ADHESION PHENOMENON AND ITS APPLICATION TO MANIPULATION FOR MICRO-ASSEMBLY

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ABSTRACT

Adhesion phenomenon is more significant for smaller objects, because adhesional force is proportional to size of the objects while gravitational force is proportional to the third power of it. For the purpose of micro-assembly, theoretical understanding is required for the Adhesion phenomenon.

Authors have developed a force measurement system in an ultra-high vacuum chamber of Auger electron spectroscopy. The force between arbitrary combination of materials can be measured at a pressure less than 100 nPa after and before Ar ion sputtering and chemical analysis for several atomic layers of the surface. The results are successfully interpreted with a theory of contact mechanics. Since surface energy is quite important in the interpretation, electronic theory is used to evaluate the surface energy.

In the manipulation of small objects, the adhesional force is always attractive. Repulsive force is essential for the manipulation. It can be generated by Coulomb interaction. The voltage required for detachment is theoretically analyzed and the effect of boundary conditions on the detachment is obtained. The possibility and limitations of micro-manipulation using both the adhesion phenomenon and Coulomb interaction are theoretically clarified. Its applicability to nano-technology is found to be expected.

KEYWORDS

Force curve, manipulation, micro-electro-mechanical systems (MEMS), Coulomb interaction, dielectric detachment, boundary element method (BEM)

1. Introduction

Micro-electro mechanical systems (MEMS) has been recently more and more required to breakthrough the limitation of conventional packaging technology. Down-sizing without consideration based on physics gives neither effective performance nor knowledge for further applications. Theoretical understanding for the adhesion phenomena is required to optimize and/or breakthrough the process of micro-assembly.

2. Force Measurement System

Author has constructed an original force measurement system in ultra high vacuum (UHV) chamber of an Auger electron spectroscope (AES)[1]. The force between arbitrary combinations of materials can be measured. Before and/or after the measurement, surface several atomic-layers can be analyzed by AES. Secondary electron microscopic (SEM) image can be observed. And also heating is available. Force curves can be obtained by the system. Fig.1 shows schematically the system designed. Semiconductor transducer is used as a force sensor. The sample pin is put at the terminal of the sensor by using a few electro-conductive paste. Since the paste can be dissolved in acetone, the sample pin is exchangeable. The system consists of four parts; the transducer block, the carrying holder, the signal output probe which are shown in Fig.1 (a), and the external signal output unit is shown in Fig.1 (b). The transducer element is attached on the transducer block and is introduced with the

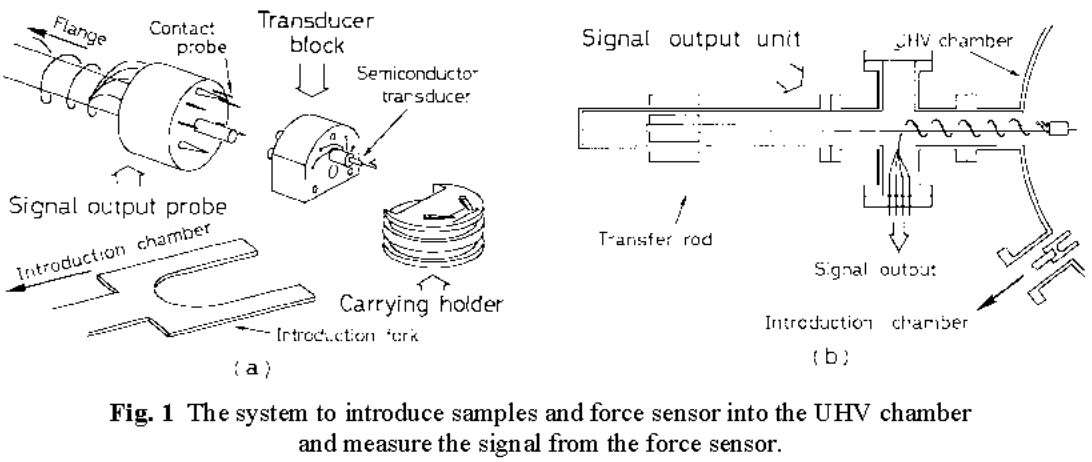

Fig. 1 The system to introduce samples and force sensor into the UHV chamber and measure the signal from the force sensor.

