RF MEMS Switch with Wafer Level Package Utilizing Frit Glass Bonding

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This paper reports experimental results of RF characteristics up to 20 GHz of a RF MEMS switch applied with wafer level packaging. A glass wafer is used as a package substrate on which frit glass is printed as material to seal the MEMS devices. The package wafer is bonded to a device wafer, which consists of actuators and base substrates .The actuators are made of single crystal silicon that has less residual stress. The base substrate has through holes formed by sand blast. The switch achieves a low insertion loss of 1.3 dB and a high isolation of 19 dB up to 20 GHz, and can be mounted on to a circuit board with bumps, like flip chip. The wafer level packaging with low cost and high reliability will transfer RF MEMS devices, which has superior high frequency characteristics even in quasi-millimeter wave band, to the practical use.

INTRODUCTION

A lot of researches and developments for RF MEMS, such as switches and tuneable filters, were reported, and it has been indicated that the packaging for MEMS is one of the problems for the practical use of MEMS devices [1]. The packaging process provides MEMS devices mechanical protection of the actuators during sawing and assembly and allows the use of conventional IC packaging such as lead frame assembly and injection molded DIP plastic packages. Furthermore, the packaging process provides the damping and shock protection for the actuators, in that packaging may be performed at a controlled pressure. Recently various techniques of wafer level packaging for RF MEMS devices were proposed [2-3]. One of the packages is considered to get smaller parasitic parameters and interference for high frequency [2]. However, few experimental results with the packages in microwave and millimeter wave bands have been reported, especially for discrete MEMS devices. This paper shows experimental results of RF characteristics up to 20 GHz of a RF MEMS switch applied with wafer level packaging. The seal material is frit glass and the actuator is made of single crystal silicon, which has less residual stress even in high temperature.

STRUCTRE AND FABRICATION

The MEMS switch is composed of three parts, which are cap, actuator and substrate shown in Fig. 1. The packaging process is shown in Fig. 2. The packaging (cap) wafer, which is a Pyrex glass with cavities and frit glass, is bonded to the device wafer. The micro switch of the device wafer consists of single crystal silicon as an actuator and a glass substrate with through-holes fabricated by sand blast. The silicon part is an active layer of a SOI wafer. The diameters of through holes with taper shape are 330um on the top and 700um on the bottom. The silicon part and the glass substrate are

