Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 90-91

D-2-3

RF-MEMS Switch Structure for Low-Voltage Actuation and High-Density Integration

Kei Kuwabara[1], Norio Sato[1], Hiroki Morimura[1], Junichi Kodate[1], Toshikazu Kamei[2], Katsuyuki Machida[2], and Hiromu Ishii[1]

[1]NTT Microsystem Integration Laboratories, NTT Corporation
3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-0198, Japan
Phone: +81-46-240-2717 E-mail: k-kuwa@aecl.ntt.co.jp
[2]NTT Advanced Technology Corporation
3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-0124, Japan

1. Introduction

Small low-power RF transceivers capable of multiband operation are demanded in order to realize ubiquitous networking [1]. RF MEMS technology has been researched to fabricate high-performance RF devices for such RF transceivers [2]. We have developed an RF CMOS-MEMS switch that aims for monolithic integration of RF MEMS switches onto a CMOS LSI [3]. To achieve the integration, low-voltage actuation of the switches is required so that they can be controlled by the LSI. High-density integration of the switches is also required in order to provide reconfigurability for multiband operation.

In this paper, we present an RF-MEMS switch structure featuring narrow-gap electrodes for low-voltage actuation and high-density integration.

2. Design Concept

In the switch structure shown in Fig. 1 [3], we analyzed the relation between the electrode area (A) and electrode gap (g) needed to meet specified actuation voltages. In the analysis, the spring constant (k) was assumed to be 10 N/m in consideration of reliable switching operation. As shown in Fig. 2, reducing the actuation voltage at a constant electrode gap needs a large increase in electrode area, which means a single chip can accommodate only a few switches. The analysis results reveal that narrowing the gap is the key to achieving both low-voltage actuation and high-density integration. A gap of less than 1 μm provides an actuation voltage of below 3.3 V and tens of switches available on a single chip, which allows multiband switching in several circuit blocks.

Important issues concerning switches with narrow-gap electrodes are isolation and manufacturability. Figure 3 shows calculated isolation characteristics as a function of the contact gap. A contact gap of more than 0.3 μm is tolerated with the assumption of a 3-dB decrease in isolation. As for the manufacturability, warpage caused by residual stress prevents fabrication of the narrow-gap electrodes. The switch structure features a sandwich structure to reduce the warpage. Figure 4 shows measured warpage of cantilevers with and without sandwiching. The results demonstrate that the sandwich structure reduces the warpage and allows fabrication of narrow-gap electrodes.

Consequently, an RF MEMS switch structure with narrow-gap electrodes enables low-voltage actuation and high-density integration.

3. Results and Discussion

We fabricated RF MEMS switches with a different gap and a different electrode area to verify the effect of a narrow electrode gap. Figure 5 shows SEM photographs of the fabricated switches. They have a flat movable electrode due to the sandwich structure.

We measured the capacitance-voltage characteristics of the switches to extract the fabricated gap and an actuation voltage as shown in Fig. 6. The capacitance is inversely proportional to the gap, which means the transition of the capacitance represents movement of the switch. From the measured characteristics, the fabricated gap can be extracted from the capacitance at a 0-V applied voltage. The actuation voltage was determined from the applied voltage at which the capacitance saturates.

Figure 7 shows measured and calculated relations between the electrode area and the actuation voltage. Calculated results for the switches without the sandwich structure mean that the actuation voltage was increased because the gap is widened due to a large warpage. In contrast, a low actuation voltage of about 3 V was achieved using the sandwich structure. A comparison of the results for the different gaps verifies that the narrower gap has an advantage of smaller electrode area at a certain actuation voltage. An electrode area of about 1×10^{-8} m^2, which enables integration of tens of switches on a single chip, was achieved with an electrode gap of about 0.8 μm.

4. Summary

An RF MEMS switch structure with narrow-gap electrodes enabled low-voltage actuation of about 3 V and high-density integration of tens of switches on a single chip. Therefore, this structure will lead to the development of RF MEMS switches for single-chip multiband RF LSIs.

Acknowledgements

The authors thank Dr. Y. Kado for his helpful support and encouragement.

References

[1] Y. Neuvo, *ISSCC Tech Dig.*, (2004) 32.
[2] C. T.-C. Nguyen *et al.*, Proc. IEEE, **86** (1998) 1756.
[3] K. Kuwabara *et al.*, *IEDM Tech. Dig.*, (2006) 735.

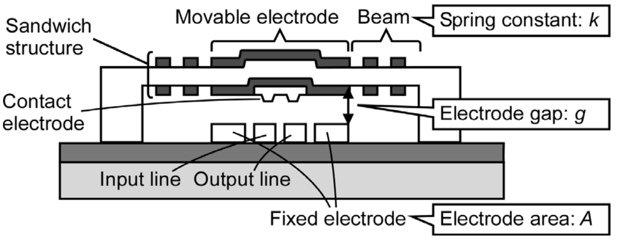

Fig. 1. Cross-sectional schematic of the RF MEMS switch and its design parameters.

