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INVESTIGATION ON THE ELECTRICAL CONTACT BEHAVIORS OF RF MEMS SWITCHES USING NANO-INDENTER

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Abstract. This paper presents a methodology of investigating electrical contact behaviors of radio frequency (RF) microelectromechanical system (MEMS) switches by using a nano-indenter. The setup simulates hot switching of radio frequency microelectromechanical system (MEMS) switches; cyclic contact test is conducted to characterize reliability of the contact material. The reliability of Au-to-Au contacts was characterized under different currents; electric contact between both ball tip and Si wafer coated with thin Au film was permanently broken after certain switching cycles. The surface of contact region was deformed by melting and it causes contact area decreasing and finally the electrical contact was broken. The procedure of the contact failure can be explained by the trace of penetration depth change of nano-indetner and SEM images of the micro-contact surface.

1. INTRODUCTION

Radio frequency (RF) microelectromechanical system (MEMS) switches have become the promising devices due to their advantages such as higher off-impedance, higher isolation, lower insertion loss, and lower power consumption than conventional semiconductor switches [1]. With its various advantages, it is expected to use in field of telecommunication, aerospace, defense application, *etc* [2]. However, RF MEMS switches have not been in commercialization to date due to the reliability problem induced by surface degradations such as melting, wear, contamination, surface smoothening, contact resistance increasing [2-4], *etc*.

In this study, a nano-indenter was modified to simulate hot switching of RF MEMS switch and investigate the contact reliability. The reliability of Au-to-Au contacts was characterized under various applied current. The change of the penetration depth was measured by nano-indenter and the contact surface was also analyzed by SEM to explain the contact behaviors.

2. EXPERIMENTS

2.1. Experimental setup

The apparatus for contact reliability test was prepared by modifying a nano-indenter (NanoTest, Micro materials Ltd.). A small spherical ball tip (diameter = 1.5 μm, SUJ2) and 1 mm dry-oxidized Si wafer (100) for flat sample substrate were used to simulate actual MEMS switch contact area.

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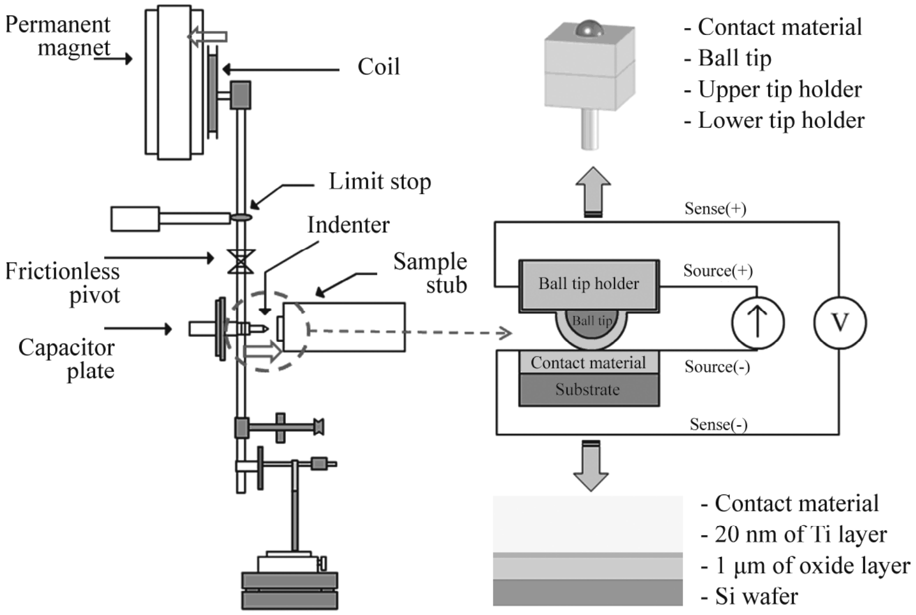

Fig. 1. Schematic layout of the experimental setup.

The ball tip and the flat substrate were wired to measure contact resistance by 4-wire measurement method. Constant current is applied via current supply (Keithley, Sourcemeter 2400), and the voltage drop across the micro-contacts is amplified for the measurement. The contact resistance and the contact force measured by the nano-indenter were acquired simultaneously (see Fig. 1).

