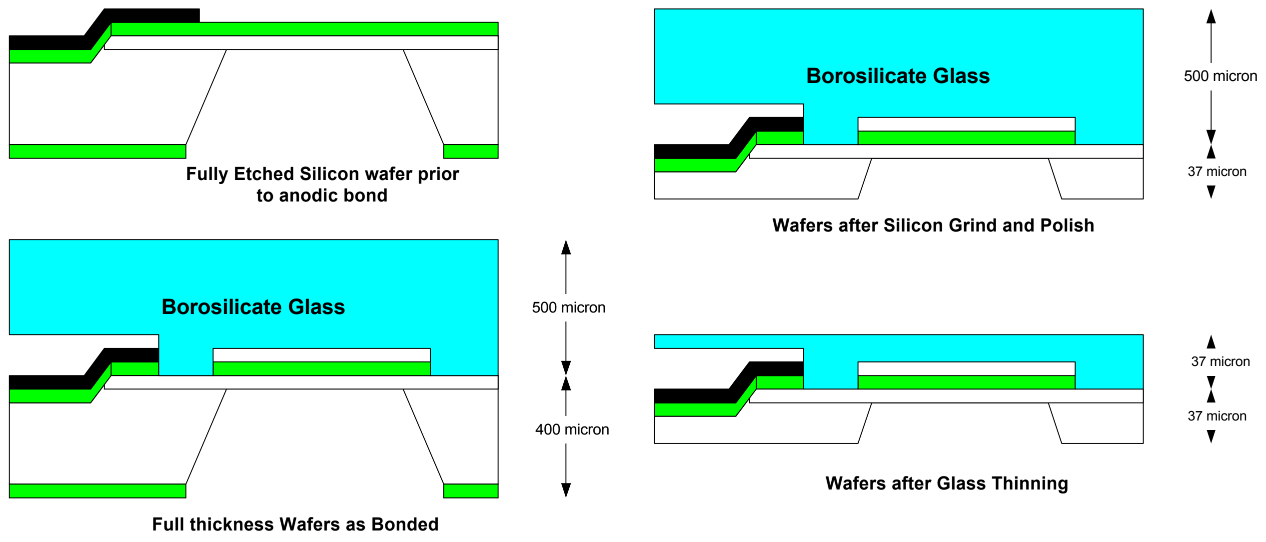

Figure 6. Bonding and thinning sequence

Concurrent with the silicon processing, glass is also processed. As mentioned previously, the glass has two different depths - one for the area over the sensing area and a deeper one over the area used for the lead-outs. The 500-micron glass wafers are initially metalized with CrAu. The deeper area is first defined and the CrAu removed in these areas. The glass is then etched in BOE. This process is then repeated for the shallower area. The depth of the deeper area is then the sum of the initial etch depth plus the second etch depth. The metal is stripped after the shallow etch and the wafers cleaned prior to anodic bond.

The glass and silicon wafers are aligned and the wafers are then anodically bonded. The next composite sandwich at this point is 900 microns (400 micron Silicon and 500 micron glass). Wafers are ground and polished on the silicon surface to result in a 37 micron nominal thickness. The wafers at this point are 537 micron thick (37 micron silicon and 500 micron glass). Wafers are then placed in straight HF to thin the glass down to a nominal 37 micron thickness to produce a composite thickness of 75 microns. The thining sequence is shown in Figure 6. Table 1 shows typical thickness control on both the glass and silicon.

Table 1. Thickness Control (in microns) for 3 wafers from one lot of wafer

	Post grind & etch-Wafer A			Post grind & etch-Wafer B			Post grind & etch-Wafer C		
Position	**Silicon**	**Glass**	**Total**	**Silicon**	**Glass**	**Total**	**Silicon**	**Glass**	**Total**
1	35	40	75	38	31	69	37	31	68
2	37	38	75	38	36	74	37	36	73
3	36	39	75	37	37	74	36	33	69
4	38	37	75	35	35	70	37	43	80
5	38	29	67	35	31	66	36	38	74
6	37	36	73	35	34	69	36	44	80
7	36	42	78	36	37	73	37	38	75
8	36	41	77	36	34	70	37	40	77
Average	37	38	74	36	34	71	37	38	75
Std. Dev.	1.1	4.1	3.3	1.3	2.4	2.8	0.5	4.5	4.5
Min.	35	29	67	35	31	66	36	31	68
Max.	38	42	78	38	37	74	37	44	80

The composite structure is very fragile because, unlike thin silicon which can bend, the glass-silicon structure has two different material characteristics and fractures in the glass tend to propagate thru both layers resulting in broken wafers.

