

Measurement of friction force between two mica surfaces with multiple beam interferometry

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Abstract. Friction forces play a crucial role in the tribological behaviour of micro-components and the application of MEMS products. It is necessary to develop a measurement system to understand and control the material characteristics. In this study, a microscopic measurement system based on multiple beam interferometry is developed to measure the friction force between two mica thin films. Some frictional behaviour between the two mica sheets in contact are reported. The evaluated shear strength of mica agrees well to the existing data. It is possible to use the developed system for micro-tribology study.

1 Introduction

In nano-scale, physical and mechanical properties of materials will show a significantly different characteristics and phenomena. The establishment and use of precision measurement technology and system become an important part to understand and to effectively control the materials, structures or installations in nano-scale. Friction forces play a crucial role in the tribological behavior of micro-components and the application of MEMS products. It is necessary to develop a measurement system to understand and control the material characteristics.

Various techniques such as Auger and X-ray photoelectron spectroscopy, scanning electron microscopy were coupled with tribometer to study the contact between two shearing surfaces in ultrahigh vacuum. Vibrational spectroscopy and X-ray diffraction were coupled with friction experiments in ambient conditions. Multiple beam interferometry (MBI) is regularly used for measuring film thickness and refractive index. Israelachvili and Tabor [1] modified one of the earlier force-measuring apparatuses to enable two surfaces to be slid parallel to each other, and allowed the measurement of the boundary friction between two mica surfaces whose exact contact area was known. Homola et.al.[2] improved the lateral sliding device that allows the load can be varied during sliding and negative loads can also be applied. Further use of MBI for in situ imaging of shearing contacts of two shearing surfaces at the same time as friction forces are measured was reported [3].

In this paper, a microscopic measurement system based on multiple beam interferometry is developed to measure the friction force between two mica thin films. Image processing software is developed to analyze the FECO images to determine the contact area. A double cantilever spring with a micro-displacement sensor is designed to measure the friction forces between the two mica thin films. The evaluated frictional coefficient of mica is compared to the existing data. The applicability of the system is validated.

2 Method and theory

2.1 Multiple beam interferometry

A schematic setup of multiple beam interferometry system is shown in Fig. 1. The white light source inject into the two cylindrical mica sheets perpendicularly. Two cylindrical axes of the mica sheets are orthogonal, and each piece of mica should be coated with a 4~6 μm layer of silver film. When the light has interference in the two highly reflective silver films by multiple reflection, the wavelength of transmitted light is related to the thickness and refractive index of the material passed through. After the light passes through two mica sheets, it injects into the slit by a right-angle mirror and sampled by a spectrometer. In the spectrograph, as shown in Fig. 2, one can see the bright fringes which are called the fringe of equal chromatic order (FECO). The vertical pixel in FECO image corresponds to the actual location of the lateral position of the mica sheets. As the mercury light passing through the spectrometry, its spectral lines have a fixed wavelength and can be used to correct the horizontal direction out of FECO images of the relationship between pixel location and wavelength. In general, the film thickness and the refractive index can be obtained by analyzing the FECO images using fast spectral correlation method. For friction study, the contact length or area can be measured from the FECO image after calibration of the pixel distance.

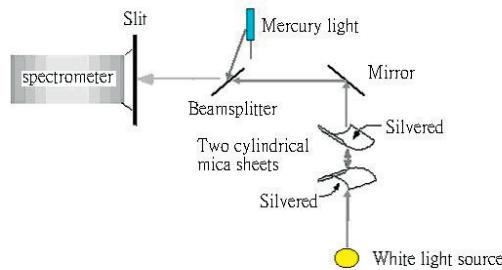


Fig. 1. Schematic setup of multi-beam interferometry system.

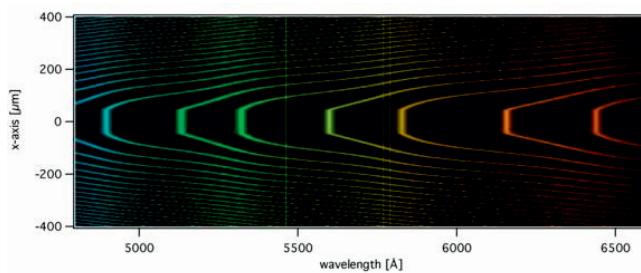


Fig. 2. Typical image of fringe of equal chromatic order (FECO).