2.2. Contact material preparation

To investigate the contact behaviors of the Au-to-Au electrical contacts, thin film of Au as contact material was deposited on the ball tip and the Si wafer at the same time. DC sputtering was used to deposit thin film layers with 20 nm of Ti as adhesion layer, followed by 500 nm of Au and the sputter power was 300 W (312 V, 0.97 A for Ti and 550 V, 0.54 A for Au). The working pressure was 0.7 mtorr with Ar gas flow of 15 sccm. The measured root mean square (rms) roughness of the surface was 3.75 nm, and sheet resistance was 0.08 Ohm/sq.

2.3. Reliability test of Au-to-Au contacts

The contact reliability test was conducted to investigate electrical contact behavior by contacting the ball tip on the same position of the flat substrate surface repeatedly. In order to characterize the Au-to-Au contact reliability, change of the contact resistance between the micro contacts was measured. Also, the number of cycles to break electrical contact is defined as indicator of the contact reliability.

The ball tip was brought to the flat substrate for electrical contact at a constant loading rate of 2 mN/sec until a maximum target load of 0.8 mN was reached. The maximum load was held for 5 seconds and then the contact was unloaded at the same rate of loading. The contact resistance is acquired and averaged when the loads were holding at maximum (see Fig. 2). The applied current was varied from 10 mA to 500 mA to specify current handling effect.

3. RESULTS AND DISCUSSION

3.1. Contact reliability

The electric contact between the Au coated ball tip and flat substrate was permanently broken after certain switching cycles. Fig. 3a shows the change in contact resistance with switching cycles of flowing 80 and 100 mA. The electric contacts could not be made after 78 times and 42 times in case of applied current of 80 and 100 mA, respectively. In light of previous reports [4,5], the contact was exponentially increased just before the failure. In this study, however, the contact resistance was just slightly increased and finally broken. This might be due to the high current compared with previous reports. Thus, the contact surface is rapidly degraded, followed by contact failure.

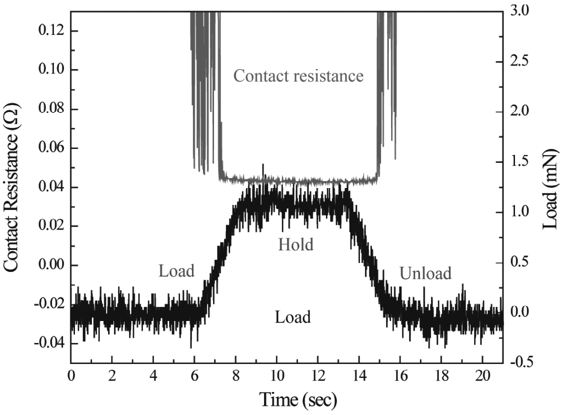

Fig. 2. Contact resistance and load change of one contact cycle.

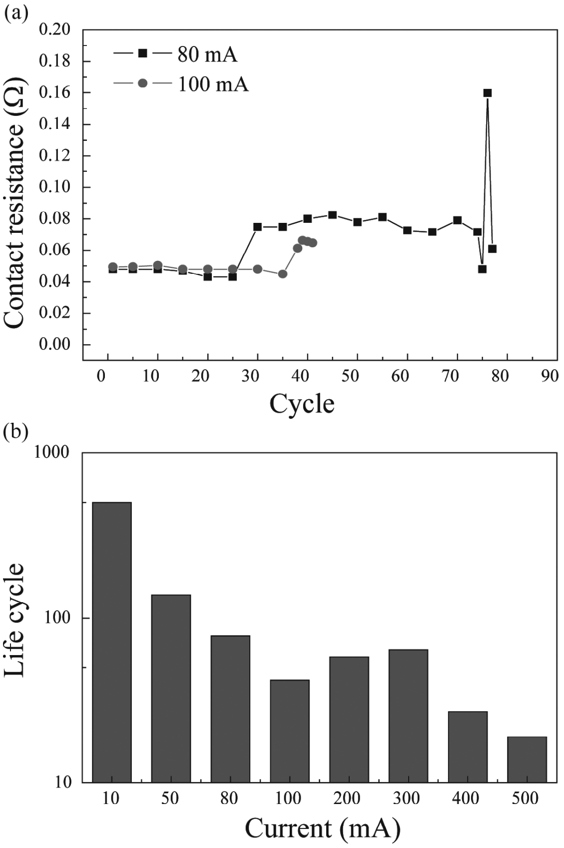

Fig. 3. (a) Contact resistance change during contact cycle at 80 and 100 mA. (b) Life cycle of Au contacts varying current 10 to 500 mA.