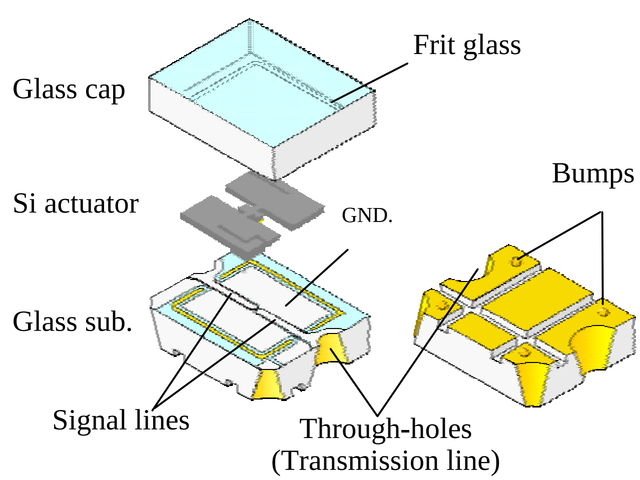

Figure 1: Exploded view of the switch

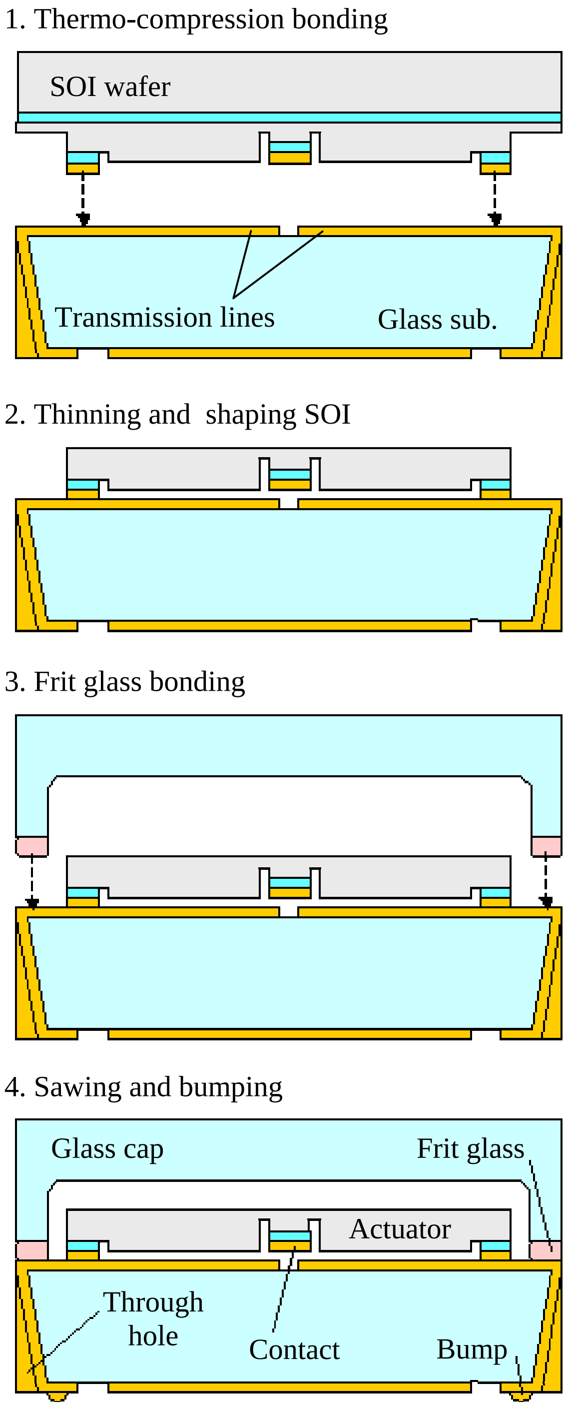

Figure 2: Process sequence for fabrication

bonded using thermo-compression bonding. Therefore, it is possible to apply materials suitable for RF to the base substrate, such as GaAs, quartz and high resistive silicon. The base has a CPW transmission line on the top of it, and can be connected to a circuit board with bumps on the electrodes of the bottom. The metalized through-holes connect the transmission line with the electrodes of the bottom. The transmission lines and control lines are made of Cr/Au. Spray coating of resist makes it possible to pattern the metal films sputtered on the wafer with through holes, without breaking lines at opening and inside of through holes. The material of the contacts is gold.

