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Electrostatic force acting on conductive ball between electrodes II: Cylindrical upper electrode with hemispherical tip for capturing/releasing conductive ball

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ABSTRACT

The electrostatic force between a conductive ball on a plane electrode and a cylindrical electrode with a hemispherical tip is analyzed. A cylindrical electrode with a dielectric film for realizing a new LSI bonding system is proposed. The force on the ball increases with increasing diameter of the cylindrical electrode. When a dielectric film is placed under the cylindrical upper electrode with a fixed gap between the electrodes, the force acting on the ball increases with increasing dielectric film thickness. Capture of the ball was experimentally confirmed. This study provides a useful foundation for electrostatic manipulation of a conductive ball.

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1. Introduction

Causing particles to jump by applying an electrostatic force is an important phenomenon in various applications including electrophotography. Examples of applications of toner particle jumping [1] in electrophotography include its use in a toner developing system [2,3] and jumping of an insulating toner in a developing process [4] that produces high-quality images. High-density bonding between LSI and circuit boards will become necessary in the near future. The realization of a precise handling technology for small solder balls is important. Control of conductive balls by electrostatic force [5] is promising for achieving high-density LSI bonding. To achieve the above developments, it is essential to understand the electrostatic force that acts on a conductive ball between two electrodes. When a conductive ball is in contact with an electrode, they will be at the same potential due to the free movement of charges. For a conductive ball on an electrode, the charge induced by an electric field can be calculated analytically as $1.65SE\varepsilon$, where 1.65 is the focusing factor of the electric field [6], S is the surface area of the ball, E is the electric field strength, and ε is the dielectric constant of air [7]. When the ball is between two electrodes, the charge induced on the conductive ball due to the electric field between them is calculated analytically to be over $1.65SE\varepsilon$ [5]. The electric force (F_e) exerted on the conductive ball is proportional to the product of the induced charge and the electric field strength. The force due to the external electric field increases as the square of the external electric field. As the electric field is increased, the particle jumps upwards when the electrostatic force acting on the particle exceeds the gravitational force and the adhesion forces. The case for when the ball is between two flat electrodes has been analyzed [5]. However, when the electrode shape is different from flat shape, the force exerted on the ball has not yet been derived due to the difficulty of estimating the induced charge on the ball. Consequently, in this study, we analyze the induced charge on the ball and the electrostatic force acting on the ball. This analysis is performed for two cases, an upper cylindrical electrode with a hemispherical tip with and without a dielectric film, and for three different separations between the ball and the upper electrode. The electrostatic force acting on the ball was analyzed for different thicknesses of the dielectric film, which was placed beneath the upper electrode. Excellent agreement was obtained between the calculated and experimental forces.

2. Manipulation of conductive ball by electrostatic force

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

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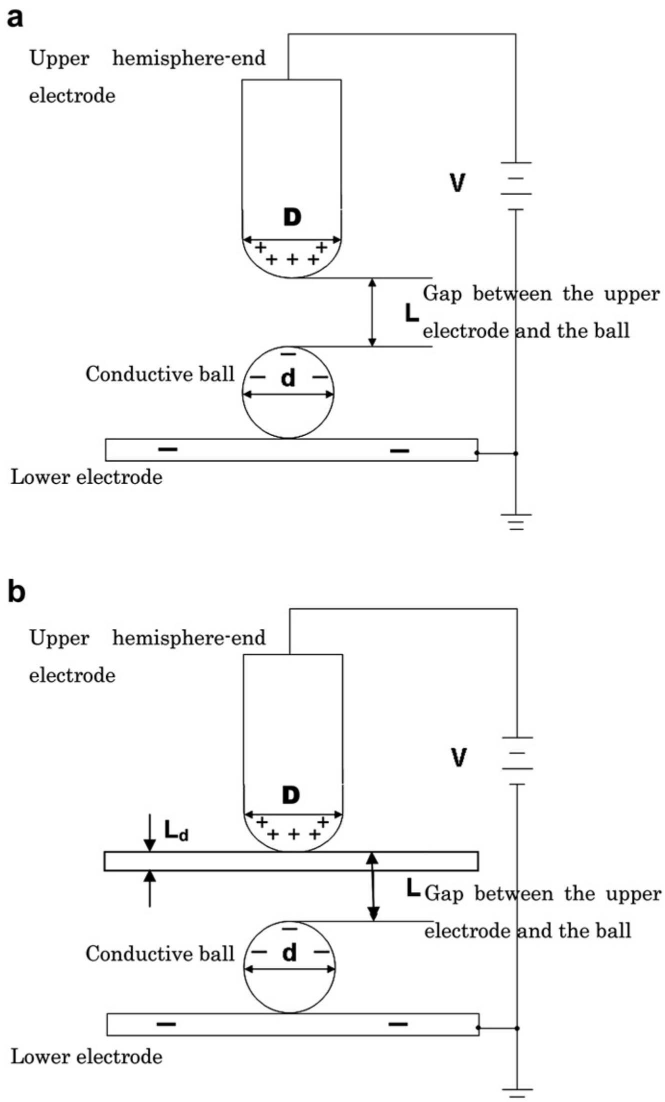

Fig. 1. Models for electric field analysis: (a) ball between two electrodes; (b) dielectric film below cylindrical electrode with a hemispherical tip.

