Special issue on International Workshop on Networked Sensing System

Trans. of the Society of Instrument and Control Engineers
Vol.E-S-1, No.1, 11/15 (2006)

RF MEMS Switch up to 20GHz with Wafer Level Packaging†

Koji SANO *, Tomonori SEKI *, Takahiro MASUDA *, Isamu KIMURA *,
Shobu SATO *, Fumihiko SATO * and Koichi IMANAKA *

A novel RF-switch with an extremely low insertion loss of −1.3 dB and a high isolation of −19 dB up to 20 GHz is reported. Ultra compact size of $1.8 \times 1.8 \times 1.0\text{mm}^3$ with CSP structure utilizing wafer level packaging technology is achieved. The wafer level packaging with frit glass makes it possible to mount the device directly on the circuit board without any extra outer package and wire bonding which deteriorate the RF characteristics. The package is made from cavitied 4-inch Pyrex glass wafer as cap-material and frit glass as seal-material. The device wafer consists of actuators and base substrates. The actuators are made of single crystal silicon that has less residual stress. The package has high reliability and can be fabricated with low cost. It can be transfer easily to wide range of not only RF MEMS devices but also another MEMS devices, to practical usage.

Key Words: MEMS, RF, switch, package, actuator

1. Introduction

A lot of reports for RF MEMS devices have been reported, and it has been indicated that the packaging for MEMS devices is one of the problems for the practical use of MEMS devices [1), 2)]. The packaging process provides MEMS devices with mechanical protection of the actuators during dicing process and assembly, and allows the use of conventional IC packaging such as lead frame assembly and injection molded plastic packages. Furthermore, the packaging process provides the damping and shock protection for the actuators, in that case of packaging may be performed at a controlled pressure. Recently various techniques of wafer level packaging for RF MEMS devices were proposed [3), 4)]. One of the packages is considered to get smaller parasitic parameters and interference for high frequency [3)]. However, few experimental results with the packages in microwave and millimeter wave bands have been reported, especially for discrete RF MEMS devices. This paper shows experimental results of RF characteristics up to 20 GHz of a RF MEMS switch applied with wafer level packaging.

† Presented at INSS 2004 (2004.6)

* MEMS Group, Advanced Device Laboratory, Corporate R&D H.Q. Omron Corporation
9-1, Kizugawadai, Kizu-Cho, Soraku-Gun, Kyoto 619-0283, Japan
Tel +81-774-74-2011, Fax +81-774-74-2001, E-mail koji_sano omronc.co.jp

(Received November 1, 2004)
(Revised July 13, 2005)

2. Structure and Fabrication

The RF MEMS switch has been fabricated for up to 20GHz operation using a 50Ω coplanar waveguide (CPW) line implementation on a glass substrate. Figure 1 shows the schematic view of the MEMS switch. The switch composed of three substrates, glass cap, single crystal silicon actuator and glass base substrate.

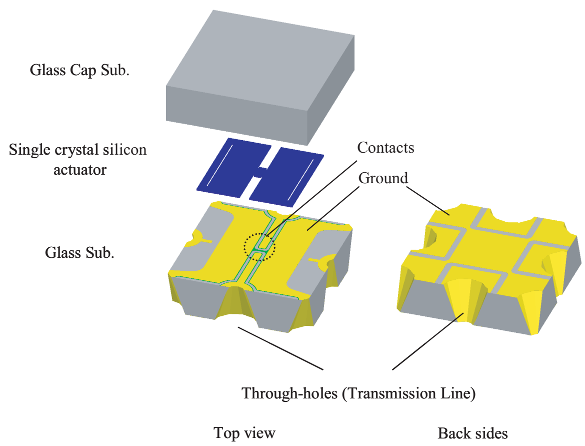


Fig. 1 Schematic view of RF MEMS Switch

Figure 2 shows the process flow of the present RF MEMS switch. The MEMS switch of the device wafer consists of single crystal silicon as an actuator and a 500μm glass substrate with through-holes by sand blast. The silicon substrate is an active layer of a SOI wafer.

