Microassembly Using Water Drop

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1. Introduction

The miniaturization of electronic devices has been progressing remarkably to match the demand for high performance and multiple functions. In their production process, however, handling of electric components becomes more and more difficult as they become smaller. A promising approach to overcome such difficulty is the application of MEMS technology (Segovia et al., 1998). Meanwhile, the basic properties of surface tension have been studied extensively (De Genes et al. 2002). Various attempts using surface tension have been reported such as micro gas-liquid separator (Shikazono et al., 2010), micro motor (Kajiwara et al., 2007) and bearing (Shamoto et al., 2005). As to the assembly of micro parts using liquid surface tension, the self-alignment principle and characteristics have been studied (Sato et al., 2000). A scheme for micromanipulation using capillary force has been proposed (Obata, et al. 2004).

This chapter presents a novel method of picking up a small electric component to the center axis of a nozzle by using the liquid surface tension of a water drop (Takagi et al., 2008; Kato et al., 2010; Haga et al., 2010). This method is characterized by combining surface tension with negative pressure produced by vacuum, which is different from the approach by Bark et al. (1998). The aim of this method is to assemble μm-order electric components with mounting machines having common positioning accuracy. The basic properties of the proposed microassembly are studied with a fabricated experimental device.

2. Principles of picking up

2.1 Conventional method

In mounting small electric components onto a substrate, picking up by using vacuum is most widely used at present. The principle is explained by Fig.1. The process is

a. A nozzle is made to touch a component on a tape and then vacuum is created inside the nozzle. The component is picked up by the negative force produced by vacuum.
b. The component is carried to a prescribed position.
c. It is placed on the prescribed position of the substrate by breaking the vacuum.

One problem of this method is the failure of picking up when the component is displaced from the desired position that is usually the center of the nozzle. Such misalignment is unavoidable in actual mounting machines. It is to be noted that such ill effect of misalignment becomes more remarkable in assembling smaller components.

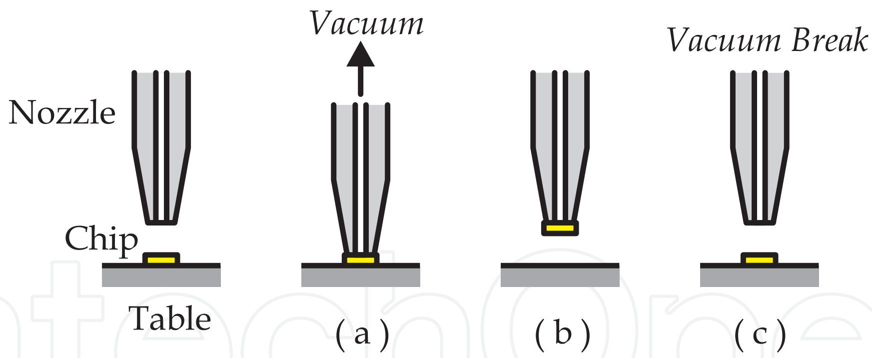


Fig. 1. Process of conventional assembly

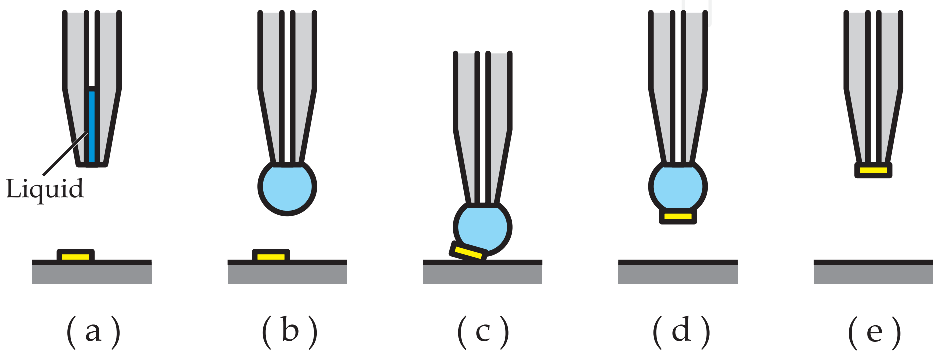


Fig. 2. Process of assembly using water drop

2.2 Picking up with water drop

In the conventional method, misalignment causes fail of picking up because it makes negative pressure for suction insufficient. As a countermeasure to such misalignment, a method of picking up using water drop is presented in this section. Figure 2 shows the process of picking up:

a. Liquid is stored in a nozzle.
b. A drop is made on the top of the nozzle by increasing the pressure inside the nozzle.
c. The drop is made to touch a component.
d. The component is picked up by raising the nozzle.
e. The drop is suctioned by making vacuum inside the nozzle so that the tip is hold at the top of the nozzle.

