Manipulation of fine objects by probes of the electrostatic chuck type

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Particle assemblage by probe manipulation is a built-up process to fabricate microstructures. We investigated the probe manipulation method featured by applying voltages to the probe to control the adhesion force. Two types of probe are fabricated. One is a monopole probe and the other is a dipole probe. The former is composed of a needle-like metal wire, and the voltage is applied between the probe and the external electrode like a metal substrate. The latter is composed of a needle-like electrode and a stainless tube arranged concentrically. The tip of the monopole probe was shaped hemispherically by insulating resin. The monopole probe can catch fine particles of 10 μm to 100 μm on the metal substrate, while the monopole probe can catch both conductive particles and dielectric particles without the restriction of substrates. The particles jump up to the tip of the probe and adhere. The features of the two probes are compared.

Keywords: Monopole probe, Dipole probe, Electrostatic chuck, Probe manipulation

I. INTRODUCTION

The size and weight of new products are decreasing. This is true not only for electronic products but also for mechanical products. The trend is supported by miniaturized electronic parts and mechanical parts. For example, capacitors and gears less than 1 mm are being produced.

Recently, new handling methods for submicro-meter-sized objects are required to assemble such small parts.

Fine objects are manipulated by various tools, and the tools hold fine objects by various forces. Chopsticks/microgrippers¹⁻² hold fine objects by friction, capillary tubes³ by suction, and needle-like probes⁴ by adhesion.

The main sources of adhesion are van der Waals force, electrostatic force and liquid bridge force. They always act upon two substances that are in contact so that they can maintain contact with each other. The probe is, therefore, the simplest among the

tools. It holds fine objects without any holding devices. The adhesion is not strong enough to hold submicro-meter-sized objects. The upper limit is about 10 μm .

We try to enhance the adhesion using external power sources to manipulate large objects by the needle-like probe. Two types of probe are fabricated,⁵⁻⁶ and manipulation experiments are conducted. In this paper, the principle and structures of each probe are explained, and the features are compared.

II. DESIGN OF PROBES

II -A. Electrostatic chuck

Electrostatic chuck (ESC) is an item of apparatus that clamps a substance by electrostatic force. For example, it is widely used to clamp silicon wafers during the chip manufacturing process.

Two types of ESC are provided. The monopolar type has one electrode, and the bipolar type has two electrodes. Fig. 1 shows schematic illustrations of

each ESC, which clamps the silicon wafer. The lead wire between an earth ground and silicon wafer in Fig. 1 (a) means that the wafer is being exposed to plasma.

Fig. 1 Monopolar electrostatic chuck (a) and bipolar electrostatic chuck

1: wafer, 2: dielectric table, and 3: electrode

II -B. Monopole and dipole probes

Two types of probe are considered, corresponding to two types of ESC. A probe corresponding to the monopolar type is called a monopole probe and a probe corresponding to the bipolar type is called a dipole probe.

Fig. 2 (a) shows an illustration of a monopole probe, which touches a sphere on a metallic substrate. The probe is only a metal needle. Fig. 2 (a) is electrically the same as Fig. 1 (a) if Fig. 1 (a) is upside down. The probe, the insulating thin oxide film, the particle, and the metal substrate in Fig. 2 (a) correspond to the electrode, the dielectric table, the wafer, and the earth ground of the wafer in Fig. 1 (a), respectively.

Fig. 2 (b) shows an illustration of a dipole probe, which catches a sphere. The similarity to Fig. 1 (b) is clear.

Fig. 2 Structures of the monopole probe (a) and the dipole probe (b)

1: tungsten needle, 2: insulating oxide, 3: particle, 4: metal substrate, 5: stainless tube, 6: Alumina tube, 7: tungsten needle, and 8: epoxy resin

III. EXPERIMENTS

III -A. Procedure

Spheres sprinkled on a substrate are manipulated by the probe. The probe is moved just above the target sphere with the proper gap. Voltage is applied between the probe and the metal substrate for the monopole probe, and between the two electrodes inside the probe for the dipole probe.

The tip of the probe is observed by two microscopes. Pictures of the microscopes are recorded by CCD cameras attached to the microscopes to ensure the results. When the gap is 0, the probe is pulled up to check whether the particle has adhered or not.

III -B. Specimen

The monopole probe is a tungsten needle (NPS Inc., W26-05-01x1.1/2) whose diameter and point radius are 660 μm and 2 μm , respectively.

The dipole probe as shown in Fig. 2 (b) is fabricated. The two electrodes are a tungsten probe, which is the same as the monopole probe, and a stainless tube, whose tip is ground to form a needle. An alumina tube for insulation and the electrodes are arranged concentrically, and they are embedded in resin. The length and diameter are 24 mm and 3.1 mm, respectively.

A gold substrate and a glass substrate are used for the experiments of the monopole probe and the dipole probe, respectively. Gold spheres, styrene spheres and glass spheres are used for manipulation.

