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Implementation of Graspless Handling System for Microparticles using AFM Probe

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Abstract— **Physical size of semiconductor components has been reduced and device density has become increased especially during for last years. As a result of this the use of various high precision manipulatable robot systems becomes norm in the industry. Normally the high precision robot system consists of precision staging system, small scale end-effector system, and highly sensitive autonomous sensing system. One of the most popular micromanipulation tasks might be handling of micro-scale objects on a surface. Although many functional aspects and constraints should be considered when the system is constructed, a key concern for the system design is level of dexterity of the manipulator especially when size of the objects to be handled and spatial resolution of the manipulator become smaller than micron or nano scale. And stiction effect has appeared since a micro-contact mechanics phenomena affects more primarily than inertial force in the high precision robot system. Thus a theoretical study has to be developed on a micro-contact mechanics phenomena. In this paper, the organized system is equipped with an omnidirectional accessible manipulation system with a new visual feedback system. Thanks to the enhanced dexterity of the system, in this paper, microparticle stiction problems that could happen to most of small object handling also can be resolved.**

I. INTRODUCTION

Semiconductor components have been sub-miniaturized and become high device density integration during last few years in order to put more number of user options and convenient features onto a small sized components. Therefore, production lines of semiconductor components are required to have high precision robot systems with a micro or nano level[1]. For instance, the size of semiconductor chip has been minimized and a gate length became several tens of nano meters. Therefore alignment of a photo mask becomes an important issues in photo lithography process[2]. And dust removal of photo mask became more important issue. Besides, Nanoimprinting undertaking to overcome a limitation of photo lithography process is needed to have within 10nm errors of stamp alignment[3]. Also flip chip package which is one of a method of semiconductor packagings are required to be able to handle solder bump in order to get high rate of yield in a production line[4]. Alignment of electric-optical modules in optical circuit boards[5] and micro mirror production equipment for displays[6] are the typical examples for the application area. High precision robot system which is able to operate a micro or nano levels consists of precision staging system, small scale end-effector system, and highly sensitive autonomous sensing system. At first, in precision staging system, sending particles and end-effecter to target point are conducted. Secondly, manipulation method such as grasp or graspless, shape of manipulator, and operation method are considered with a particle in end-effecter system. Besides adhesion phenomena of a particle and manipulator has to be considered to handle several tens of μm or less particle. Thirdly, it is essential to have feedback of coordinate or contact information of manipulator and particle through autonomous sensing system such as vision and force sensor.

Therefore, the objective of this paper is to implement high precision robot system considering constraint and design condition so that it is applied to production lines. Then the implemented high precision robot system which was carried to target point using tens of μm particle will be verified.

Metin Sitti at the Carnegie Mellon University has researched to implement high precision robot system. He used $4.5\mu m$ polystyrene(PS) sphere as particle. And he has implemented visual feedback system using microscope. Also he succeeded to push several particles to target point with graspless method using AFM probe using a piezo stage having 3 translation degree of freedoms. He attached a particle using adhesive force on the lower part of transparent glass slide to avoid interference of manipulation tip and vision camera. It is possible to avoid the interference of manipulation tip and vision system. But in real production lines, a particle and vision camera are located in the same direction. Thus it is difficult to apply to real production lines[7]-[9].

Ning Xi at the Michigan State University has also implemented force feedback system using 200nm latex as a particle. He predicted the coordinate information of particle based on contact information from force feedback system. And he succeeded to push a particle to target point with graspless method using AFM probe mounted on piezo stage having 3 translation degree of freedoms. But when pushing speed of manipulator gets faster, it is possible for a particle to be bounded toward unexpected direction. In this case the contact information will be lost and it is needed to conduct scanning again to get coordinate information of a particle[10]-[11].

Therefore, our system conducts with following method to make up for drawback of those two systems mentioned. visual feedback system is implemented for a modified coordinate information when a particle is bounded toward unexpected direction. Also vision camera and manipulator are put on the upper part in order to apply to real production

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system in the future. Finally, manipulation tip implements an omnidirectional accessible manipulation system to keep off the interference in transport path of particle.