The diameters of through-holes are 250μm on the topside and 600μm on the backside. The silicon substrate and the glass substrate are bonded using thermo-compression bonding (1). Therefore, it is possible to apply materials suitable for RF to the base substrate, such as GaAs, quartz or high resistive silicon. After the bonding process of glass substrate with SOI wafer, the handle layer of the SOI wafer is removed by KOH. Then the oxide layer is removed, and a shaping process forms the active layer of the SOI wafer to the MEMS Switches (2). The packaging (cap) wafer, which is a 30μm cavitied 4-inch Pyrex glass (Corning #7740), is bonded to the device wafer after screen printing and grazing of frit glass (3). The base substrate has CPW transmission line on the topside of it, and can be connected to a circuit board with bumps on the electrodes of the backside (4). The metalized through-holes connect the transmission line with the electrodes of the bottom. The transmission lines and control lines are made of Chrome/ gold (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 holes. The material of the contacts is gold.

Figure 3 shows the MEMS switches in wafer level packaging before dicing process. Figure 4 shows a part of the MEMS switches wafer. The technique of frit glass bonding is used for commercial MEMS sensors, such as accelerometers [4]. 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 250m and 10μm. The package wafer printed with pastes of frit glass is pre-glazed. The condition of frit glass bonding is at 450 degrees Celsius with 5000N of pressure is applied for 30 minutes. The cavity of the device is sealed with decompression inert nitrogen gas.

The size of the fabricated MEMS switch is $1.8 \times 1.8 \times 1.0$mm^3 and the 'ON' voltage of the actuator is less than 12 V and the switching speed is less than 0.5 ms. In case of the atmospheric pressure environment, the switching speed becomes 2ms.

3. Experimental Results

Figure 5 shows the high frequency characteristics of the RF MEMS Switch. S-parameters of the RF characteristics are measured on an HP 8722ES Network Analyzer, using 650μm pitch Air Coplanar^{TM} Probe. In the broadband from DC to 20 GHz, it shows the superior characteristics, such as an insertion loss less than −1.3 dB, an isolation more than −19 dB and a return loss more than −19 dB (Figure 5). Increasing of the loss in higher frequencies would be caused by reflection at through-holes.

