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RF MEMS 스위치 적용을 위한 밀봉성 패키지의 특성 연구

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Characteristic study of hermetic package for RF MEMS switch

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Abstract - In this paper, we compared the mechanical characteristics between LTCC-based RF MEMS packaging structures fabricated using two different types of bonding materials; BCB and gold-tin. The BCB-based packages showed an average shear strength of 32.1 MPa and helium leak rate of 1.76×10^{-8} atm·cc/sec for a cavity volume of 0.45×10^{-3} cc, while the packages bonded by gold-tin layer (80 wt.% gold, 20 wt.% tin) showed an average shear strength of 42.70 MPa and helium leak rate 1.38×10^{-8} atm·cc/sec for a cavity volume of 1.21×10^{-3} cc.

1. Introduction

Over the last decades, microelectromechanical systems (MEMS) technologies have attracted great attentions of radio frequency (RF) researchers, because they can exceedingly reduce the size, weight, loss, and power dissipation of components in wireless systems [1]. While excellent RF MEMS devices have been reported, their integration to real-commercial system is still restricted by packaging problems [2, 3]. The operations of RF MEMS switches are highly sensitive to ambient (e.g., humidity, particles); therefore the hermetic encapsulation schemes should be considered just to avoid any problematic operations. In RF MEMS packages, RF friendly packaging geometries and materials should be firstly considered to minimize the RF loss of the device. Electrical interconnection is also one of the considerable factors to transmit the signals and to feed bias, efficiently. Higher mechanical strengths and superior hermetic properties are important to improve a reliability of the encapsulation device, and lower process temperature is also desirable to avoid the device failures.

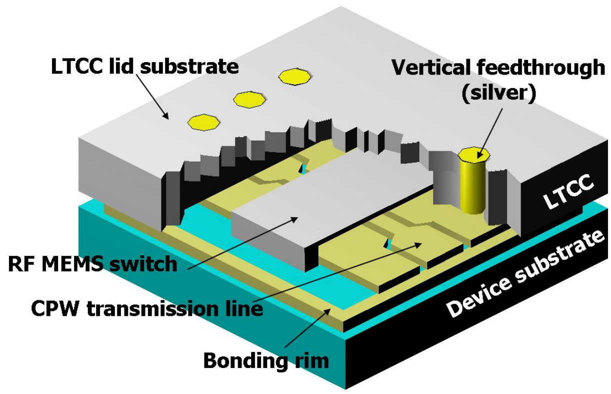
Vertical interconnection has been currently focused in MEMS and IC packaging due to the industrial requirement of 3D integration system. It is quite attractive compared to coplanar interconnection despite of its complex fabrication since it has a low feed line loss at high frequency and small packaging area. A Low temperature co-fired ceramic (LTCC) is a promising material as a capping substrate for RF MEMS packages due to its superior RF characteristics and process simplicity to make the vertical feedthroughs. For the mechanically reliable packaging, adhesive and eutectic bonding methods are broadly used by the reason of their good feature - low temperature process irrespective of substrate materials. The adhesive bonding The adhesive and eutectic bonding for low temperature process and strong binding can be realized by the use of benzocyclobutene (BCB) and gold-tin (Au_5Sn). While BCB shows several merits, the gold-tin is in the limelight in these days due to their additional merits such as a no creep movement and no thermal fatigue.

In this paper, two types of LTCC-based low temperature packaging methods for RF MEMS devices using BCB and gold-tin bonding layer were introduced, and their mechanical characteristics were tested and compared to each other.

2. Design and Fabrication

2.1 Design

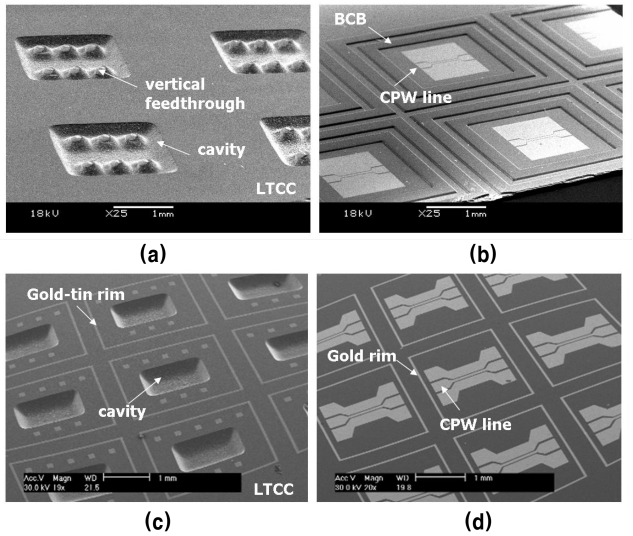
The proposed RF MEMS switch packaging structure consists of an LTCC lid substrate with vertical feedthroughs, device substrate and bonding layer as described in Figure 1. The substrates are assembled together via bonding rim (sealing layer) and interconnecting patterns on each feedthroughs. The silver-filled vertical feedthroughs are mechanically formed during the manufacturing process of an LTCC lid substrate; they achieves interconnections via metal patterns between feedthroughs at the LTCC lid substrate and MEMS structure at the device substrate. The internal cavity is defined at the LTCC lid substrate, and the 3D RF MEMS structure is finally located inside that space. In the case of BCB adhesive bonding, the BCB bonding layer is patterned on the device substrate for sealing, and the silver-epoxy patterns are deposited on each feedthrough through the screen-printing process and is connected with the CPW transmission line. The other case, gold-tin eutectic bonding, the gold-tin sealing rim and interconnection patterns are patterned on LTCC substrate to achieve the bonding and connecting with gold rim and the CPW transmission line, respectivelty.



