VACUUM PACKAGING OF MICRORESONATORS BY RAPID THERMAL PROCESSING

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ABSTRACT

Vacuum packaging of microresonators using RTP(Rapid Thermal Processing) aluminum-to-nitride bonding has been demonstrated. Polysilicon microresonators are fabricated with integrated sealing rings using surface micromachining technology. The top most layer on the sealing ring is silicon nitride. Aluminum sealing rings are patterned on the Pyrex glass cap wafers. The bonding and sealing of device wafer to cap wafer is done by heating the wafers in the RTP chamber at 750°C for 10 seconds in vacuum. The quality factor of a vacuum-packaged micro resonator is measured as 400±50.

1. INTRODUCTION

Micro mechanical resonators have the advantages over conventional resonators for narrow bandwidth (high quality factor, or high Q) applications[1] and for their potential of integration with electronic circuits.[2] One of the challenges in commercializing MEMS resonators is packaging. Due to air damping effect in the micro scale, vacuum packaging is essential for microresonators to achieve high-Q performance. For example, the quality factor of a double-folded beam, comb-shape resonator is around 20-40 as measured in air and can be as high as 50000 as measured in 10^{-7} Torr vacuum.[2]

In the previous vacuum packaging approaches, drawbacks such as extra lithography steps[1] and difficulty in wafer-level packaging[3] remain to be problematic for practical implementation. Wafer-level RTP bonding for MEMS packaging with accelerated hermeticity testing is proven to be effective and easy for implementation.[4,5] In this paper, RTP aluminum-to-silicon nitride bonding is used to seal microresonators in vacuum.

2. FABRICATION AND VACUUM PACKAGING PROCESS

Figure 1(a) and 1(b) show the design layout and cross-sectional view of a microresonator with an integrated sealing ring for the vacuum packaging process, respectively. Surface micromachining technology is used to realize the polysilicon comb-shape microresonators and integrated sealing rings. As shown in Fig. 1(a), the width of the sealing ring is designed from 100 to 250 μm to ensure best packaging results.[5] Typical sealing areas for comb-shape microresonators range from 600x600 to 1000x1000μm^2. The A-A' cross-sectional view in Fig. 1(a) is illustrated in Fig. 1(b). The 0.5μm-thick polysilicon(Poly0) interconnection line goes underneath the sealing ring with 2μm thick PSG layer(PSG1) on top to achieve electrical insulation. Extra PSG(PSG2, 1.75μm) and polysilicon(Poly2, 2μm) layers are used to stack up the sealing ring to ensure a clearance between microresonator structure and the packaging glass cap on top. Low-stress LPCVD silicon nitride of 0.5μm is used as the topmost layer of the sealing ring. A glass cap wafer is evaporated and patterned with 4μm-thick aluminum sealing rings.

After degreasing using aceton and IPA(Isopropanol Alcohol), the device and cap wafers are pre-baked in vacuum at 300°C for over 4 hours to drive out water and gas species. An adequate vacuum pre-baking procedure minimizes outgasing inside the package during the heating and bonding process.[6] After vacuum-baking, the device and cap wafers are flip-chip assembled immediately to minimize the water and gas adsorption and loaded into a quartz chamber. The vacuum in the quartz chamber is achieved by using a mechanical pump. The bonding and packaging process is done by RTP heating for 10 seconds at 750°C.

