Manipulation of a Small Conductive Ball by Electrostatic Force Generated by Hemisphere-end Stick Electrode

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Abstract

Recently, manipulation techniques for handling a conductive small-particle have been in demand. Electrostatic manipulation with a single probe is a promising technique for such manipulation. In this study, the force worked between the upper hemisphere electrode and ball is studied. The force worked on the ball is analyzed. It is found that when the diameter of hemisphere is decreased, the force decreases, and that the voltage for catching ball increases as the humidity increased. It is confirmed that the ball is caught by the hemisphere electrode covered by dielectric film.

Introduction

The electrostatic force plays an important role in various fields including the toner control of the electrophotographic printing process essentially[1, 9]. The electrostatic force depends on the conductivity of particle[2, 6]. On the insulating case, particle holds electric charge charged by friction, and an electrostatic force is decided by the electric charge and neighboring electric fields. On the other hand, in the case of conductive case, an electric charge is induced in neighboring electric fields, and an electrostatic force is determined by the induced electric charge and neighboring electric fields. The electrostatic force between a conductive ball on a plane electrode is analyzed[3~4].

In recent years, there has been a great demand for manipulation techniques in applications such as LSI bonding, biology, and microelectromechanical systems. Electrostatic manipulation using a single probe is promising for manipulation. This technique can manipulate small objects individually. It is thus not very efficient, but it is able to position objects precisely. In manipulation of small objects, the influence of gravitational force is extremely small, whereas the electrostatic adhesion force is strong. It is thus important to understand the electrostatic force acting on a conductive ball to advance manipulation technology.

The concept of the manipulation method of conductive ball between the electrodes[10~12] is illustrated in Figure 1. The ball lies on the lower electrode when the voltage is not applied. As shown in section (b), when the voltage is applied, the ball moves upwards due to the electrostatic force worked on the ball consequence to the electric field. Then the ball is attached to the dielectric layer below the upper hemisphere-end electrode. As for the next step, when the voltage is reversed, the ball starts moving downwards as reverse the electric force and the gravitational force only works on the ball.

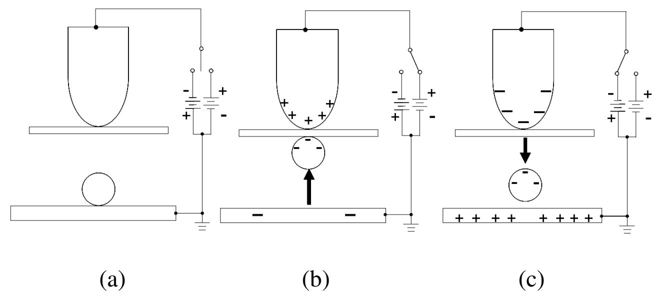

Figure.1 *Concept of conductive ball control by electrostatic force.*
(a) Before capture, (b) Captured by electrostatic force, (c) Released from the electrode.

Experimental

Figure 2 shows the experimental model. The experimental arrangement of the system shown in Figure 2 consists of four parts: upper hemisphere-end electrode, lower electrode, dielectric film and conductive ball. An electrostatic force is generated on the conductive ball when a voltage is applied between the upper hemisphere-end electrode and lower electrode. When the electrostatic force overcomes the sum of gravity and affinity force, the conductive ball is jumped upward. The voltage at which this effect occurred is measured.

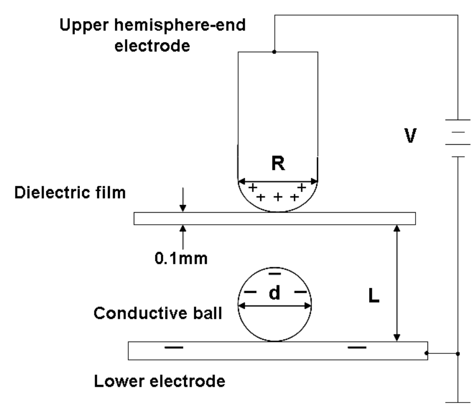

Figure.2 *Experimental model.*

Analysis

Electric field analysis[5, 8] used the Elfin software package (ELF Corp., Japan) for the case when a dielectric film is placed beneath the hemisphere electrode.