In this paper, theoretical approaching of adhesion phenomena in several tens of μm or less particle and non-stick condition will be introduced in section II. And next section will deal with the implementation of high precision robot system with two design conditions. In section IV, the result of carried particle using our system will be dealt with. In final section, there are our conclusions and future work.

II. Theoretical Approaching of Adhesion Phenomena

A. Component of Contact Forces

In case of handling particle whose size is several tens of μm or less, contact forces become bigger than inertial force between manipulator and particle. Thus it will happen for those particle to be stuck to manipulator while handling. Accordingly it is essential to verify whether manipulation is possible or not after calculating contact forces of manipulator and particle. Generally contact forces consist of electrostatic force, capillary force, and van der waals force. Three components of contact force are explained in the following sections[12]-[14].

1) Electrostatic Force: Electrostatic force occurs from the difference of electric charges between two objects. But if a distance between two objects is less than 1nm, an electro tunneling might happen. Thus the difference of electric charges will be disappeared. The kind of AFM probe is the contact mode and non-contact mode. Considering that manipulator used in system is contact mode AFM probe, the distance of particle is 0.4nm(atomic constant distance)[15]. Therefore electrostatic force will be ignored.

2) Capillary Force: Capillary force occurs from surface tension of fluid layer between two objects. When humidity is over 40% and in case of hydrophilic objects, capillary force becomes stronger[15]. However, the humidity of our system condition is less than 40% also manipulator and particle are hydrophobic objects, thus capillary force will be ignored as well.

3) Van der Waals Force: Van der waals force is the smallest force among those three components, but in our system it is the most important component of the contact forces. Van der waals force is a function of contact area, contact distance, and material property like (1)-(2). Equation 1 is relation between flat plate and ball contact. Equation 2 is relation between ball and ball contact.

$$F_{Plate-Ball} = \frac{AR}{6D^2} \quad (1)$$

$$F_{Ball-Ball} = \frac{A(R_1 \times R_2)}{6(R_1+R_2)D^2} \quad (2)$$

A stands for Hamaker constant, R is Ball Radius and D is contact distance. When the contact mode AFM probe is used, D becomes 0.4nm.

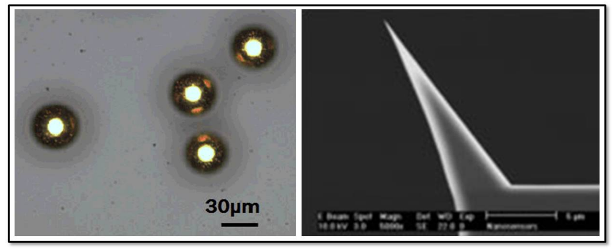

Fig. 1. Particles and Manipulator

B. Calculation of Contact Forces

As it was mentioned above, manipulator and particle were chosen for the use of contact mode AFM probe, maintenance of less than 40% of system condition humidity and the use of hydrophobic objects as a means of minimizing contact forces. AdvancedTEC contact mode AFM probe(Nanosensors) as a manipulator invented for high precision positioning was used like right side of Fig.1. Accordingly, vision camera could see end point of manipulator over side. Also gold coated 30μm polystrene(PS) sphere was used as a particle like left side of Fig.1.

The value of variable and geometry information used to calculate van der waals force are table I[16].

TABLE I
Hamaker Constant and Geometry Data

	Material	Hamaker constant(A)	Radius(R)
Particle	Gold coated(Au)	54.6×10^{-20}	$15\mu m$
Manipulator	Silicon(Si)	27.1×10^{-20}	$5nm$
Plate	Glass(SiO2)	5.7×10^{-20}	

When the materials of those two objects are different in the the air, A becomes (3)[17].

$$A_{1-Air-2} = \left(\sqrt{A_{1-Air-1}}\right)\left(\sqrt{A_{2-Air-2}}\right) \quad (3)$$