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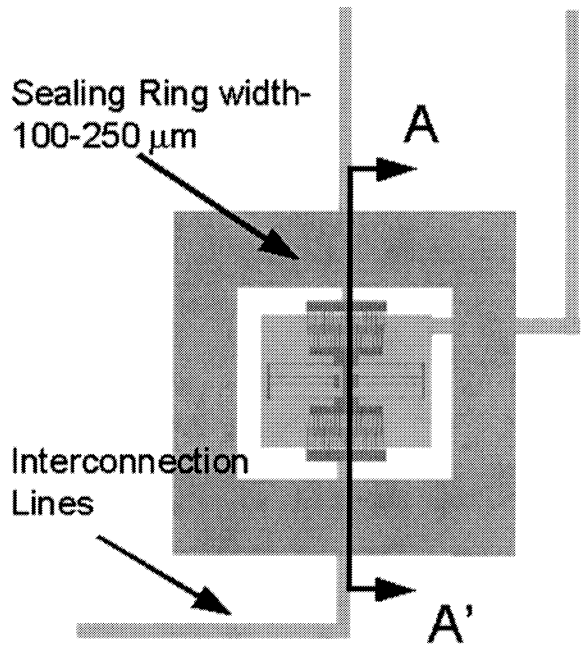
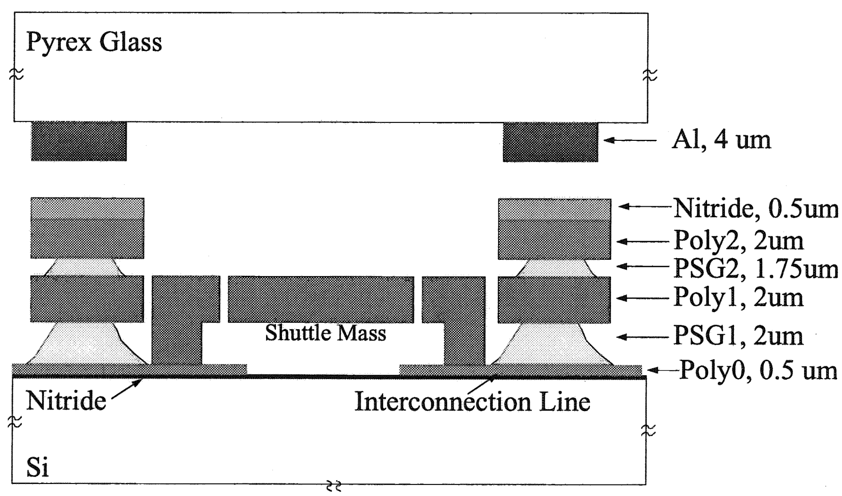


(a)



(b)

Figure 1. Comb-shape microresonators with integrated sealing rings for vacuum packaging. (a): Layout design. The width of sealing rings range from 100 to 250μm. (b): Cross-sectional view of A-A' with a glass cap wafer on top. Low-stress LPCVD silicon nitride layer is used as the topmost layer on the sealing ring.

3. VACUUM PACKAGING RESULTS

After RTP wafer bonding, the packaged resonators are immersed in DI water for hermeticity test. It is a first estimation of the packaging quality. Figure 2 shows an example of successful packaging result. A comb-drive resonator is resonating at 17.0KHz under the glass package immersed in DI water. The DI water is completely blocked outside by Al-nitride bond. After the hermeticity of the package is confirmed, it is ready for testing.