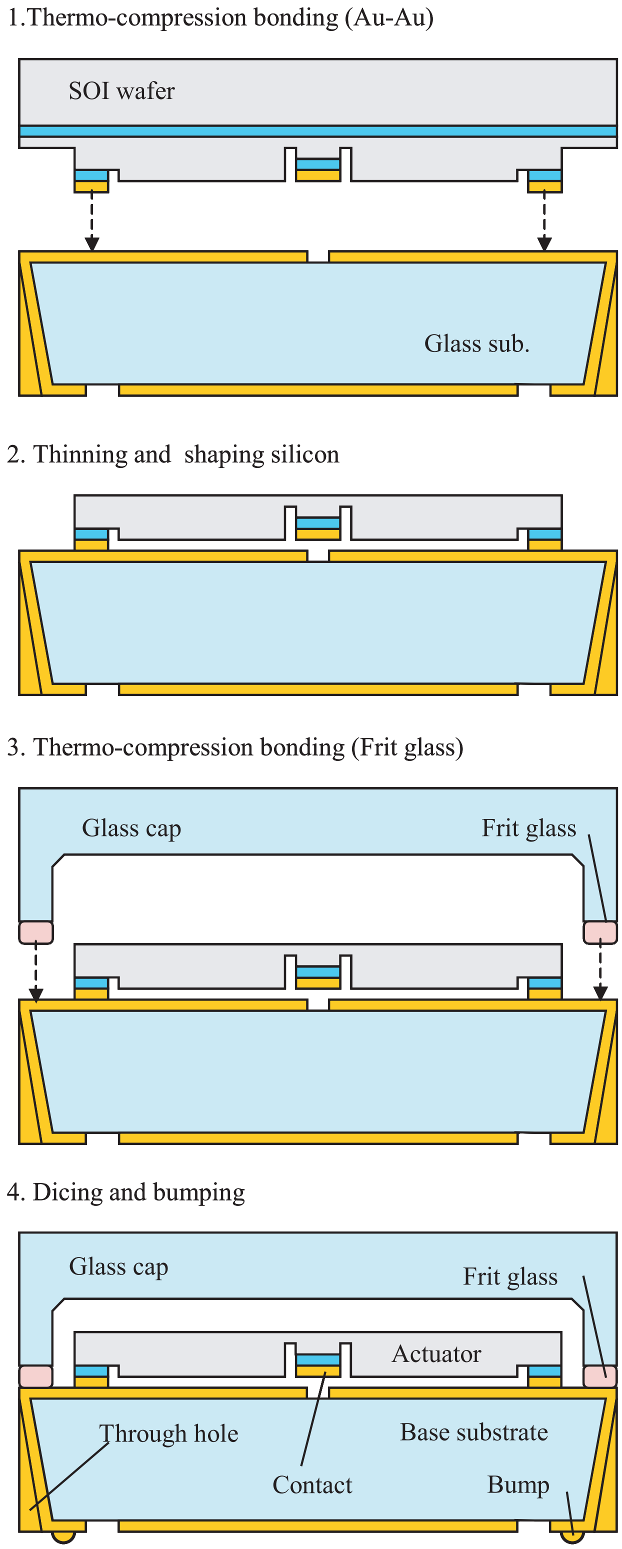


Fig. 2 Process flow for RF MEMS Switch.

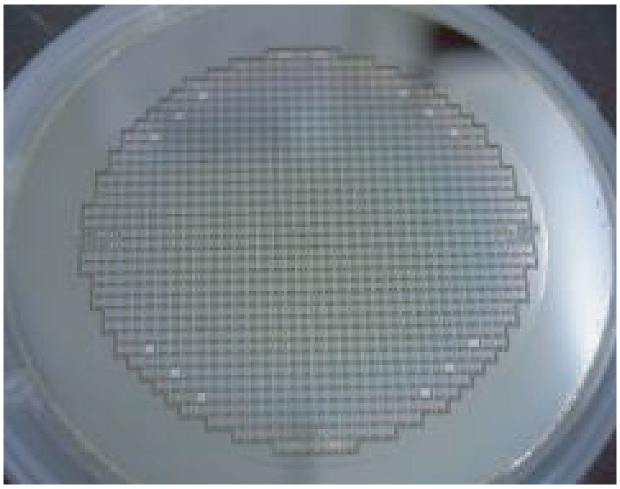


Fig. 3 Wafer level packaging before dicing process.

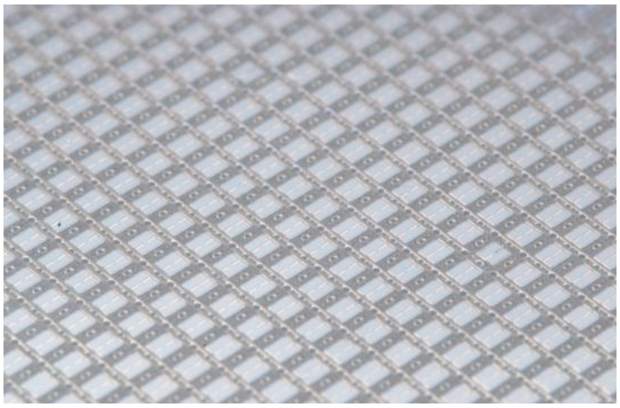


Fig. 4 Photographs of the MEMS switches.

4. Discussions

As a comparison, the high frequency characteristics, especially an insertion loss of a MEMS switch using wire bonding has been measured for outer side connection. Figure 6 shows an insertion loss up to 6GHz of MEMS Switch with wire bonding for plastic mold package [5].