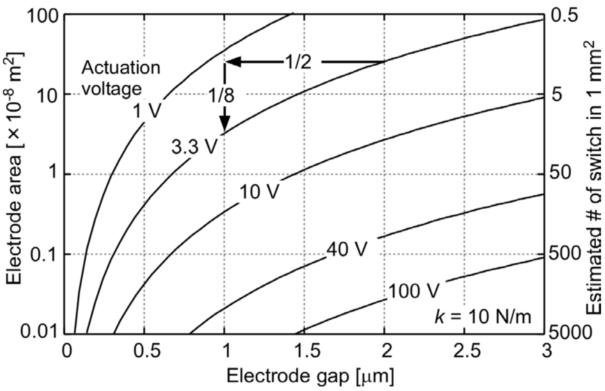

Fig. 2. Relation between the electrode gap and the electrode area needed to meet specified actuation voltages. In estimating the number of switches, it was assumed that the switches were arrayed with twice the area of the electrode.

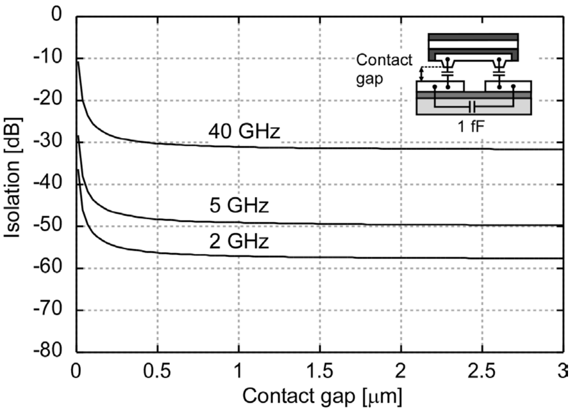

Fig. 3. Calculated results for contact gap dependence of isolation characteristics at several frequencies.

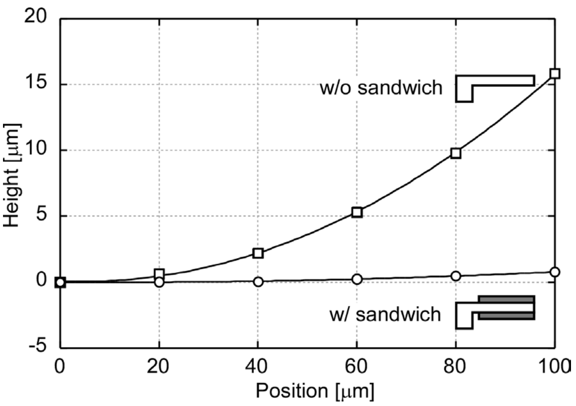

Fig. 4. Measured warpage of cantilevers with and without the sandwich structure.

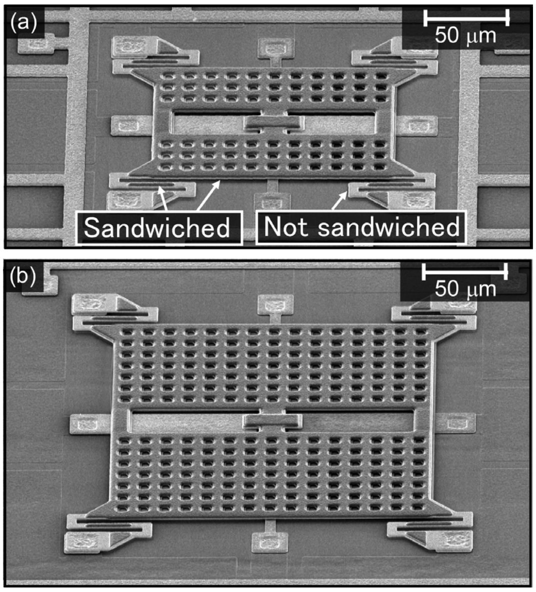

Fig. 5. SEM photographs of fabricated RF MEMS switches with a (a) small and (b) large electrode area. The movable electrode of the switches is flat due to the sandwich structure.

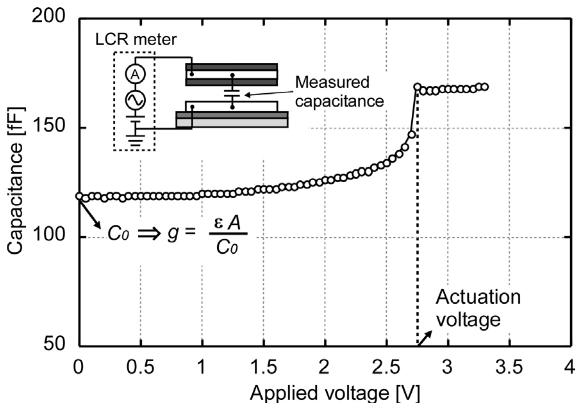

Fig. 6. Measured capacitance-voltage characteristics of the RF MEMS switch. The electrode gap and actuation voltage can be extracted from the characteristics.

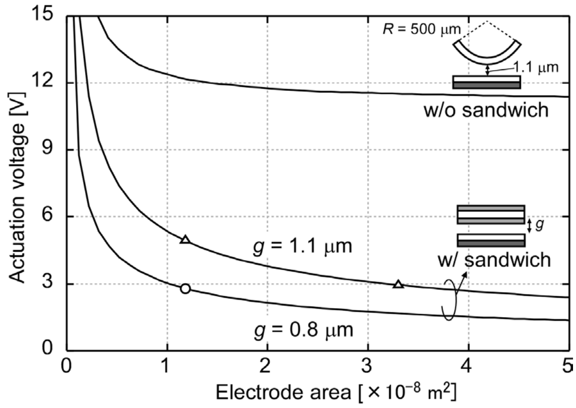

Fig. 7. Measured and calculated relations between the electrode area and actuation voltage of RF MEMS switches. The lines denote calculated results and the symbols denote results extracted from the capacitance-voltage measurements.