In the stage (d), the component moves to just the bottom of the drop automatically due to gravitational force and is hold at the center axis of the nozzle. It is referred to as *self-centering effect* in the following. Due to this effect, a component even displaced from the desired position can be picked up to the center axis of the nozzle.

3. Experimental system

Figure 3 shows an outline of the experimental system. Objects to be picked up are placed on a three-axis positioning stage (Fig.4). A nozzle and its holder is fixed on a slider of the positioner for rough positioning (Fig.5). Figure 6 shows the details of the nozzle. An ejector is connected to the nozzle through the holder. It controls the pressure inside the nozzle.

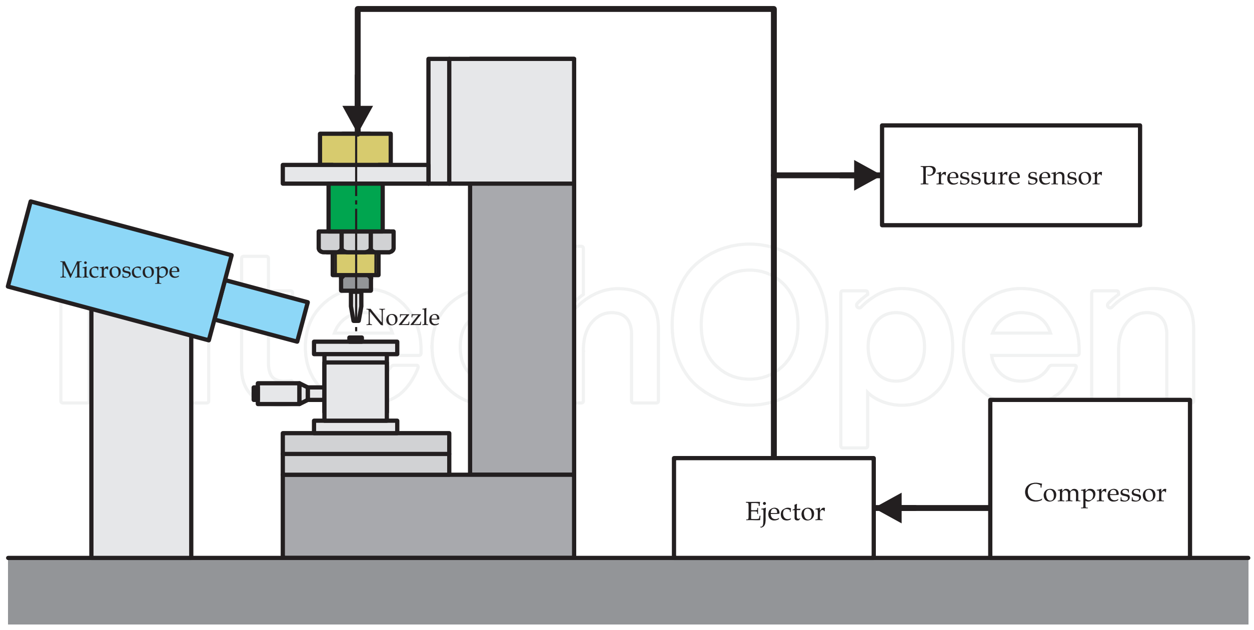


Fig. 3. Experimental system

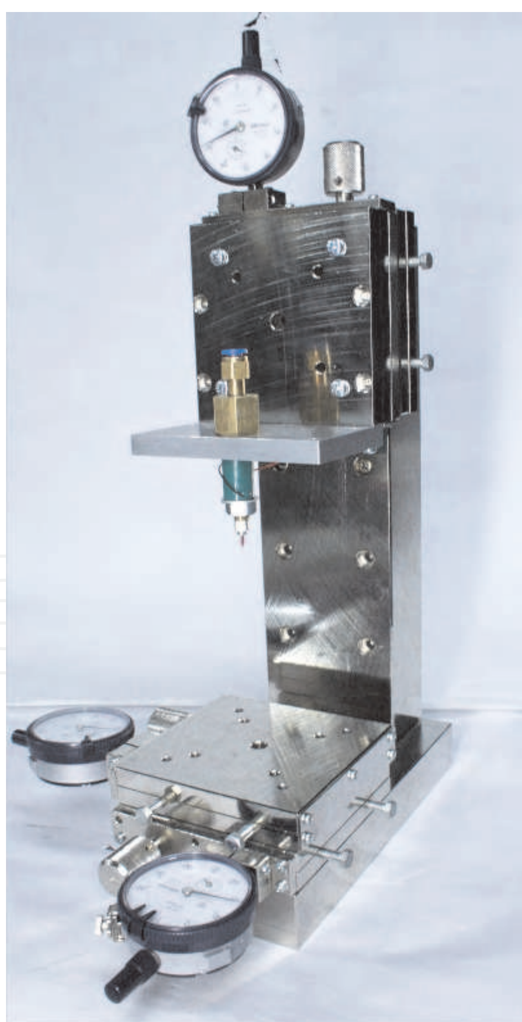


Fig. 4. Three-axis positioning stage with a nozzle and its holder

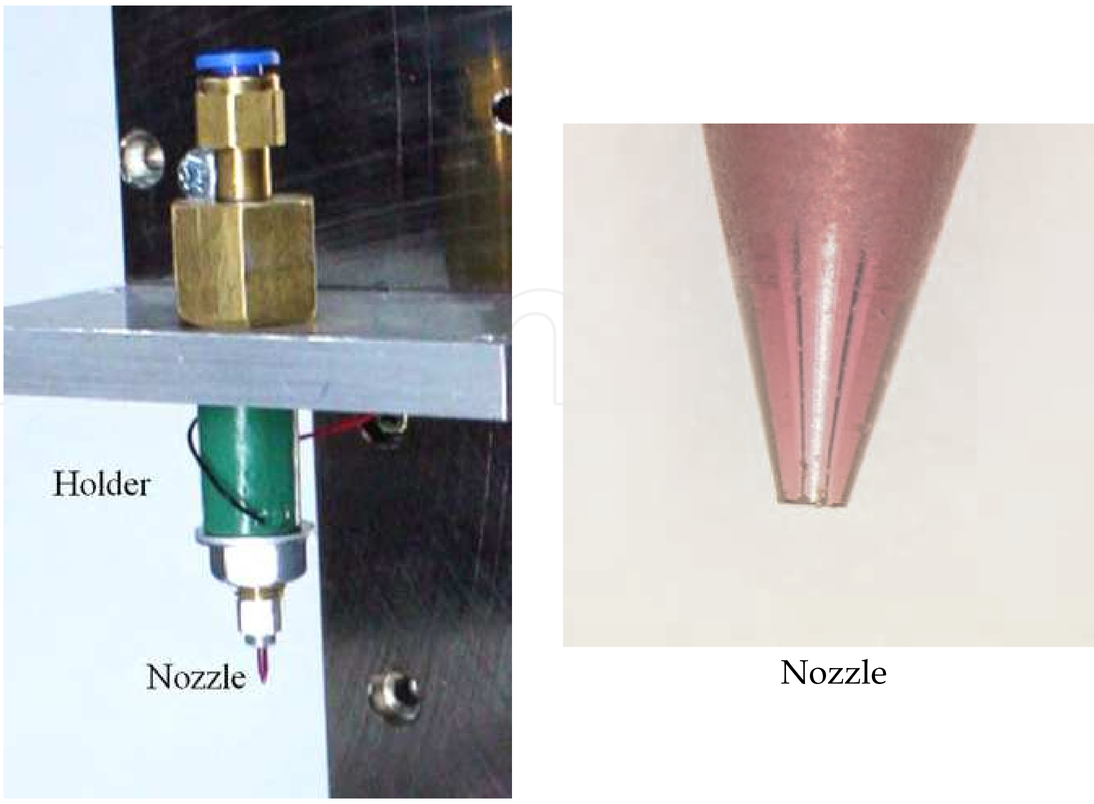


Fig. 5. Nozzle and holder

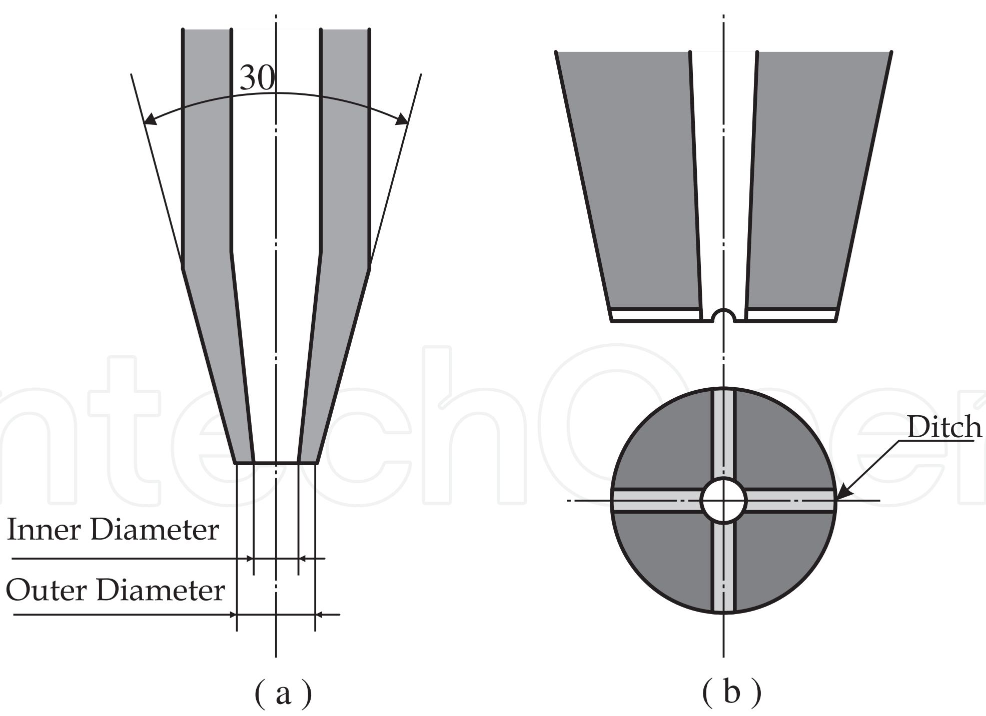


Fig. 6. Details of the nozzle

Ultra pure water is used as the liquid to avoid the ill effects of contamination on tips and assembled products. For observation, a microscope is used to measure the relative displacement of the tip to the nozzle and the diameter of the water drop.

4. Picking up chip

4.1 Object for picking up

Figure 7 shows a targeted surface mount component. This is a chip resistance called as "0402" that is an actual industrial component. The width *w*, depth *d* and height *h* are 0.4, 0.2 and 0.1 mm, respectively. The width of electrical plate e is 0.1 mm. The coordinate axes X, Y and Z are defined as shown in Fig.7.