Relation between particle and plate is contact gold with glass, and relation between particle and manipulator is contact gold with silicon. Therefore Hamaker constant is calculated like (4)-(5) using (3).

$$A_{Particle-Air-Manipulator} = 38.5 \times 10^{-20} J \quad (4)$$

$$A_{Particle-Air-Plate} = 17.6 \times 10^{-20} J \quad (5)$$

Van der waals force is calculated like (6)-(7) using (4)-(5). Since van der waals force between plate and particle is bigger than it is between manipulator and particle like (6)-(7), thus the particle is possible to be manipulated without stiction between manipulator and particle.

$$F_{Particle-Air-Manipulator} = 2.0 \times 10^{-9} N \quad (6)$$

$$F_{Particle-Air-Plate} = 2.8 \times 10^{-6} J \quad (7)$$

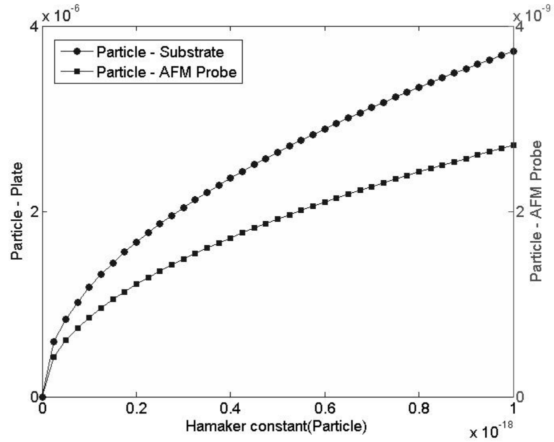

Fig. 2. Van der Waal Forces with Variation of Particle Material

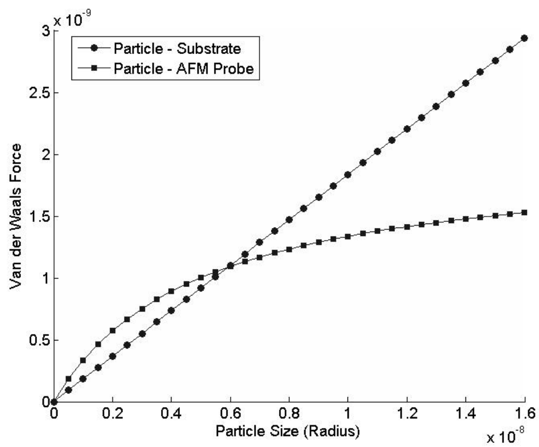

Fig. 3. Van der Waal Forces with Variation of Particle Size

When the material of particle was changed, hamaker constants and van der waal forces were changed as well. However the van der waal forces were not reversely changed like Fig.2.

When the size of particle was change, van der waal forces were changed as well. As it is shown in Fig.3 the van der waal forces were reversely changed at particular size of particle which is 5.9375nm(Radius).

In other words, any particle of a hydrophobic material and a radius bigger than 5.9375nm(Radius) can be manipulated without stiction.

III. EXPERIMENTAL SETUP

A. Autonomous Visual Feedback System

Visual feedback system was used for identification of coordinate information of manipulator and particle. The vision feedback system was implemented like Fig.4 using uprignt microscope(Olympus BX51 TRF) which makes objective lens can be located on the head part of particle in order to get exactly same conditions as real production lines. Resolution of digitizer(Vistek SVS 285) is 1360×1024. And a frame grabber used Matrox Helios series(Helios XCL).

Fig. 4. Layout of Omnidirectional Accessible Manipulation System with Visual Feedback System

Vision processing for coordinate tracking of manipulator and particle consists of following three procedures. First, filtering process has to be conducted to get high accuracy and efficiency of vision processing. Modified binary median filter which improved the processing time of median filter was used. It is a combination of binary processing and median filtering. Thus time complicity of the modified binary median filter is notably reduced compared to median filter. Detailed information of time complicity is given in table II[18]-[19]. Next, recognition process has to be conducted for a particle using a point correlation method. A mask which consists of 8 points was used to identify coordinate information of particle. Final process is to identify coordinate information of manipulator. The same point correlation method was used when identifying coordinate information of particle. However, this time, its mask consists of 16 points. Therefore total vision processing time is about 40ms(25Hz)[20].

