Single-Mask, Flip-Bonded Titanium-On-Glass (FBTOG) Technology for Wafer-Level Batch Fabrication of Suspended High-Aspect-Ratio Bulk Titanium Microstructures

Y. Zhang, G. Zhao, Q. Shu, Y. Tian, W. Li and J. Chen*

National Key Laboratory of Nano/Micro Fabrication Technology
Institute of Microelectronics, Peking University, Beijing, CHINA

Abstract

A Flip-Bonded Titanium-On-Glass (FBTOG) technology, which combines titanium Inductively-Coupled-Plasma (ICP) deep etching and adhesive wafer bonding technique, was developed to fabricate suspended in-plane high-aspect-ratio bulk titanium microstructures at wafer level. 25μm thick suspended structures with a trench aspect ratio of about 10 are demonstrated. A 2200μm-long comb-drive actuated bulk titanium lateral relay showed a contact resistance of 2.3Ω at a moderate actuation voltage of 30V.

Keywords: Titanium-On-Glass; High-Aspect-Ratio; bulk titanium; lateral relay

1. Introduction

Silicon Deep- Reactive-Ion-Etching (DRIE) enables the microfabrication of high-aspect-ratio structures (HARS), which can realize many promising applications, e.g. inertial sensors, micro-actuators, power MEMS, microfluidics etc. Recent developments of DRIE have allowed for the realization of bulk titanium HARS with high mechanical endurance, excellent corrosion resistance and bio-compatibility, which is very attractive for in vivo and/or harsh environments applications [1]. N.C. MacDonald’s group has presented several bulk titanium devices, using Titanium-On-Insulator (TOI) technology, such as torsion-mirror and out-of-plane microswitch, which were vertically driven [2]. However, most of them were manufactured on non-standard 2.5×2.5cm titanium substrates, which should be mounted on a carrier wafer for many fabrication processes. Technology to fabricate bulk titanium HRAS for in-plane sensing and actuating hasn’t been reported, especially at wafer level.

In this paper, a Flip-Bonded Titanium-On-Glass (FBTOG) technology is employed to fabricate suspended in-plane high-aspect-ratio bulk titanium microstructures at wafer level. In order to create structures with small feature size, titanium DRIE is carried out before flip bonding of the two substrates; DRIE lag and footing effects are also diminished with this approach. Several bulk titanium lateral relays were successfully manufactured and tested.

* Corresponding author. Tel.: +86-10-6275-2536 ext.20; fax: +86-10-6275-1789.
E-mail address: jchen@ime.pku.edu.cn.
2. Fabrication

Fig.1 illustrates a bulk-titanium lateral relay in FBTOG technology, which is separated by capacitive gap of several microns and anchored through an isolating layer to the substrate. Fig.2 illustrates the fabrication process flow:

(a) A 15μm-thick SU-8 was spun and patterned on a customized 170μm thick, 4’ single-side polished chemical-pure titanium wafer of which the Coefficient of Thermal Expansion (CTE) is 10.3ppm/°C. SU8 was used as etching mask instead of TiO_2 because SU8 can be selectively removed, while the residue TiO_2 may bend the free standing structures or lead to unpredictable performance of devices for its internal stress.

(b) High-Aspect-Ratio trenches were etched on the bulk-titanium substrate with chlorine plasma in an STS Multiplex ICP etcher. Titanium etch rate of 0.9μm/min was achieved with a 3:1 selectivity to SU8. After etching, the residual SU8 mask was stripped in fume nitric acid. As shown in Fig.3, 25μm deep trenches with straight sidewalls (85±1°) were generated with a minimal width as small as 2.5μm. A range of microstructures, such as springs, beams, comb electrodes, capacitive structures were clearly defined including 2 types of lateral-contact relays.

Table 1. Titanium etching recipe.

<table>
<thead>
<tr>
<th>ICP source power</th>
<th>Platen power</th>
<th>Cl₂ flow rate</th>
<th>Chamber pressure</th>
</tr>
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<tbody>
<tr>
<td>400W</td>
<td>100W</td>
<td>60sccm</td>
<td>3mT</td>
</tr>
</tbody>
</table>

(c) The deep trenches were refilled with parylene (SEM in Fig. 4), followed by O₂ plasma etch-back planarization until the top surface was cleaned.
(d) The titanium wafer was flipped and bonded to a double-side polished soda-lime glass wafer (CTE: 9.5ppm/°C) of 500μm with 6μm-thick SU-8 at 95°C. Then, the SU8 intermediate layer was UV cured from the glass side and hard baked at 150°C for full crosslink.
(e) The titanium wafer was thinned in a mixed etchant of HF/HNO₃/H₂O (1:1:15), followed by Chemical-Mechanical-Polishing (CMP) until the isolation trenches were completely exposed. The trench sidewalls were well protected by parylene during the etching. Fig.5 illustrates the sample surface before and after CMP, a smooth finish with RMS below 1nm was obtained.
(f) Bulk-titanium HARS were dry released by sequential O₂ plasma and O₂ (85%)/SF₆ (15%) plasma etching. With a lateral undercut of 8-10μm, all the movable structures were successfully released without stiction. Although few SU8 residues were spotted on the glass surface, device operation was not affected.

Fig.1 3D view of a bulk titanium lateral relay in FBTOG technology.

Fig.2 The process flow of FBTOG technology.
3. Results and Discussion

The FBTOG technology was employed to fabricate two types of electrostatically actuated lateral contact relays (Fig.6 and Fig.7). As shown in Fig.6, without blanket Au coating, Relay_A pulls-in in SEM by accumulation of surface charge. Testing results were listed in Table 2. The DC performance tests were carried out on a probe station in the air. The capacitive gaps of the fabricated relay were narrower than that of the design, which lead to lower measured threshold voltages ($V_{th}$).

Table 2. Simulation and testing results of the two microrelay types.

<table>
<thead>
<tr>
<th></th>
<th>Calculated spring constant (N·m⁻¹)</th>
<th>Calculated $V_{th}$ (V)</th>
<th>Measured average $V_{th}$ (V)</th>
<th>Calculated driving force at $V_{th}$ (μN)</th>
<th>Measured average $R_{contact}$ (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relay_A</td>
<td>2.6</td>
<td>297</td>
<td>160</td>
<td>10.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Relay_B</td>
<td>2.3</td>
<td>65</td>
<td>30</td>
<td>2.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Fig. 6 The layout (a) and SEM photographs of Relay_A (b) with a close-up view (c), which pulls-in (d) in SEM by accumulation of surface charge.

Fig. 7 The layout (a) and SEM photographs (b) of the lateral contact Relay_B, with close-up views of the comb fingers and contact head.

4. Conclusion

A wafer level FBTOG fabrication technology was developed to manufacture bulk titanium HARS for in-plane lateral sensing and actuating. Suspended structures of 25μm thick with a trench aspect ratio of 10 are demonstrated with no “footing” introduced damage, which provides features required for a range of high-performance bulk-titanium transducers. Several bulk titanium lateral relays were successfully manufactured and tested, a 2200μm-long comb-drive actuated relay showed a contact resistance of 2.3Ω at a moderate actuation voltage of 30V.

Acknowledgements

This work is supported by the National High Technology Research and Development Program of China (863) Grant No.2006AA04Z348, the National Natural Science Foundation of China (NSFC) Grant No. 60706029 and No. 50535030.

References