IV. RESULTS AND DISCUSSION

IV -A. Catch and release by monopole probe

The monopole probe can not attract gold particles over a gap. However, it can pick up gold particles when voltages of 40-60 V are applied after the probe is in placed in contact with the particle.

Consider pulling up the probe as shown in Fig. 2 (a). Four forces are exerted on the sphere. The force of gravity, F_g , and adhesion between the sphere and the substrate, A_s , act downward. Electrostatic force, F_e , and adhesion between the probe and the sphere, A_p , act upward.

Our experimental results on the catch and release of gold particles are summarized as follows.

(1) Gold particles of 10 μm to 300 μm can be picked up by applying 40-60 V.

(2) For a successful catch, the probe should touch the particle with a very little contact pressure.

(3) Once the particles are in the air, they do not fall if the voltage is cut off.

(4) The particles are released by pulling down the probe until the particle touches the substrate and pulling up the probe without applying voltage.

Considering the above results, gold particles of 10 μm to 300 μm satisfy the following inequalities.

$$A_p < A_s + F_g \quad (1)$$

$$A_p + F_e > A_s + F_g \quad (2)$$

$$A_p > F_g \quad (3)$$

Reproducible results were not obtained for glass particles.

The electrostatic force, F_e , is considered to be Johnsen-Rahbek's force.⁷ It is the main adhesion for monopolar ESCs. Very little current flows through the probe and the gold particle. The voltage drop across the insulating oxide film is very large, and this causes Johnsen-Rahbek's force.

IV -B. Catch and release by dipole probe

The dipole probe attracts both conductive particles and dielectric particles over the gap. Fig. 3 (a) and (b) are pictures taken by the CCD camera. They show a gold particle and a styrene particle adhered to the tip of the dipole probe, respectively.

By applying 5 kV, the gold particle of 0.4 mm is attracted from a distance of 0.5 mm. The styrene particle of 3 mm is attracted from a distance of 1 mm

Fig.3 Attraction of a gold particle of 0.4 mm (a) and a styrene particle of 3 mm (b) by the dipole probe

by applying 2 kV. The attraction force is the gradient force⁸ similar to the adhesion of bipolar ESCs.

The gradient force is exerted on objects placed in an electric field with a strong gradient. The intensity is proportional to the gradient of the square of the electric field. Theoretical analysis of the adhesion of the monopole probe is difficult, because estimation of Johnsen-Rahbek's force requires information on a submicroscopic scale. On the other hand, simulation is a powerful method of analyzing and developing the dipole probe.

Fig. 4 is an example of the simulation by the FEM (Maxwell, Ansoft Co.). The attraction force exerted on a gold particle of 1.2 mm is calculated as a function of the horizontal distance from the center of the probe. The gap is 1.2 mm, and the applied voltage is 5 kV. The maximum attraction force is obtained at a few hundred micrometers to the opposite direction of the stainless needle electrode. This agrees with the experiments. The particles adhered aside from the center.

Fig. 4 Relationship between the horizontal distance and attraction force for a gold particle of 1.2 mm. Applied voltage and distance from bottom of the probe is fixed to be 5kV and 1.2mm, respectively.

Release is possible only by turning off the switch. The particles slide down to the bottom and fall. The particles, therefore, fall just below the center of the probe. The particles should adhere to the bottom of the probe. The simulation is used to determine the shape and position of the electrode for this aim.

IV -C. Comparison of two probes

The features and application fields of the two probes are summarized in Table 1. It is important that current does not pass through fine objects during manipulation by the dipole probe. On the other hand, very little current passes through fine objects in monopole probe manipulation. Fine objects can be welded by the monopole probe.⁵ The dipole probe is used only for manipulation.

Considering these features, the monopole probe is applicable to MEMS fields and micro-machines. The dipole probe is applicable to the electronics industry. If a miniaturized dipole probe is fabricated, for example, using the lithographic method, it can be applied to the biological field such as cell manipulation.

Table 1 Comparison of monopole probe and dipole probe

	Monopole probe	Dipole probe
Force	Johnsen-Rahbeck's force	Gradient force
Substrate	Only metal substrate	Any substrate
Applied voltage	>100V	A few kV
Objects	Conductor/Semiconductor	Any materials
Object's size	> A few hundreds μm	> A few mm
Mechanical parts	○	○
Electronic parts	×	△
Application	MEMS Micro-machine	Electronics Biology

V. CONCLUSION

Two types of probe whose attraction force is controlled by external electric power are fabricated. Gold particles of 10 μm to 300 μm are picked up by

the monopole probe, which is composed of a tungsten needle, by applying 40-60 V between the probe and a metal substrate. The ordinary probe cannot pick up such particles. The dipole probe, equipped with two electrodes, can attract both conductive particles and dielectric particles over a gap by applying 2-5 kV between the electrodes. The monopole probe is applicable to MEMS and the dipole probe to the electronics industry.

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