<Figure 1> Schematic view of the RF MEMS switch packaging method with the LTCC lid substrate

2.2 Fabrication

The process is carried out as a chip-scale due to the shrinkage of the LTCC substrate and as a test structure just including a coplanar waveguide (CPW) transmission line without RF MEMS structure. The LTCC and device substrates of BCB-based (Figure 2. (a), (b)) and gold-tin based packages (Figure 2. (c), (d)) are shown in Figure 2. In the package bonded with the BCB sealing layer, the BCB sealing rim is applied as a dual-fold structure to improve the hermeticity and shielding ability (figure 2. (b)). The BCB double rim is patterned on the device substrate that the electroplated gold CPW line formed, and the interconnection patterns are deposited on each feedthrough at the LTCC substrate by the screen printing of silver epoxy. In the gold-tin bonded packages, however, a gold rim and a CPW transmission line are patterned on device substrate together (figure 2. (d)); a chrome-gold-tin-gold multilayer (80 wt.% gold, 20 wt.% tin) rim and interconnection patterns are deposited on the LTCC substrate. The rest of the processes are same both the use of BCB and gold-tin bonding. The internal cavity is defined at the LTCC substrate (inside the packaging, or same side of the interconnection patterns) using sandblast process; and the gold contacts pads for probing are patterned on the opposite side of the LTCC substrate. The cavity can be defined as manifold shapes. It can be achieved with islands for insertion loss reduction (figure 2. (a)) or not (figure 2. (c)). Finally, two substrate are adhesively or eutectically bonded under a temperature of 210 ℃ (BCB) and 310 ℃ (gold-tin) using a flip-chip technology, respectively.



<Figure 2> Cavitiy and bonding rims on LTCC and device substrate of each package: (a) LTCC for adhesive bonding, (b) BCB double rims at device substrate for adhesive bonding, (c) gold-tin rims at LTCC for eutectic bonding, and (d) gold rims at device substrate for eutectic

3. Measurement and Discussion

3.1 Measurement

The mechanical performances of the packages using different kinds of sealing materials were evaluated by measuring the leak characteristics and shear strengths of the package. The leakage was measured to evaluate the hermetic properties by the fine leak test using helium gas. The mechanical bonding strength was evaluated by shear strength test. As shown in Table 1, the package using the BCB adhesive layer showed a helium leak rate of 1.76×10^{-8} atm・cc/sec for a cavity volume of 0.45×10^{-3} cc, and showed the average shear strength of 32.17 MPa with the standard deviation of 4.57 MPa. On the other hand, the packages using the gold-tin eutectic layer showed a helium leak rate of 1.38×10^{-8} atm・cc/sec for a cavity volume of 1.21×10^{-3} cc, and showed the average shear sterngth of 42.70 MPa with the standard deviation of 5.36 MPa.

<Table 1> Comparisons of the mechanical performances between the BCB bonding and the gold-tin bonding packages

	BCB bonding rim	Gold-tin bonding rim
Bonding temperature	210 ℃	310 ℃
Avg. shear strength	32.17 ± 4.57 MPa (7 samples)	42.70 ± 5.36 MPa (8 samples)
Helium leak rate	1.76×10^{-8} atm・cc/sec (per 0.45×10^{-3} cc)	1.38×10^{-8} atm・cc/sec (per 1.21×10^{-3} cc)

3.2 Discussion

The gold-tin eutectic bonded packages showed better mechanical performances than the BCB adhesive bonded packages in terms of the leakage and the bonding strength. The gold-tin single rim shows almost 3.3 times lower helium leak rate per same unit volume, and about 10.53 MPa higher shear strength than BCB double rim. The gold-tin bonding experiences higher process temperature than the BCB bonding, however, it can offer a relatively lower process temperature compared to other hermetic high-temperature bonding processes (e.g., fusion bonding) and melting temperatures of metals. The results show that the gold-tin bonding packages can offer better mechanical performances in hermetic packaging than the BCB bonding ones.

4. Conclusion

The hermetic RF MEMS packaging method was proposed using LTCC substrate and two different bonding materials of BCB and gold-tin. Each bonding layer was formed in different methods, and bonded with an LTCC lid substrate at 250 ℃ and 310 ℃, respectively, by means of the flip-chip technology.

Mechanical performances of each packages with different bonding materials were evaluated through the helium leak and the shear strength tests, and compared each other. The measured bonding strength and helium leak rate of the BCB bonding packages were 32.1 ± 4.57 MPa and shear strength and 1.76×10^{-8} atm・cc/sec for a cavity volume of 0.45×10^{-3} cc, respectively; while the gold-tin bonding packages showed the shear strength of 42.70 ± 5.36 MPa and the helium leak rate of 1.38×10^{-8} atm・cc/sec for a cavity volume of 1.21×10^{-3} cc. The gold-tin bonding packages showed almost 3.3 times lower helium leak rate per same unit volume, and about 10.53 MPa higher shear strength than BCB bonding ones. The results show that the proposed RF MEMS packages using gold-tin eutectic bonding provide the improved mechanical performances in comparison with the BCB adhesive bonding packages.

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