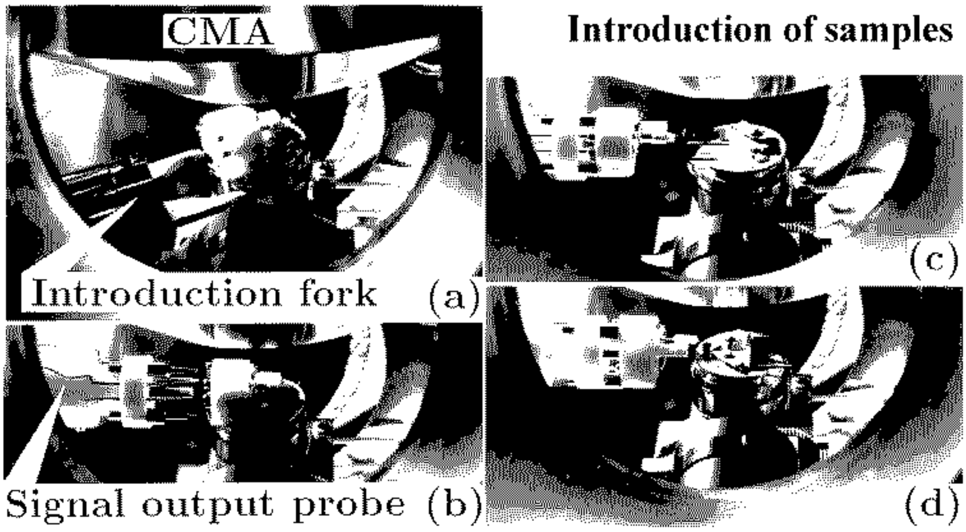

Fig. 2 Photograph of operation. Introduction of samples and sensor into the UHV chamber of AES

carrying holder from the introduction chamber to UHV. Then, transfer rod is moved so that the transducer block is caught by the signal output probe. And the holder is manipulated so that the sample disk on the holder contacts with the sample pin connected to the transducer. Electrical junctions between the block and the probe are achieved by the contact probes. The operation can be seen in the Fig.2.

3. Valence Auger electron spectroscopy (AES) analyses

Usually AES is used for the detection of the elements at the several atomic layers of surfaces. The valence Auger spectra also have information on the chemical interaction [2~5]. For example, in the analysis of Si samples, we can easily identify oxidized silicon from non-oxidized one. Heating and Ar ion sputtering also change the chemical state of the surface. AES analysis can be carried out, fefore and/or after the force measurement between arbitrary combinations of materials.

4. Interpretation of force curves to evaluate surface energy

The force curve has a significant information on the surface. Author has proposed theories to interpret them [6,7] and suggested how the force measurement system should be designed to obtain the information from the surfaces [8]. The interpretation suggests us the property of sample materials, such as work of adhesion. The work of adhesion can be defined from surface energy. Author has proposed a simple formula for the surface energy based on quantum mechanics [9]. At first, it has treated as the simplest theory. Recently, it is found that the formula gives a good approximation rather than density functional theories (DFT)[10]. These theories are based on a jellium approximation. The effects of atomic orientation on the surface and interfacial energy can be evaluated by molecular mechanics. The reliability of molecular mechanics calculation depends on the reliability of inter-atomic potential energy. Authors has been examined the applicability of an embedded atom method (EAM) to surfaces and interfaces [11,12]. The reliable measurement of the surface and interfacial energy is very difficult, because it is very sensitive to the surface contamination. Both theoretical approaches and experimental approaches are essential for the purpose of interpretation of the force measurement.

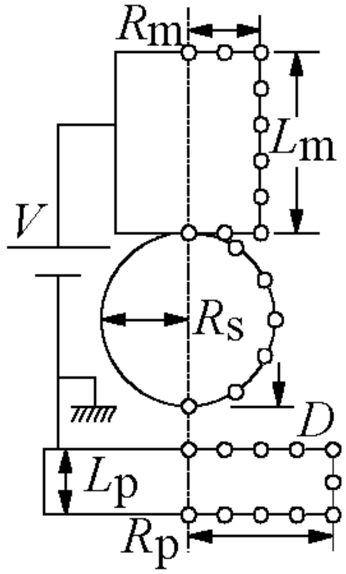

Fig.3 Schematic illustration of model used

5. Application to micro-manipulation

Above theoretical estimation of material constants is essential also for prediction and control of micro-manipulation. The adhesion phenomenon can be used for manipulation of small objects. For the purpose of manipulation, repulsive forces must also be generated. Author has used boundary element method (BEM) to evaluate the

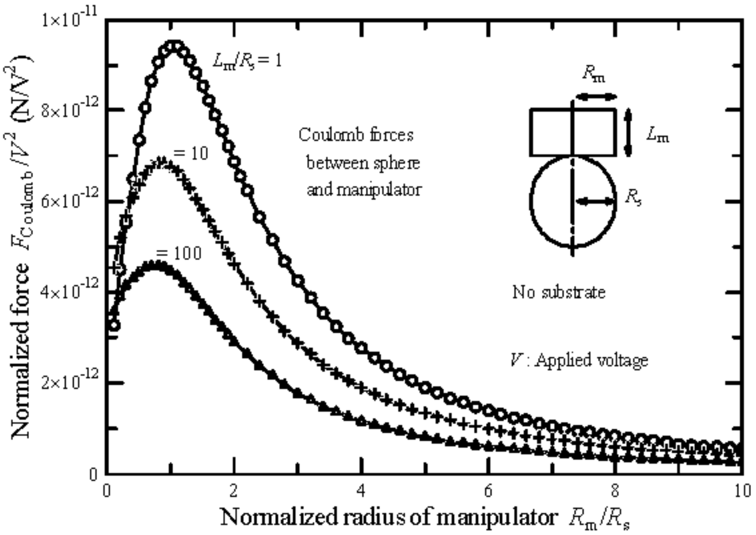

Fig.4 Without substrate, the force is maximal around R_m=R_s. Optimal shape of manipulator exists.