2.2 Theory of friction

Generally, the mechanics of two initially curved bodies in contact can be regarded as Hertzian or non-Hertzian. In Hertzian type, the contact surfaces of two elastic bodies are considered molecularly smooth, and would separate freely at zero contact area and load. Johnson et. al.[4] extended the

Hertz theory to two adhering solids by including surface energies in their formulation. However, in reality, not molecularly smooth surfaces are forced together, the surfaces first touch at the tips of the asperities which initially deform elastically. As the surfaces slide past each other, there is a transverse resistance to the motion, called the friction F . Assuming there is no adhesion at zero load, the friction is given as

$$F = \mu T \quad (1)$$

where μ is the coefficient of friction, T is the externally applied compressive load.

Bowden and Tabor [5] extended the law of friction to the case where the friction is dominated by adhesive contacts. The model postulates that the friction arises from the forces required to shear the adhesive junctions, given as

$$F = S A \quad (2)$$

where S is the critical shear stress at the contacting surface, A is the molecular contact area. Apparently, the frictional force is not proportional to the load.

3 System configuration

The experimental system constructed to measure the frictional force is shown in Fig. 3. The system contains a white light source, a multi-beam interference system based on two mica sheets, a spectrometer to generate spectrograph and a PC-based image processing systems for data processing. The multi-beam interference system consists of the structure ontology, motorized translation stage and piezoelectric translators for coarse and fine movement of mica sheet, two silica lens with mica sheet adhered on the surface. The two mica sheets were placed in two lens holder and form symmetric three-layer interference (mica-air layer under test-mica). The white light passing through an optical access and is launched into the multi-beam interference system with air between two mica sheets. The light emerging from the multi-beam interference system is guided into a spectrometer and the produced FECO fringes were grabbed by the image processing system for further processing to determine the contact area.

The frictional force measuring device is enlarged as shown in Fig. 3. The top mica sheet holder is fixed at the bottom of two thin spring plates which are connected to a U-shaped mounting frame, and the bottom mica sheet was fixed. The mounting frame is fixed on a precision motorized translation stage having a measurement range of 80 mm and resolution of 0.16 μm . The spring constant of the frame was analyzed by using ANSYS and calibrated by inductive sensor using dead weight. The

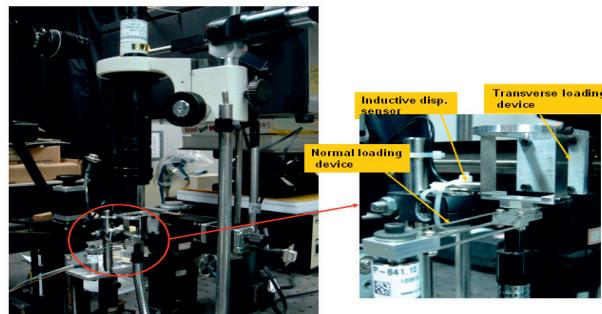


Fig. 3. The experimental system constructed to measure the friction force.

experimental data compared to the numerical ones is shown in Fig. 4. The spring constant was determined as 3020 N/m. The transverse motion of the mounting frame and thus the top mica sheet is initiated by the translation stage. The transverse movement of the top mica sheet was measured by using an inductive displacement sensor having a measurement range of 1 mm and an accuracy of 0.4 μm .

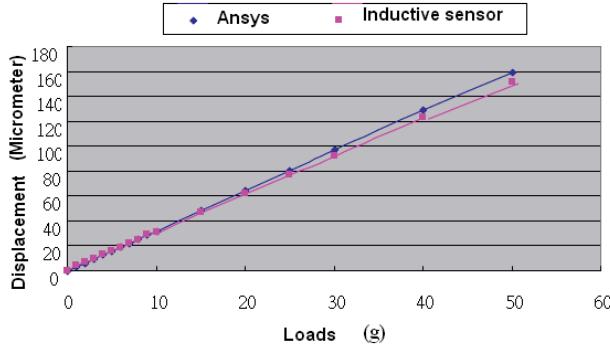
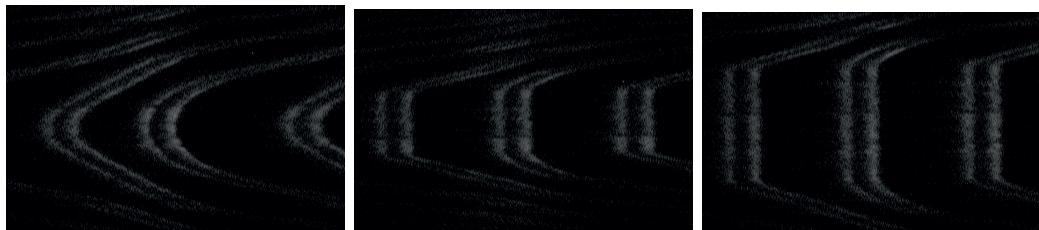


Fig. 4. The frame displacements obtained by using ANSYS and inductive sensor for calibration of spring constant.