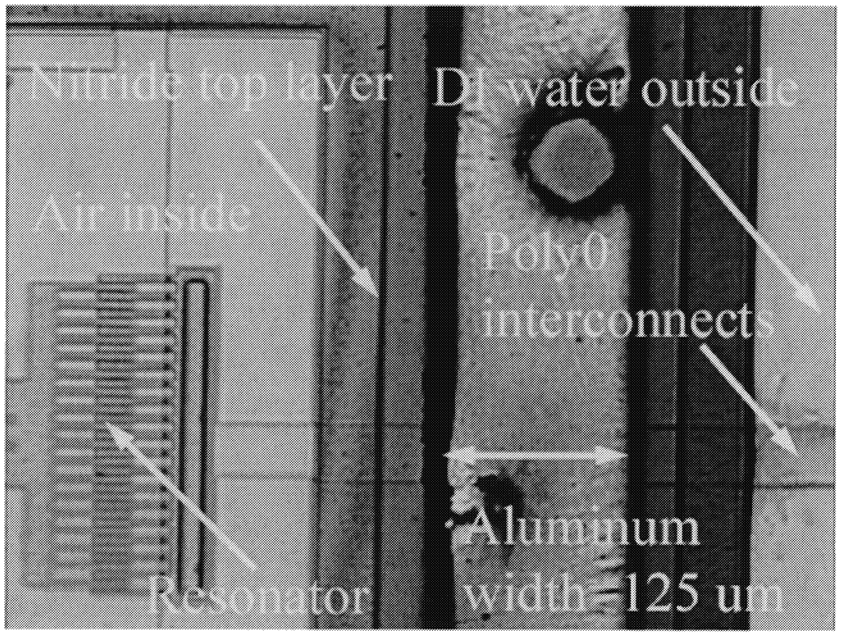


Figure 2. After RTP bonding, comb-drive resonator is resonating at 17.0 KHz under glass package immersed in DI water.

Figure 3 shows a silicon-glass package mounted on a circuit board and wirebonding is used to connect the polysilicon interconnection line to the copper line on the circuit board. Figure 4 shows the measured spectrum of a vacuum-packaged, double-folded comb-drive resonator by using a micro-stroboscope.[7] The quality factor is extracted as 400±50 corresponding to a pressure of about 1 Torr inside the package.[8] Moreover, the quality factor has a distinctive value for microresonators with and without vacuum pre-baking before packaging. For example, a microresonator without vacuum pre-baking, has a quality factor of 200±50 which is 50% lower than a microresonator of the same type that has gone through vacuum pre-baking at 300^{o}C for 4 hours. However, more research needs to be done in order to obtain an optimal pre-baking time for vacuum MEMS packaging to ensure a sustainable, high quality vacuum. Figure 5 shows the SEM photo of the silicon substrate The bonding interface is examined after forcefully breaking the bond. The glass debris is attached to the silicon substrate suggesting the bonding strength is greater than the fracture toughness of Pyrex glass.

4. CONCLUSIONS

In this paper, MEMS vacuum packaging process based on RTP aluminum-to-nitride bonding has been described. The quality factor of a vacuum-packaged, comb-shape microresonator was measured as 400±50 corresponding to a pressure about 1 Torr inside the package. The effect of vacuum pre-baking of wafers prior to bonding and packaging was proved to be important.

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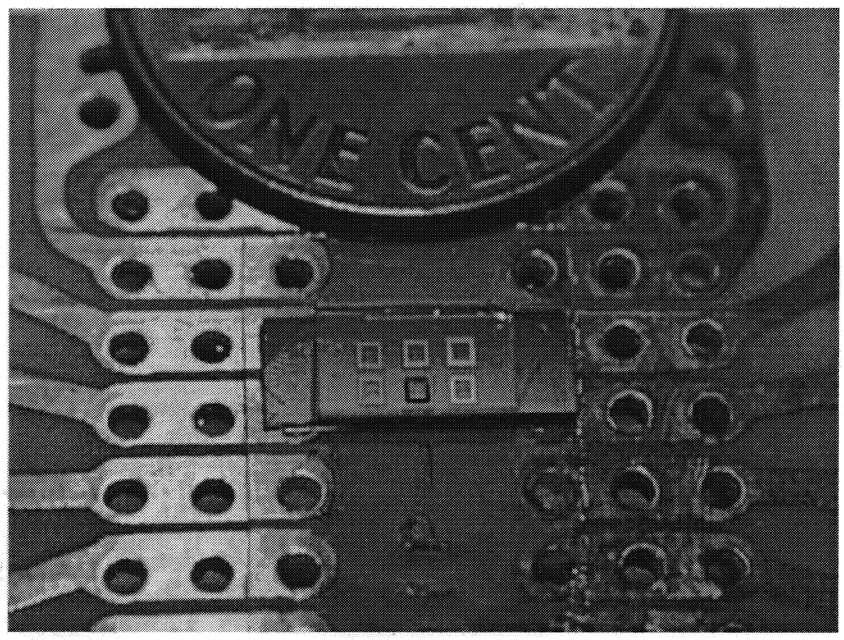

Figure 3. A silicon-glass package is mounted on to a circuit board and is ready for spectrum measurement. In this particular case, a total of 6 microresonators are packaged in parallel.