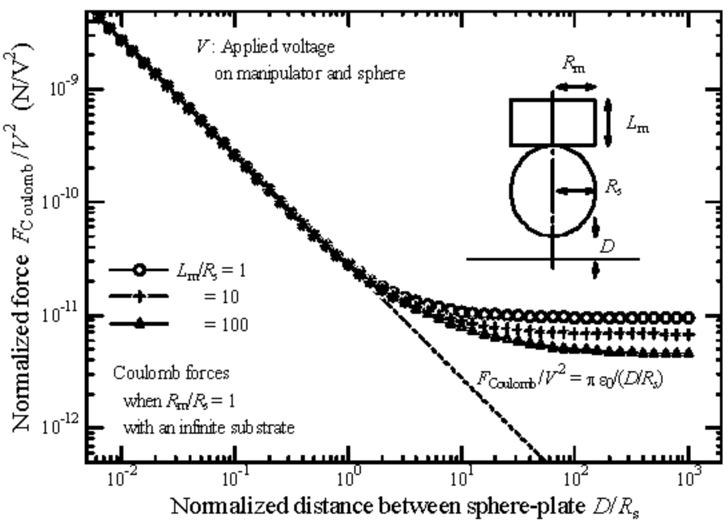

Fig. 5 The effect of the gap between manipulating object and substrate.

forces generated by Coulomb (dielectric) interaction. And the voltage required for detachment is expressed clearly [13]. Fig.3 shows a schematic illustration of the model used. The system consists of three objects; i.e., a manipulating probe, a spherical particle, and a substrate plate. The manipulator and the plate are cylindrical, and axial symmetry is assumed. As shown in Fig.3, the spherical particle is held in point contact with the manipulator by the adhesion phenomenon. All the objects are conductive. Therefore, the voltage applied to the manipulator and the spherical particle is equal to each other, and the voltage of the plate is zero.

Fig.4 shows the results calculated for the substrate-less system. The force is maximal around R_m=R_s . It suggests that the radius of the manipulator should be same in size with the object to manipulate in order to generate large repulsive forces. Fig.5 shows the effect of the gap distance on the dielectric repulsive force. As can be seen, the force increases as the gap distance decrease. It suggests that the precise cotrol of the gap distance is important to generate large force. An asymptote is obtained and it is good approximation for the gap less than the radius of object.

The attractive force can be evaluated, and the repulsive force can be evaluated by the asymptote. The necessary condition for manipulation by both adhesion phenomena and Coulomb interaction is clearly expressed in a diagram as show in Fig.6. The threshold between "release" and "hold" depends on the work of adhesion.

Theoretical approaches [9] suggest the work of adhesion is in the order of 1 (J/m^2) and if there exist the effect of surface roughness and/or surface contamination, it would be in the order of 0.01~0.1 (J/m^2) or less.

6. Conclusion

Theoretical approaches based on physics are essential for the micro-manipulation. Any theory must be examined by experiments which are done in well defined conditions. Both theoretical and experimental approaches are essential for the optimization and the breakthrough of the limitation of conventional technology such as packaging. In the present paper, I have summarized and introduced the strategy of our approaches. Original force measurement system constructed in UHV chamber of AES. Though the interpretation of the force curves, our contact theories give the information on the surface and interfacial tension of the sample materials. Quantum theory and molecular mechanics approaches give the information on temperature dependence and crystalline effects on surface and interface. Finally, they can be applied to micro-manipulation for the next packaging technology in the future.

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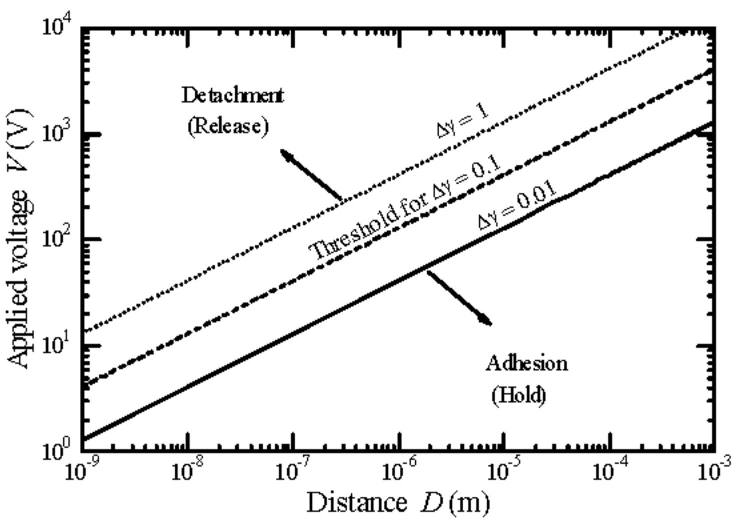

Fig. 6 Diagram which exhibits the region of boundary condition where the manipulation is possible by both adhesion phenomena and Coulomb interaction.