Figure 7 shows simulation (HFSS ANSOFT) results of MEMS Switch with wire bonding for plastic mold package at 10GHz. The loss occurred around wire and lead flame.

In addition, an improvement of RF characteristics, especially lower insertion loss, is discussed. The thickness of the base glass substrate with through-holes is 500μm. The pitch between two holes is 975μm. 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.

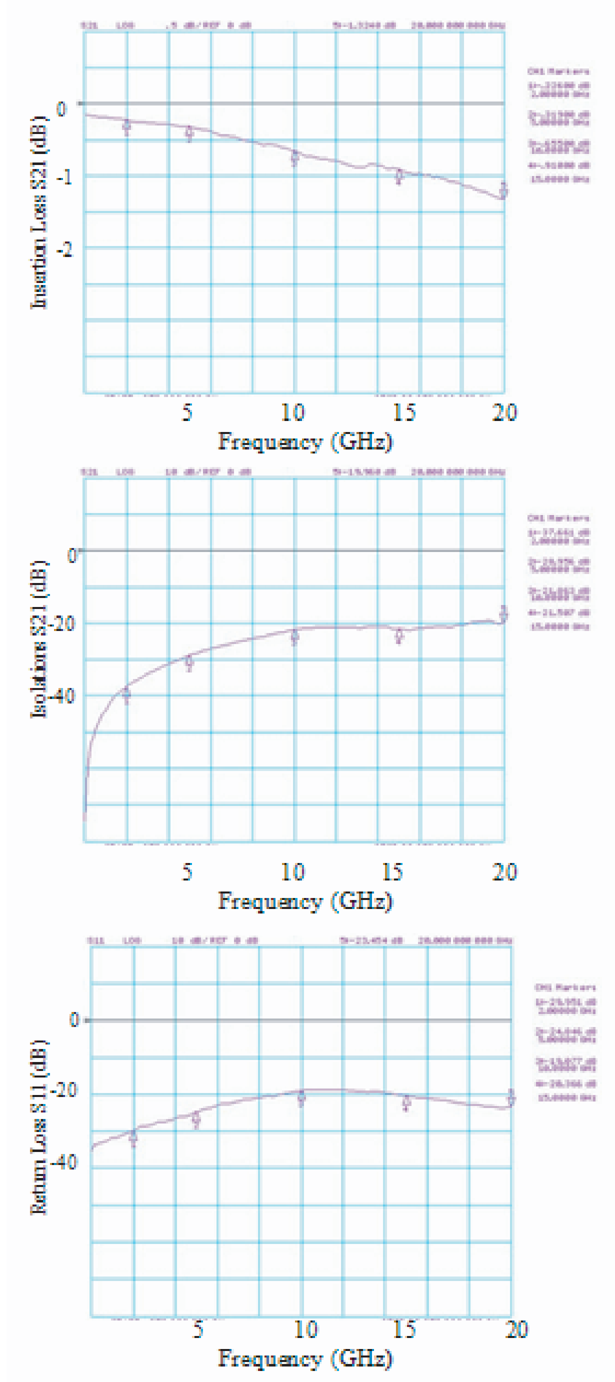


Fig. 5 Measured S-parameters for RF MEMS Switch.

5. 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, a high isolation more than −19 dB and a high return loss more than −19dB, even in