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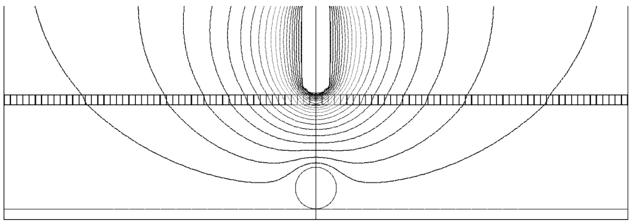

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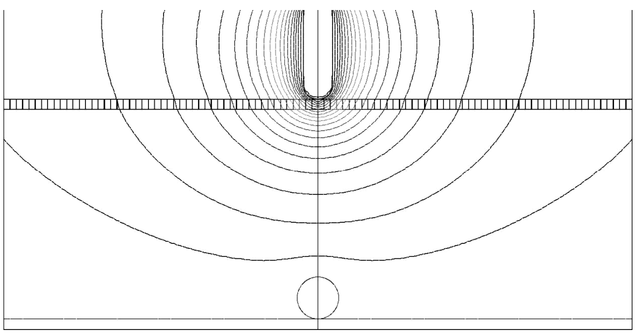
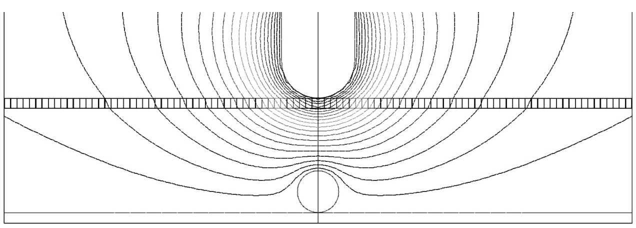


(b)

Fig.3 *Equipotential lines when diameter of conductive ball (d) 0.4mm, and the diameter of upper hemisphere-end electrode (R) 0.28mm, (a)The gap between the dielectric film and lower electrode (L) 1mm, (b) The gap between the dielectric film and the lower electrode (L) 2mm.*



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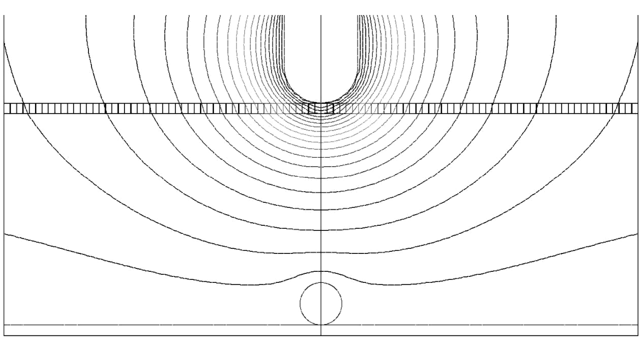
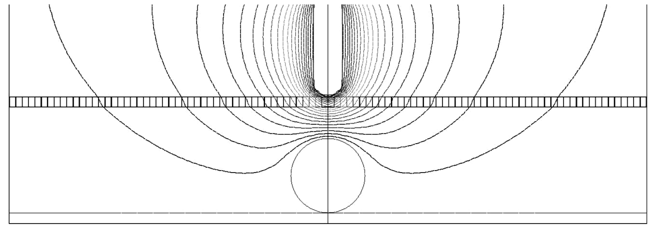


(b)

Fig. 4 *Equipotential lines when diameter of conductive ball (d) 0.4mm, and the diameter of upper hemisphere-end electrode (R) 0.7mm, (a)The gap between the dielectric film and the lower electrode (L) 1mm, (b) The gap between the dielectric film and the lower electrode (L) 2mm.*



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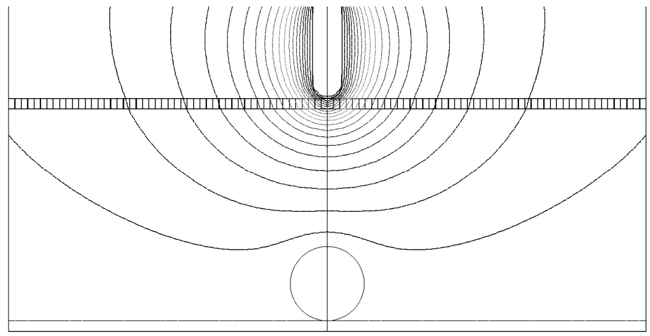
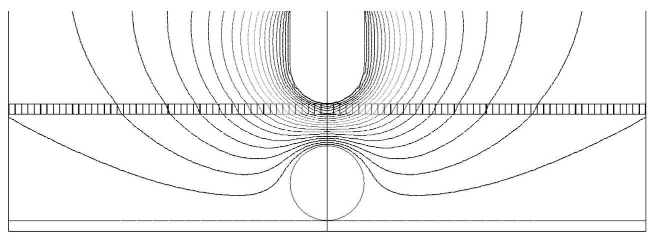