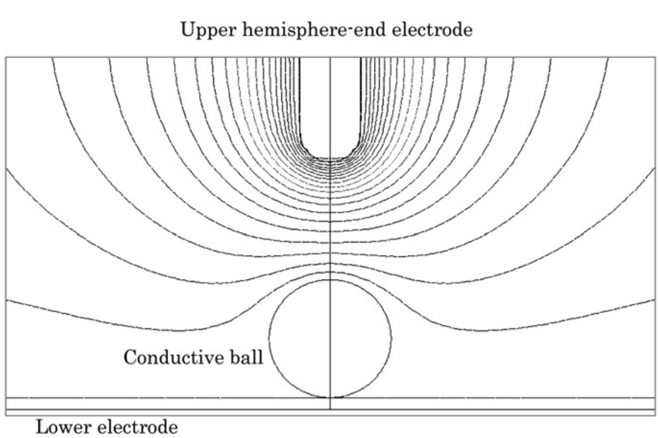

Fig. 2. Equipotential lines.

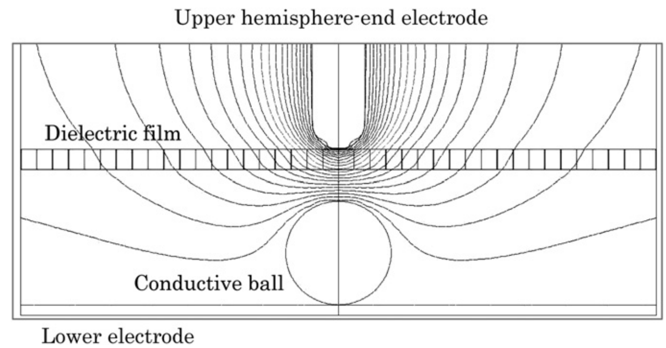

Fig. 3. Equipotential lines when there is dielectric film below the cylindrical electrode with a hemispherical tip.

3. Analysis of electric field between electrodes

In this study, the electric field between a lower plane electrode and a cylindrical upper electrode with a hemispherical tip is analyzed [8]. The electric charge induced and the force acting on a conductive ball placed on the lower electrode is analyzed using the Elfin software package (ELF Corp., Japan). This analysis is performed for two cases: when the ball is placed directly under the cylindrical electrode with a hemispherical tip (Fig. 1(a)) and when a dielectric film is placed beneath the electrode with a hemispherical tip (Fig. 1(b)). In both cases, a voltage is applied to the upper electrode. Furthermore, analysis is performed for different locations of the ball on the dielectric film, namely concentric and eccentric with the upper electrode.

3.1. Electrode with a hemispherical tip

The key elements of the system are a manipulation probe, which is a cylindrical electrode with a hemispherical tip, a conductive ball, and a plane electrode. All these objects are conductive. Fig. 1(a) shows the arrangement of the system. An electrostatic force is generated on the conductive ball when a voltage is applied between the two electrodes. The ball jumps up and adheres to the probe due to the electrostatic interaction [9] between the electrode with a hemispherical tip and the ball. The ball adheres to the probe tip. The ball is released from the upper electrode when the gravitational force exceeds the holding force. This catch and release mechanism

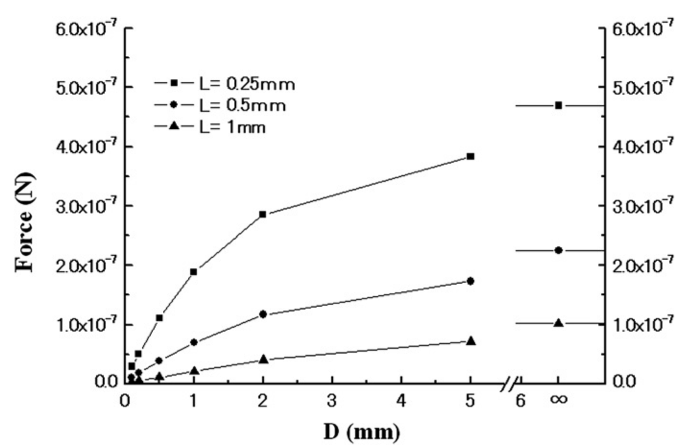

Fig. 4. Dependence of the total electrostatic force (F) on the diameter of the electrode with a hemispherical tip (D) for three different distances between the ball and the probe (L).

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