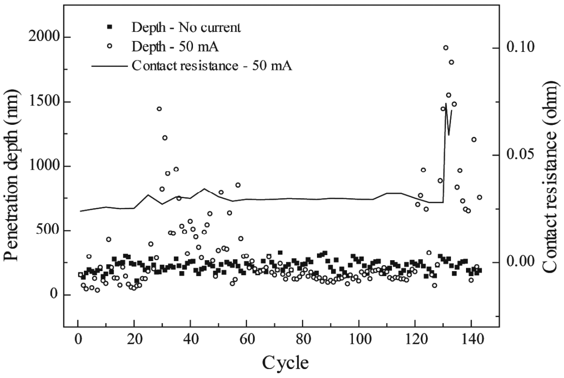

Fig. 4. Penetration depth and contact resistance change during contact cycle at 50 mA.

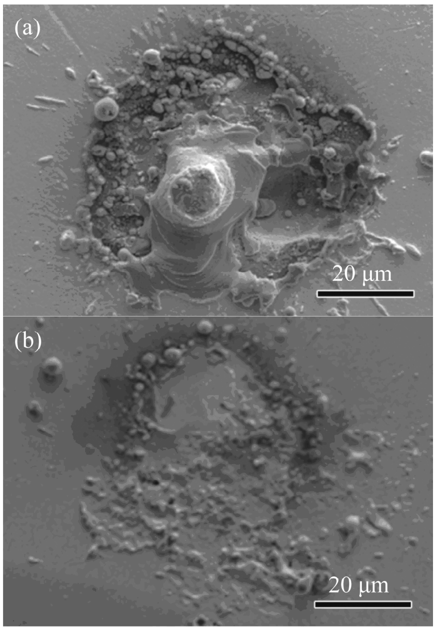

Fig. 5. SEM images of contact area degradation at 100 mA, (a) ball tip surface and (b) Sample surface.

In Fig. 3b, the life cycles of electric contact varies with applied currents ranging from 10 to 500 mA. In the case of 10 mA, electrical contact is made over 500 cycles without failure while only 19 cycles made at 500 mA. In short, current plays an important role in determining reliability, life cycle of contacts are decreased rapidly as the current increased. Au-to-Au contacts cannot warrant in high current handling condition.

3.2. Contact failure

Fig. 4 shows contact resistance and the penetration depth of the tip contacting on the flat substrate surface within the life cycle of flowing current of 0 and 50 mA. In the case of no current applied on the switching test, there was no remarkable change in the penetration depth. On the other hand, when the 50 mA of current applied through the contacts, several irregular penetration depths peaks were detected and the contact resistance is also changed at the same region. The measured irregular penetration depths were above 500 nm. By analyzing the loaddisplacement curves via the nano-indenter, these irregular displacements was plastic deformation between the ball tip and flat substrate; it may caused by abrupt micro-contact surface melting due to accumulated joule heat induced by applied current. Except for the irregular region, the contact showed elastic deformation, and typical depth was about 200 nm. If we assume these surface deformations causes decreasing in the contact area and breaking of electric contact, the existence of above irregular peaks could be indicators of contact failure. It may assist expecting life cycle and analyzing electric contact behaviors.

Fig. 5 presents SEM images of contact area of (a) ball tip surface and (b) substrate surface after switching test failed at 42 cycles at 100 mA. The local surface was melted by high current during the contact, and then the contacts were broken. The melted contact region was deformed and pulled off above the original flat surface. This pulled-off asperities lead to decrease of contact area and finally the contact was permanently broken.

4. CONCLUSION

The electrical contact behaviors of RF MEMS switch is investigated by using a modified nano-indenter; Au-to-Au contact life cycle test was conducted to characterize contact reliability.

During the cyclic hot switching test, failure occurred by breaking electrical contact and increasing of contact resistance. Electric current affected on the contact reliability; the Joule heat induced by current had melt and deforms the contact surfaces. It causes decreasing of contact area, followed by increasing contact resistance and breaking electric contact. The procedure of the occurring failure is explained by change of penetration depth, the irregular peaks indicated the deformation of the contact surface during the test. It could be a powerful method to characterize contact behaviors of RF MEMS switch contact materials with precise depth profile of nano-indenter.

ACKNOWLEDGEMENTS

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