(b)

Fig.5 *Equipotential lines when diameter of conductive ball (d) 0.7mm, and the diameter of upper hemisphere-end electrode (R) 0.28mm, (a)The gap between the dielectric film and the lower electrode (L) 1mm, (b) The gap between the dielectric film and the lower electrode (L) 2mm.*



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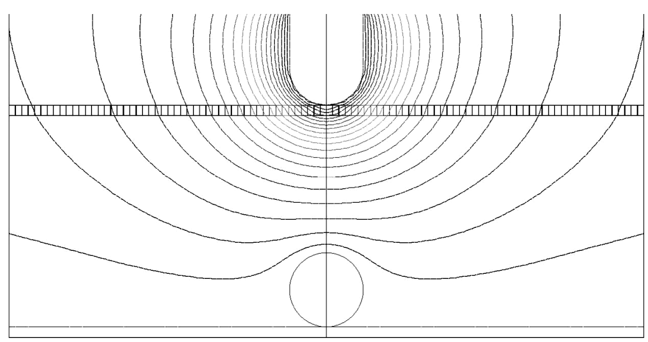


(b)

Fig. 6 *Equipotential lines when diameter of conductive ball (d) 0.7mm, and the diameter of upper hemisphere-end electrode (R) 0.7mm, (a)The gap between the dielectric film and the lower electrode (L) 1mm, (b) The gap between the dielectric film and the lower electrode (L) 2mm.*

Results and Discussions

The experimental conditions are listed in Table 1. The conditions of temperature and humidity are 25℃ and 30%, 40%, 50%, respectively and thickness of dielectric film is 0.1mm.

Table 1. *Experimental conditions.*

Variable	Value
Diameter of upper hemisphere-end electrode (R)	0.28mm, 0.7mm
Gap between the dielectric film and the lower electrode (L)	1mm to 2mm
Diameter of conductive ball (d)	0.4 mm, 0.7mm

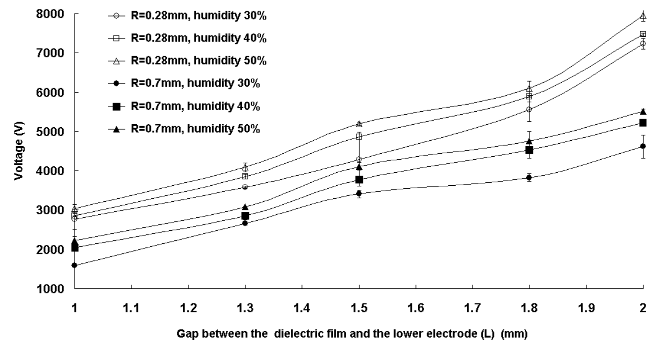
1. Voltage dependence on the gap between the dielectric film and the lower electrode (L)

In this experiment, the dependences of the voltage (V) on the gap between the dielectric film and the lower electrode (L) were investigated by varying the distance in the range 1mm to 2 mm. The diameter of upper hemisphere-end electrode (R) was kept constant at 0.28mm and 0.7mm. Figure 7 shows the dependences of the voltage (V) on the gap between the dielectric film and the conductive ball (L). The voltage increases with increasing the gap between the dielectric film and the lower electrode (L) in these humidity cases. When the diameter of upper hemisphere-end electrode (R) was decreased, the voltage (V) increased. When diameter of conductive ball (d) was increased, the voltage (V) decreased.

2. Dependence of adhesion force between conductive ball and lower electrode on humidity

From the Figure 7, it can be observed that the voltages of the ball start jumping increases with the increment of humidity in every case. This is assured due to the increment of affinity force between the ball and the lower electrode. When the humidity is high, the liquid bridging occurs and consequently the affinity force increases.

Therefore to detach the ball from the lower electrode in higher humidity, high voltage should be applied to overcome the liquid bridging comparatively to the lower humidity.