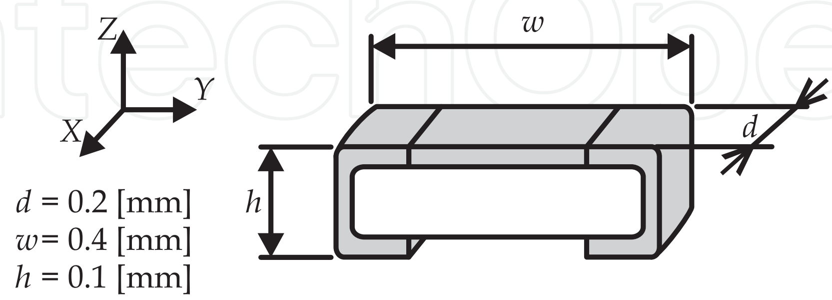


Fig. 7. Surface mount component

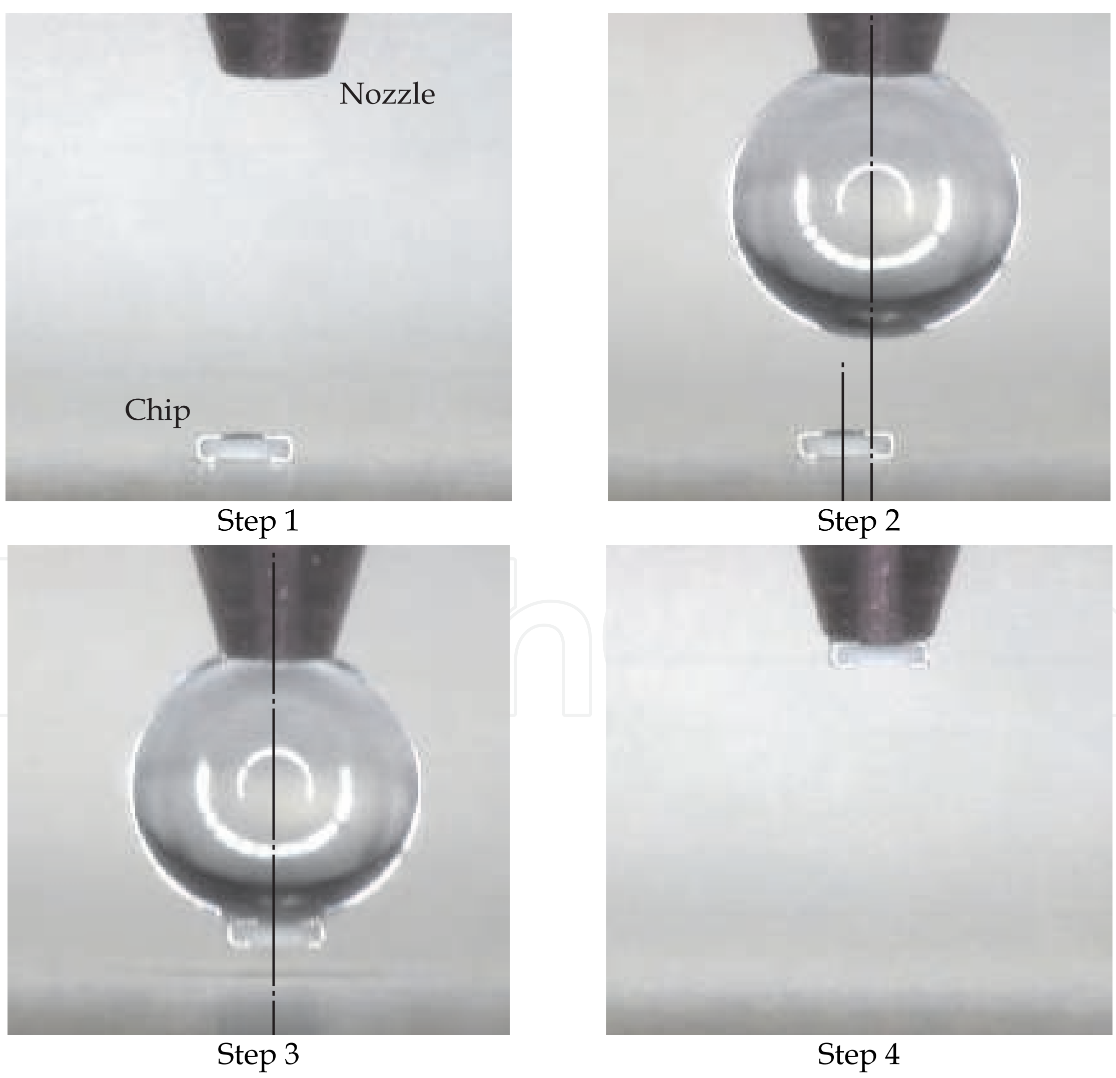


Fig. 8. Self-centering effect

4.2 Self-centering effect

Figure 8 demonstrates an actual process of picking up. Step 1 shows the initial state. In Step 2, a drop is produced at the top of the nozzle. A displacement of the tip from the center axis of the nozzle is observed. In Step 3, the tip moves to just the bottom of the drop after the nozzle descends for the drop to touch the tip. It is due to the self-centering effect. Then the drop is suctioned by vacuum so that the tip is held at the top of the nozzle as shown in Step 4.

This result demonstrates well the self-centering effect that enables picking up even in the presence of misalignment.

4.3 Effects of horizontal misalignment

Next, the effect of misalignment in the horizontal directions is investigated. Figure 9 shows the definitions of variables: radius of drop R and displacement of the tip to the nozzle center D_α $(\alpha = x, y)$. Picking up was carried out for various D_α .