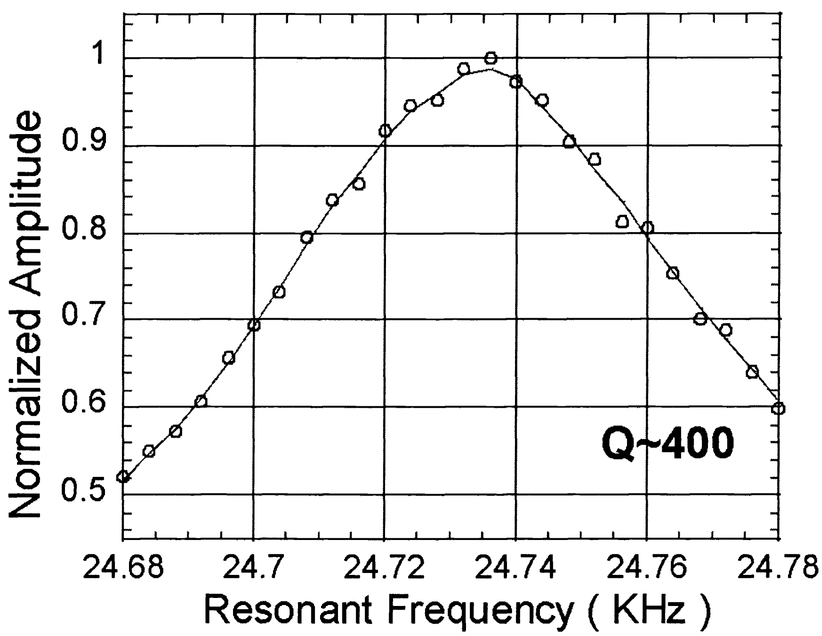

Figure 4. The spectrum of a vacuum packaged comb-resonator measured by a microstroboscope. The quality factor is extracted as 400±50 corresponding to a pressure of 1 Torr inside the package.

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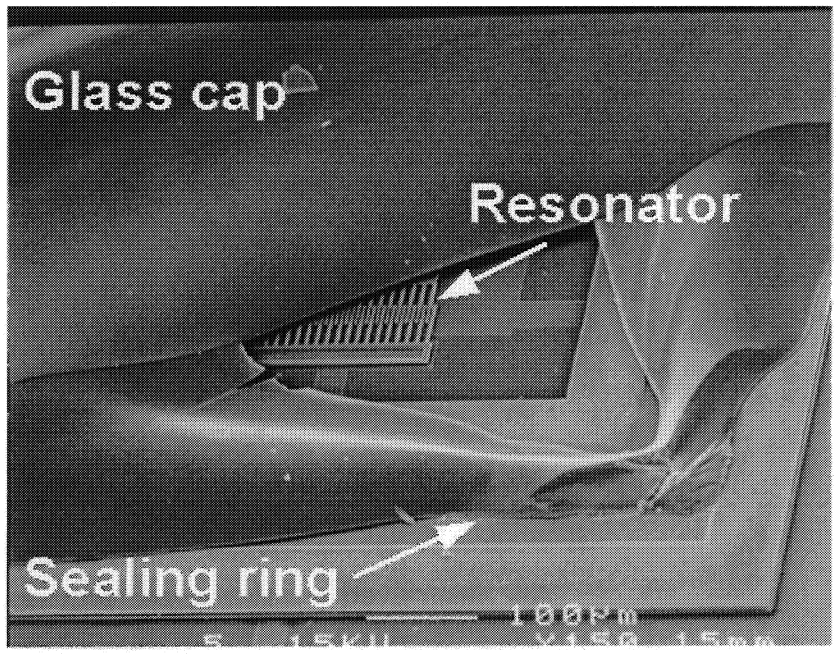

Figure 5. SEM of silicon substrate after the Al-to-silicon nitride bond is forcefully broken. Bulk glass is found on the silicon substrate.

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