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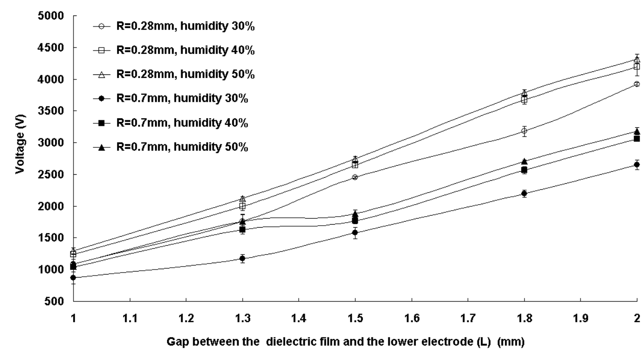
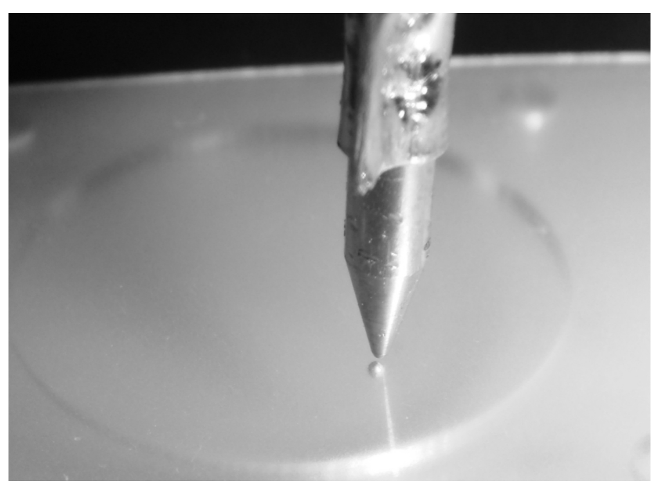


(b)

Figure.7 Dependences of the voltage (V) on the gap between the dielectric film and the lower electrode (L), (a) diameter of conductive ball (d)=0.4mm, (b) diameter of conductive ball (d)= 0.7mm.

The photographs in Figure 8 show the state of catching ball. It is confirmed that the conductive ball is caught at just under the hemisphere electrode.



(a)

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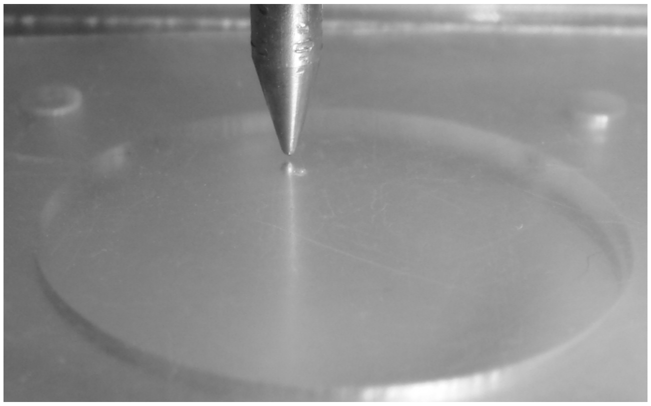

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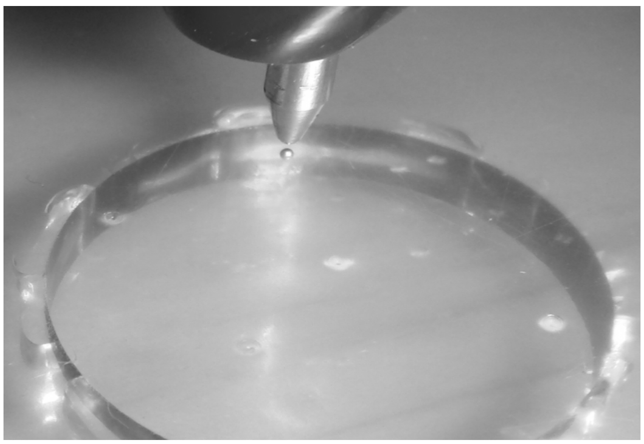

(c)

Fig. 8 *Photographs showing the state of catching ball on the dielectric film, which is below the cylindrical electrode with a hemispherical tip.*

Conclusions

Experiments on capturing conductive ball were performed. The ball jumps up to the cylindrical electrode with a hemispherical tip and adheres to the dielectric film adjacent to the tip when a dielectric film is placed below the upper hemisphere-end electrode. The electric field between a lower plane electrode and a cylindrical upper electrode with a hemispherical tip is also analyzed.

When the humidity is high, the affinity force between the ball and the lower electrode becomes stronger due to affinity force arising from liquid bridging. This study provides a useful foundation for electrostatic manipulation of a conductive ball. They are also useful for understanding the behavior of conductive balls in electric fields.

Acknowledgements

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Author Biography

Bin Xu received his B.S Degree in Systems Engineering from the Nippon Institute of Technology of Japan in 2010. He joins currently Hoshino laboratory at Nippon Institute of Technology, Japan as a master degree student for System Engineering and his research interest includes electrostatics and analysis of electrical field between electrodes.

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