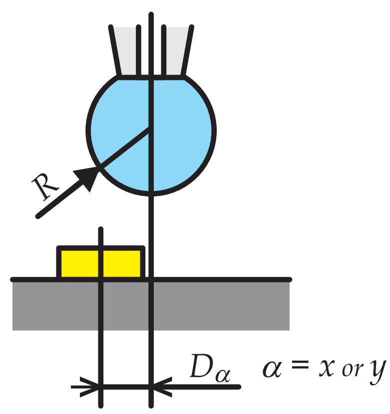


Fig. 9. Definition of Parameters

The results are classified as shown in Fig.10:

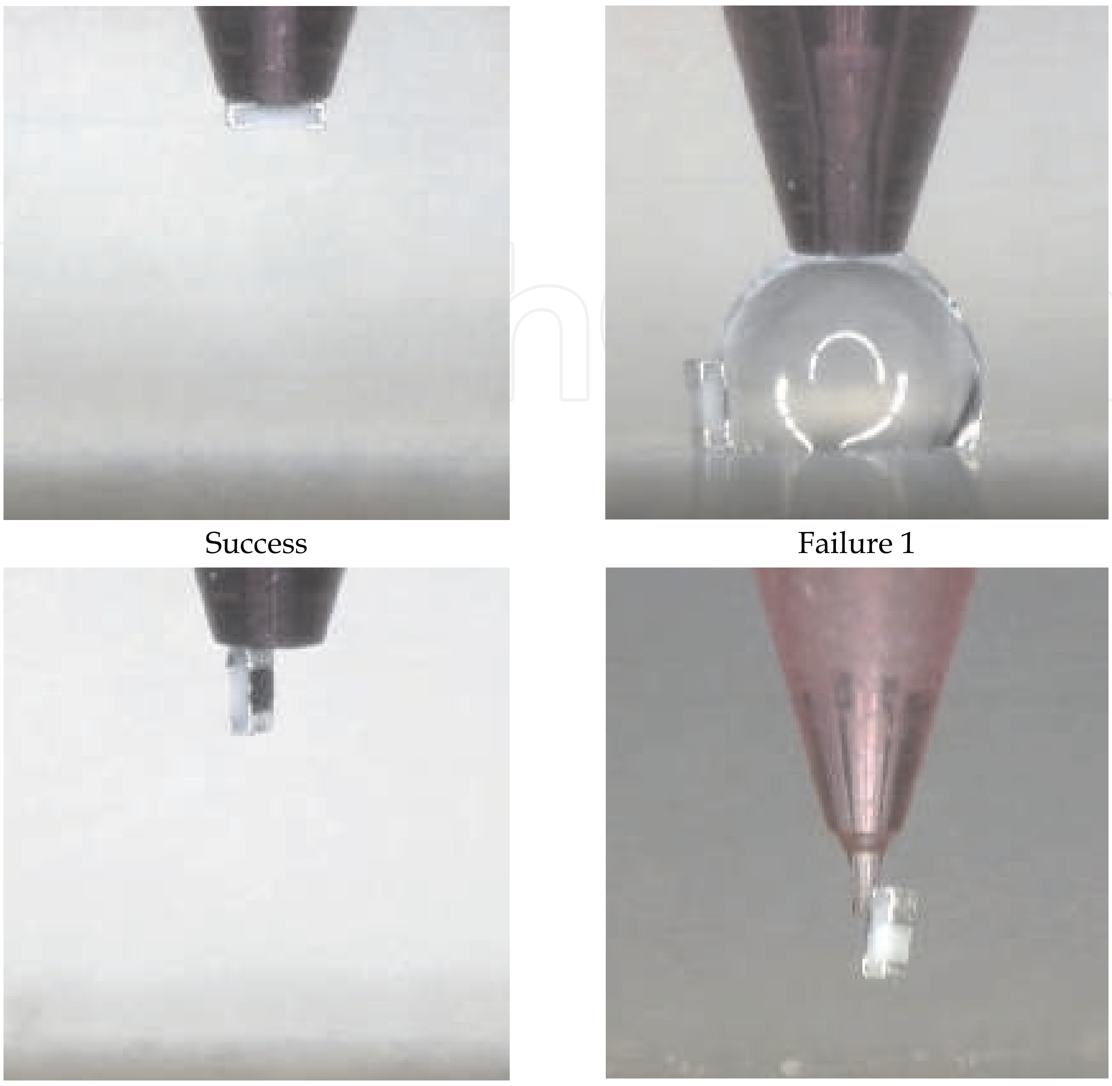
Success: The tip is picked up successfully at the center axis of the nozzle due to the self-centering effect.

Failure 1: The drop touches the surface of the stage on which the tip is placed. This phenomenon is observed for large misalignment. When the nozzle is lifted up, the tip is left on the stage because the drop breaks into two parts on the stage and on the nozzle.

Failure 2: The drop touches only the electrical plate when the chip is displaced in the Y-axis direction. After suction, the tip stands to the base of the nozzle.