B. Omnidirectional Accessible Manipulation System

As it was mentioned, particle and vision camera have to be located in the same direction in real production lines. If the system handling a particle has only translation degree of freedom on plane surface, an interference of manipulator and particle might happen like Fig.5. Therefore our system added one rotation degree of freedom into the 2 translation degree of freedom on plane surface to avoid the interference like Fig.6. In order to implement our system, motorized and piezo stage of Physic Instrument(PI) were used. M-

TABLE II
COMPARISON OF TIME COMPLEXITY

Method	Fream Scan	Sort Algorithm	Total
Region median filter(Bouble sort, Insertion Sort,Selection Sort)	$O(A \times B)$	$O(n^2)$	$O(A \times B \times n^2)$
Region median filter(Quick sort, Merge Sort, Heap Sort)	$O(A \times B)$	$O(n \log n)$	$O(A \times B \times n \log n)$
Modified Binary region median filter	$O(A \times B)$	1	$O(A \times B)$
A : Frame image width size(1360), B : Frame image height size(1024), n : Sorting digit(9)			

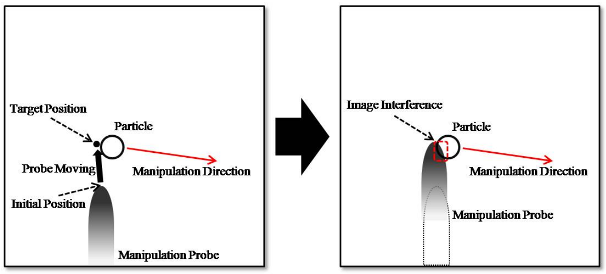

Fig. 5. Interference of Manipulator and Particle

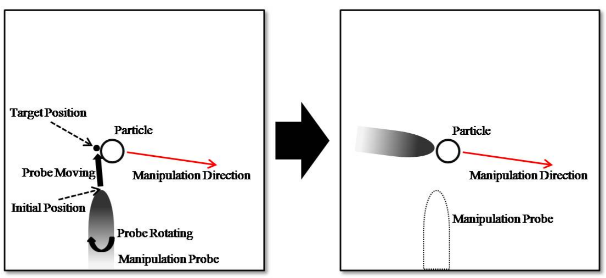

Fig. 6. Non-interference of Manipulator and Particle

038.DG is rotation motor stage having 3.5μrad minimum incremental motion. And M-112.1DG is translation motor stage having 50nm minimum incremental motion. They are located under the rotation stage. Thus they made it possible to move a manipulator to x-axis and y-axis. Also in the upper part of the rotation stage, the two same stages were used in order to make a system which the end point of manipulator can be calibrated into the center of the rotation stage. P-611.2S and P-611.ZS are translation piezo stage having 2nm resolution. They were used to handle particle more precisely. And M-451.DG is elevation motor stage. It was used to locate manipulation system on z-axis. Lastly whole implementation of system was equipped with isolated vibration table of Newport to reduce a vibration from the ground. Therefore the omnidirectional accessible manipulation system was equipped like Fig.4

IV. MANIPULATION EXPERIMENT

A. System Schematics and Control Program

1) System Schematics: Normally, a high precision robot system consists of precision staging system, end-effecter system, and autonomous sensing system. Our system was implemented like Fig.7. As it was mentioned above, omni-directional accessible manipulation system is implemented