Figure 6 shows the view of the top silicon surface looking thru the glass. A close-up of one die is shown as an insert. The three gold fingers are the electrical contact area. The "tick" marks at the left and right of the die (as well as at the top and bottom) indicate saw alignment targets for dicing the die. The die is made in a relatively sparse array so that the full thickness wafer can be etched before polishing. This requires a reduction in density. However, for the application, the reduced density is not as important as the ease of manufacturing.

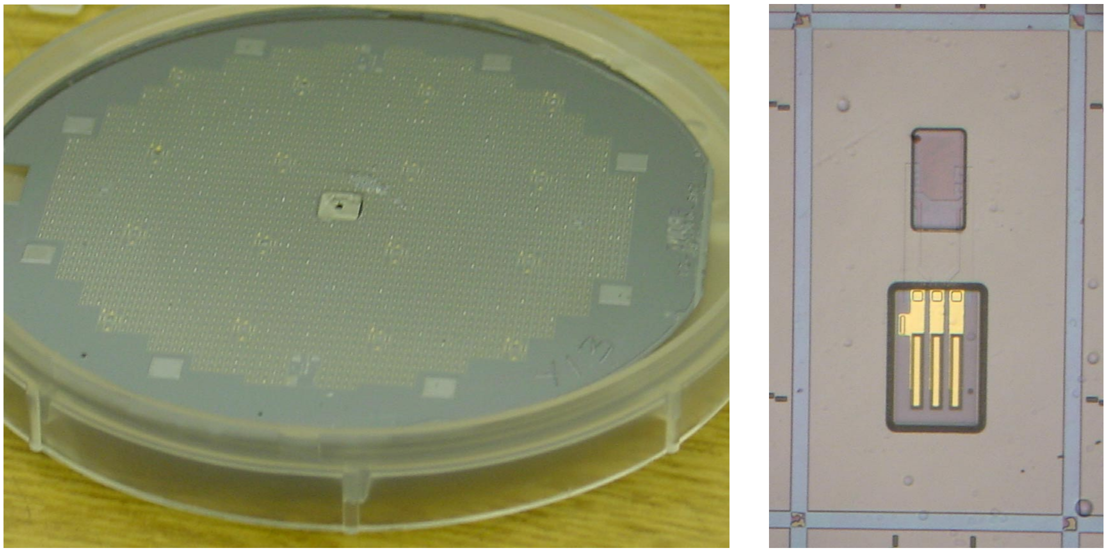

Figure 6. Wafer level view of 75-micron thick glass and silicon sandwich. Figure to the right is a picture of a single die from the wafer, looking thru the glass down onto the top silicon.

CONCLUSIONS

A robust process has been developed for the manufacturing of an ultra-miniature pressure sensor for catheter applications. The process uses anodic bonding with precision alignment requirements, precision silicon grinding and polishing, and glass thinning. The resultant device is only 240 microns or less when sawn by 900 microns long by 74 microns thick. The composite sandwich is composed of about 37 microns of silicon and 37 microns of glass. The process is such that full 100-mm wafers can be delivered for dicing on a routine basis.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Canh Pham for expertise in the anodic bond and alignment of the glass and silicon sandwiches. In addition, the product is only feasible due to the precision dicing and lead-attach expertise at Jomed. Special thanks to Steve Rodriguez at SMI for scheduling the production runs, to Chris Ingman and Mike Meyer at Jomed for manufacturing expertise, and to Mike Eberle at Jomed for continued guidance and support on this project.