ABSTRACT
A micro-tribotester has been designed and fabricated to evaluate friction and wear on lateral contact surfaces of silicon materials. In the design of the tribotester, FEM analysis was used to find the resonant frequency and elastic displacement of the device under electrostatic excitations. The micro-tribotester was fabricated with a standard bulk silicon process. Static and dynamic friction tests were done on the fabricated device under various DC and AC stimulation conditions. From the measured maximum deflections of the detecting beams in the loading and sliding directions, static and dynamic friction coefficients of contacting sidewalls have been obtained. Characteristics of tribological behaviors in MEMS were discussed.

INTRODUCTION
Tribological reliability has become a major hurdle towards wide application of silicon-based MEMS devices [1]. Because most of the microsensors and microactuators are fabricated by using planar or bulk semi-conductor manufacturing process based on silicon materials, almost all rubbing failures in MEMS devices happen on the underside or side contacting surfaces [2]. This feature, in addition to the large surface-to-volume ratio and small scale, gives rise to some technical difficulties and restrictions on testing and modification of tribological properties of MEMS devices. Commercial tribometers, such as pin-on-disc tester and AFM/FFM, are hardly applicable to the situations of sidewall friction in MEMS.

To physically simulate and test friction and wear occurred on side contacting surfaces in MEMS, a micro-tribotester has been designed and fabricated in this study. Static and dynamic friction test results are presented to show the capability of the tribotester.

DESIGN AND FABRICATION
As shown in Fig.1(a), the designed tribotester consists of two disconnected comb-drive shuttles, A and B, which are arranged to be perpendicular to each other in a plane. Each shuttle has an extended arm in its movable part, suspended by three pairs of beam laterally. In the uncharged state, there is a gap, 3µm as designed, between the extended arm of shuttle A and the tip of the arm of shuttle B (see Fig.1(b)). Based on the model of electrostatic comb-drives, the sidewalls of the tip end of shuttle B and the extended arm of shuttle A can get into touch when a 30V DC voltage is applied on shuttle B. If the applied voltage is higher than 30V, the arm of shuttle A will bend under the action of shuttle B. The acting force can be adjusted by tuning the electric potential applied on shuttle B, and experimentally obtained from the deflection of the arm of shuttle A. In the same way, the frictional force acting on the contact can be derived from the measured deflection of the arm
of shuttle B. To facilitate the measurement of the deflections of the extended arms on a digital microscope, a stationary reference block is incorporated at the sides of the arms. The normal force and frictional force at the contact can be got through the relative movements of A and B to the stationary reference block.

The micro-tribotester was fabricated with a standard bulk MEMS process. The fabricating process includes four main steps. Firstly, wet etching of silicon wafer was used to make shallow cavities on the top of the wafer. Secondly, Cu electrodes were produced on the top surface of the glass substrate through sputtering and lift-off processes. Thirdly, the top surfaces of silicon wafer and glass substrate were bonded together with the aid of electrostatic force. Finally, ICP (Inductively Coupled Plasma) etching was used to create the comb-fingers and other suspended beam structures of the tester. Figs of 2 (a) and 2 (b) show the SEM photos of the whole tester structure and the magnified local testing part respectively.

**EXPERIMENT RESULTS**

Static friction test was done on the fabricated micro-tribometer by gradually elevating the electric potential, $V_A$, applied on the shuttle A while keeping the voltage, $V_B$, applied on shuttle B as constant. The normal force and frictional force were derived from the measured deflections of the arms of shuttles A and B. Fig. 3 shows the variation of the ratio of frictional force to normal force with the driving voltage on shuttle A in the case of $V_B=40V$. When $V_A$ is less than 35V, frictional force increases with $V_A$ monotonically, and no relative slip occurs between the arms. At the point of $V_A=35V$, springback force overcomes frictional force, resulting in a sudden slip between the arms and a drop in the curve. Beyond the point, frictional force goes up with $V_A$ again. The maximum value of the ratio, 0.9, can be taken as the static friction coefficient.

Dynamic friction test was performed on the tribotester by setting shuttle A to work in its resonant state. Frictional force was measured under different normal forces (see Fig.4). The dynamic friction coefficient obtained in the experiment is in the range of 0.25-0.3.

**CONCLUSIONS**

The following conclusions can be drawn from the study:

1. The tribotester is capable of simulating the friction and wear occurred on side contacting surfaces in MEMS.
2. The measured static friction coefficient is 0.9. Stick-slip was observed during static friction test. Dynamic friction coefficient of the silicon pair is in the range of 0.25-0.3.

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**REFERENCES**