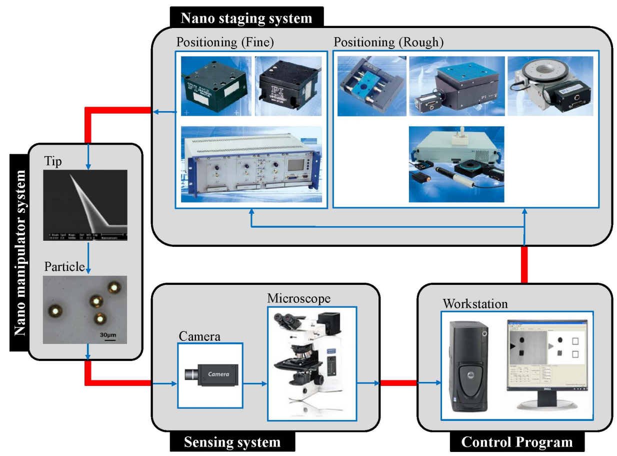

Fig. 7. System Schematics

for the precision stage system. And autonomous visual feedback system is implemented for autonomous sensor. AdvancedTEC contact mode AFM probe is also used as a end-effecter.

A control program is like Fig.8. The control system is implemented using Microsoft Visual C++ 6.0 based on MFC. The realtime image of camera and vision processing image will be shown in the control program. And it is possible to handle omnidirectional accessible manipulation system, to set up scale of microscope and to modify size of mask for vision processing of particle and manipulator. The implemented program will work based on thread so that monitoring coordinate of manipulation tip and particle is possible all the time.

B. Planning Concept

In order the particle to be carried to target point, our system operates like Fig.9. Manipulation method to target point from present point is graspless and pushing. Besides, particle will be manipulated in straight line, because it has to be the shortest way to manipulate. Also the straight line is autonomously created using control program. But there are a lot of veering from its straight line in manipulation of graspless and pushing method. Therefore our system needs to modify the path like Fig.10. Thus its straight line is divided several unit straight line path, and it is requested to check coordinate information after manipulation of unit straight line path. When particle veered from unit straight line path, direction of manipulation is modified using calculated coordinate information. Through veering of this process, particle will

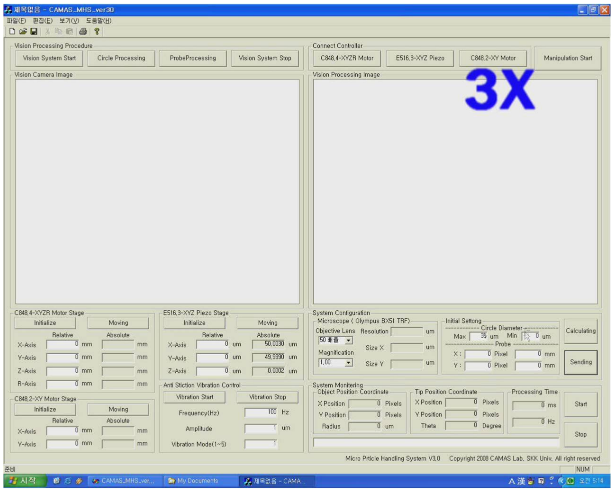

Fig. 8. Graphic User Interface of Control Program

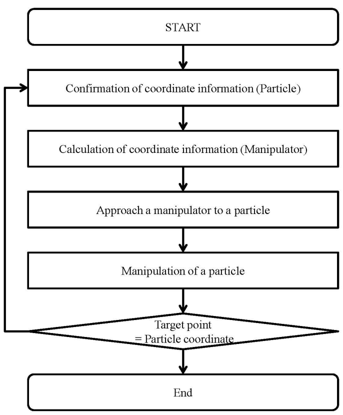

Fig. 9. Flowchart

be sent to final target point with the shortest path. Through repeating of this, particle will be manipulated to a final target point.

C. Experimental Result

1) Approaching Manipulator: Manipulator approaches into the around of particle using our system in order 30μm particle to be manipulated from present point to target point. Our system is calculating a path using coordinate information of manipulator and particle. So manipulator is moved to around of particle like Fig.11.

2) Unit Segment Manipulation: Particle is manipulated by unit straight line path after approaching. Manipulation direction is not changed after manipulation like Fig.12. In this case particle will be manipulated by unit straight line path once more.