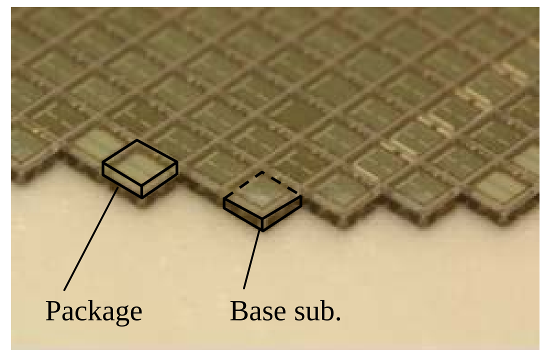

Figure 3: MEMS switches in wafer level package

PACKAGING

Figure 3 shows the MEMS switches in wafer level package. The technique of frit glass bonding is used for commercial MEMS sensors, such as accelerometers [4]. The technique is not suitable for CMOS compatible process because of its high bonding temperature. But in this case, the MEMS switch is a discrete one, not integrated with other circuits. So the technique is acceptable for the switch. The main material for frit glass bonding is lead glass. Lead glasses are manufactured as powder and mixed into screen printable pastes. The width and thickness of the bonding line are 250 um and 10um. The package wafer printed with pastes of frit glass is preglazed. The frit glass bonding is at 410 degree Celsius. The cavity of the device is sealed with decompression inertial nitrogen gas. The temperature is higher than that in the case of B-stage epoxy [2] or benzocyclobutene (BCB) [3] as sealing materials. However, no critical bowing and deflection of the actuator is confirmed after packaging, because the actuator is made of single crystal silicon utilizing an active layer of an SOI wafer, which has less residual stress compared with deposited thin film actuators. The deflections before and after the packaging are 0.087um and 0.061um. The tensile strength is around 30 Mpa. The leak rate of the package is less than $1.3*10^{-10}$ Pa m^3/s.

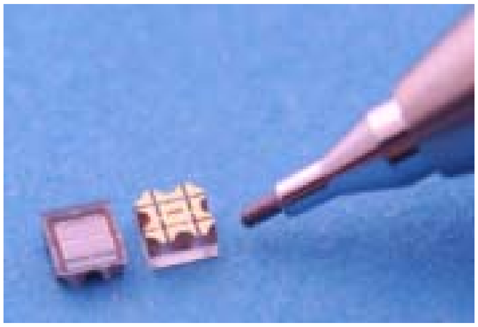

Figure 4: Top and bottom views of the switch

EXPERIMENTAL RESULTS

The size of the fabricated switch is 1.8*1.8*1.0 mm^3 as shown in Fig. 4. The 'ON' voltage of the actuator is 9 V and the switching speed is 0.3 ms. Figure 5 shows the high frequency characteristics of the device. In the broadband from DC to 20 GHz, it shows the superior characteristics, such as an insertion loss less than -1.3 dB and an isolation more than –19 dB. Increasing of the loss in higher frequencies would be caused by reflection at through-holes. As a comparison, the characteristics of a MEMS switch without through-holes shown in Fig. 6, which has the same length as a transmission line of the switch with vertical feed-through, are evaluated. A broken line in Fig. 5 shows a relatively lower loss in higher frequencies compared to the switch with holes [5].

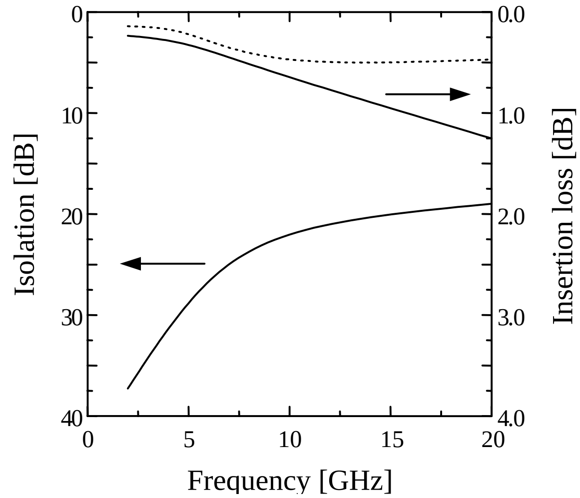

Figure 5: RF characteristics of the switches
Solid lines: switch with holes / Broken line: switch without holes

DISCUSSIONS

In this section, an improvement of RF characteristics, especially lower insertion loss, is discussed. The thickness of the base substrate with through-holes is 500 um. The pitch between two holes is 975 um. The RF characteristics, especially the insertion loss, are easily improved by applying a thinner wafer to the substrate. Though-holes in the thinner wafer have shorter length, smaller diameter and closer pitch. The loss, such as interference, emission and reflection, will be decreased in the thinner substrate. Also, further small holes can be formed using laser fabrication.

Figure 6: MEMS switch without holes

CONCLUSION

This paper reported the characteristics of RF MEMS switch with wafer level packaging utilizing frit glass as sealing material. As a result, the superior high frequency characteristics have been achieved, such as a low insertion loss less than -1.3 dB and a high isolation more than –19 dB, even in microwave and quasi-millimeter wave band up to 20 GHz. The packaging technology can be used to RF MEMS devices for the practical use with low cost and high reliability.

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