4 Experimental results and discussion

During the experiment, the speed of translation stage was set to $1\mu\text{m}/\text{s}$. Fig. 5 shows the FECO images of the two mica sheets in contact due to adhesion force and a normal force of 15mN, respectively. The displacement of the top mica sheet was measured by the inductive sensor. When the translation stage began to move, the top mica sheet was retarded initially by the adhesion force between the two mica sheets. As the relative displacement is increased and the spring force overcome the maximum friction force, the top mica sheet started to slide and the friction force between the two mica sheets started to decrease gradually. The friction force is determined by multiplying the spring constant to the relative displacement between the translation stage and the top mica sheet. Fig.6 shows the determined friction forces verses the displacements measured from the translation stage. The maximum friction force is 102 mN. The friction force under various sliding speeds was also measured as given in Fig. 7. It can be seen that the friction force does not vary much as the sliding speed increased. Further measurement of friction forces under various normal load from 0 to 20 mN by adding 2.5 N each time between the two mica sheets. Fig. 8 shows the determined friction force verse the contact area. The shear strength S was determined as $2.3 \times 10^3 \text{ N/cm}^2$, which is close to the value, $2.5 \times 10^3 \text{ N/cm}^2$, given in reference [2].



(a)Separated by 70 nm (b) Contact under adhesion force (c) Contact under a 15 mN normal load

Fig. 5. Experimental FECO images of the two mica sheets under various contacts.

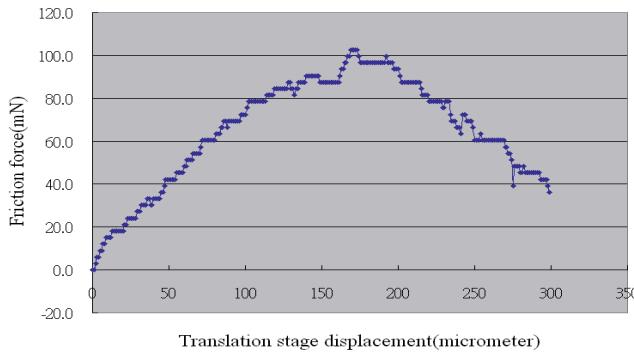


Fig. 6. The determined friction forces verses the displacements measured from the translation stage.

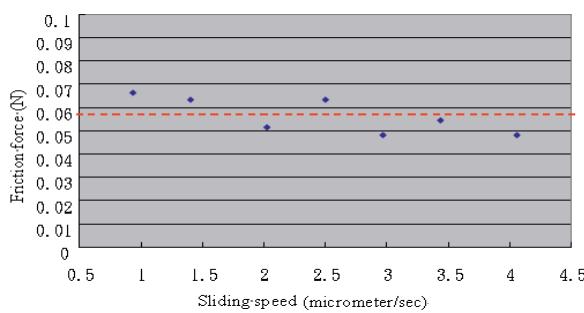


Fig. 7. Friction force measured under various sliding speeds

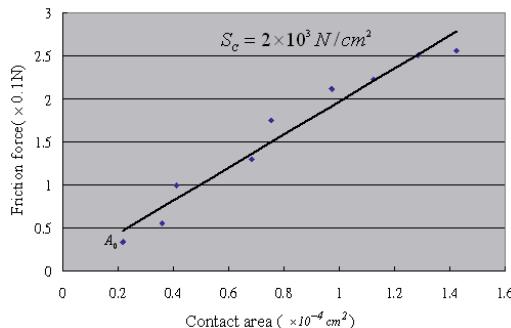


Fig. 8. Friction force measured under various contacting areas under a normal load from 0 to 20 mN.

5 Conclusion

A microscopic measurement system based on multiple beam interferometry is developed to measure the friction force between two mica thin films. The frictional behaviour between the two mica sheets are reported. The evaluated frictional coefficient of mica agrees well to the existing data. It is possible to use the developed system for micro-tribology study.

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References

1. Israelachvili, J. N., and Tabor, D. "The shear properties of molecular films," Wear, 24 (1973)
2. Homola, A. M., Israelachvili, J. N., Gee, M. L., McGuigan, P. M., "Measurement of and relation between the adhesion and friction of two surfaces separated by molecularly thin liquid films, "J. tribology , 111,(1989)
3. Golan , Y., Drummond , C., Israelachvili, J. N., Tenne, R., "In situ imaging of shearing contacts in the surface forces apparatus",Elsevier Science (2000)
4. Johnson, K. L., Kendall , K., and Roberts, A. D., Proc. R. Soc. London A 324, 301(1971)
5. Bowden, F.P.,and Tabor, D.,Friction and lubrication, Latimer Trend & Co.,Ltd., Whitstable, (1967).