3) Modified Manipulation Direction: In most case manipulation direction is changed after manipulation like Fig.13. Because there are a lot of veering from its straight path in manipulation of graspless and pushing method. In this case manipulator is aligned to new manipulation direction

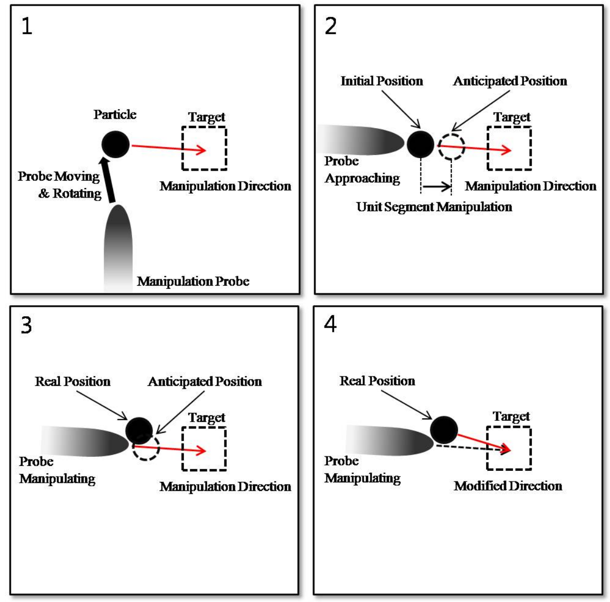

Fig. 10. Manipulation Planning

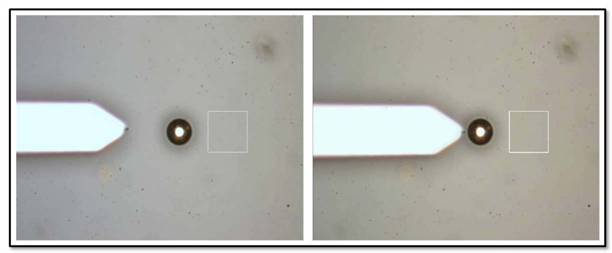

Fig. 11. Approaching Manipulator

using rotation stage. Then particle will be manipulated by unit straight line path.

4) Test Result: Finally, 30μm sized particle is transported to target point through graspless and pushing method like Fig.14. When a manipulation distance is 50μm, a working time is 60 seconds. And manipulation error becomes less than 3μm(10%)

V. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

In this paper high precision robot system is implemented using autonomous visual feedback system with microscope and omnidirectional accessible manipulation system. And

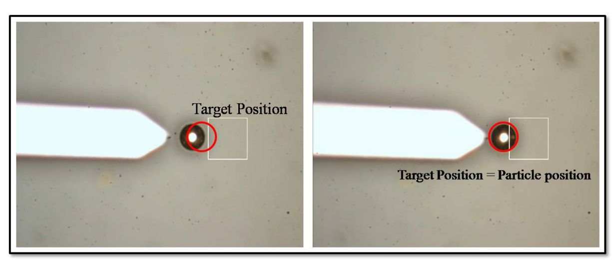

Fig. 12. Unit Segment Manipulation

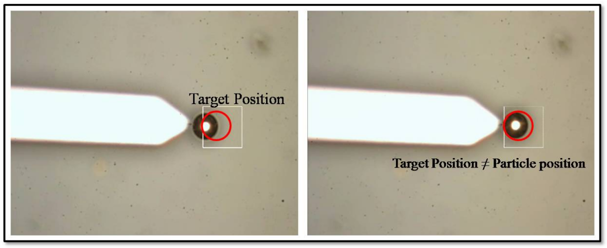

Fig. 13. Modified Manipulation Direction

Fig. 14. Manipulation Result

contact force is calculated using adhesion phenomena. Therefore particle is able to manipulate without stiction. And implemented program works based on thread so that monitoring coordinate of manipulator and particle is possible all the time. Finally, 30μm sphere particle is pushed to final target point using graspless and pushing method within 10%

B. Future Works

Algorithm which calibrates difference between rotation stage and manipulation tip is necessary afterward. And it will be essential to make high precision robot system which is able to overcome adhesion effect while hadling smaller μmm sized particle than now.

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