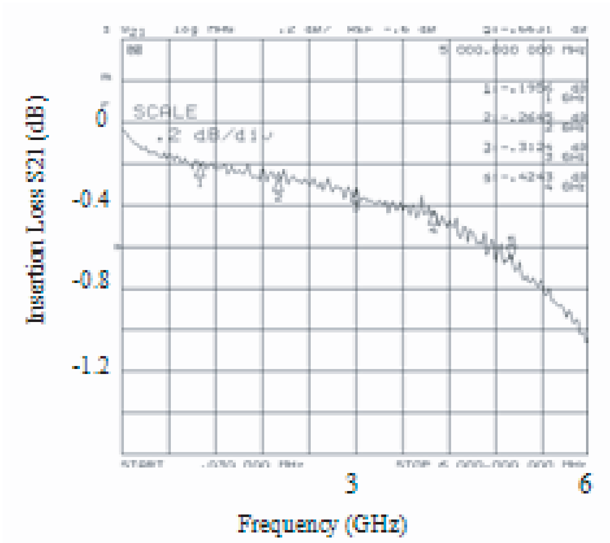


Fig. 6 Measured insertion loss of MEMS Switch with plastic mold package.

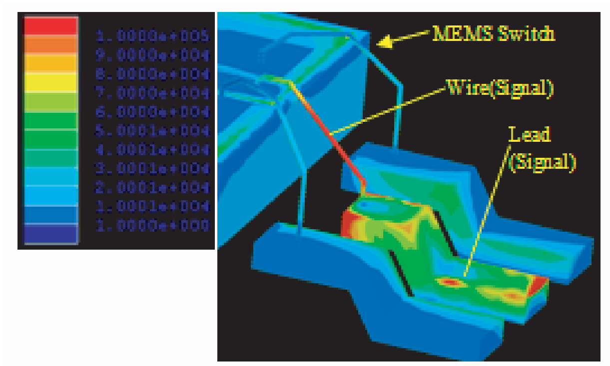


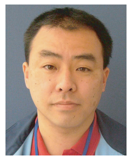
Fig. 7 Simulation of MEMS Switch with plastic mold package. with plastic mold package.

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.

References

1) J Jason Yao: RF MEMS from a device perspective, J.Micromech. Microeng., Vol. 10 (2000) R9-R38, April(2000)
2) G. M. Rebeiz and J.B. Muldavin: RF MEMS switches, switch circuits, and phase shifters, SUMBITTED HFREVIEW, Jun. (2001)
3) Y. K. Park, *et al.*: A novel low-loss wafer-level packaging of the RF-MEMS devices, MEMS 2002, pp. 681-684, Jan.(2002)
4) A. Jourdain, P. De Moor, S. Pamidighantam and H. A. C. Tilmans: Investigation of the hermeticity of BCB-sealed cavities for housing (RF-) MEMS devices, MEMS 2002, pp. 677-680, Jan. (2002)
5) T.Seki: Large force electrostatic MEMS relay for DC to 20GHz, IEEE MTT-S 2002 Microwave Symposium Workshop Notes, WMJ-Advances in RF MEMS Technology, pp.2-12, June. (2002)

Koji Sano



He received the B. E. degree from Tsukuba University in 1993. He is a senior research engineer at Omron Corporation. His current research is concentrating on MEMS switch.

Tomonori Seki

He received the M. E. degree from Kumamoto University in 1993. He is a senior research engineer at Omron Corporation. His current research is concentrating on MEMS switch.

Takahiro Masuda

He received the B. E. degree from Osaka City University in 1998. He is a research engineer at Omron Corporation. His current research is concentrating on MEMS switch.

Isamu Kimura

He received the B. E. degree from Tsukuba University in1991. He is a senior research engineer at Omron Corporation. His current research is concentrating on MEMS sensor.

Shobu Sato

He received the M. E. degree from Tokyo Institute of Technology in 1999. He is a research engineer at Omron Corporation. His current research is concentrating on MEMS switch.

Fumihiko Sato

He received the B. E. degree from Osaka University in 1978. He is a MEMS group manager at Omron Corporation. His current research is concentrating on MEMS.

Koichi Imanaka

He received the B. E. degree from Osaka University in 1974, the M. E. degree from Osaka City University, and the Ph. D. degree from Neuchatel University in Switzerland. He is a director of R&D development at Omron Corporation. His current research is concentrating on MEMS and optical systems.

Reprinted from Trans. of the SICE
Vol. E-S-1 No. 1 11/15 2006