Failure 3: When the outer diameter of the nozzle is too small, the tip attaches to the side of the nozzle even if the drop touches only the chip. It is avoidable if the diameter of the nozzle is selected appropriately.

Figures 11 and 12 show the experimental results for various D_x and D_y , respectively. The dotted line in these figures represents the limit $D_{\max}$ of misalignment that is determined by the geometrical constraints shown in Fig.13. It is given by



Success Failure 1

Failure 2 Failure 3

Fig. 10. Classification of operation

$$D_{\max} = \sqrt{R^2 - (R-h)^2} + \frac{l}{2} \quad \text{for } R \geq h \tag{1}$$

where l is the depth d of the tip in Fig.11 and the width w in Fig.12.

These results show that picking up is carried out successfully when misalignment is less than 0.2 mm. Since the common positioning accuracy of present mounting machines is 0.05 mm approximately, the proposed method is applicable even if tips are displaced and also for future smaller tips. In addition, larger drops enable successful picking up for more displaced tips.

It is also found from the experimental results that **Failure 1** and **Failure 2** occur when misalignment approaches to $D_{\max}$. In addition, **Failure 2** occurs only for Y-axis misalignment. The reason may be the inhomogeneousness of the surface of the chip in the Y-axis direction. It indicates that the surface structure and shape affects on the applicability of the proposed method.

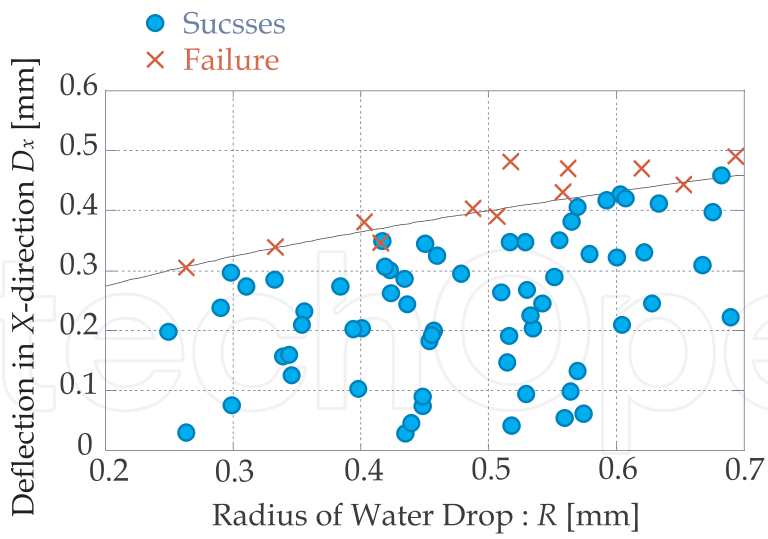


Fig. 11. Effects of deflection in X-direction

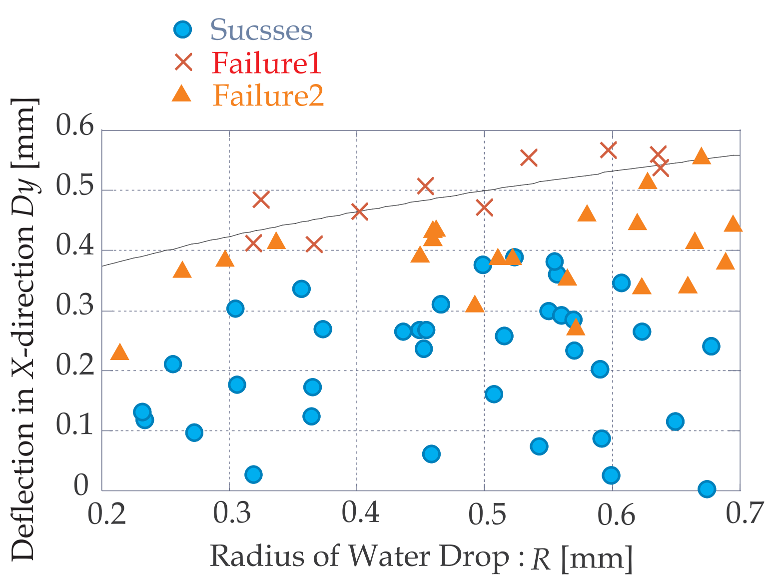


Fig. 12. Effects of deflection in Y-direction

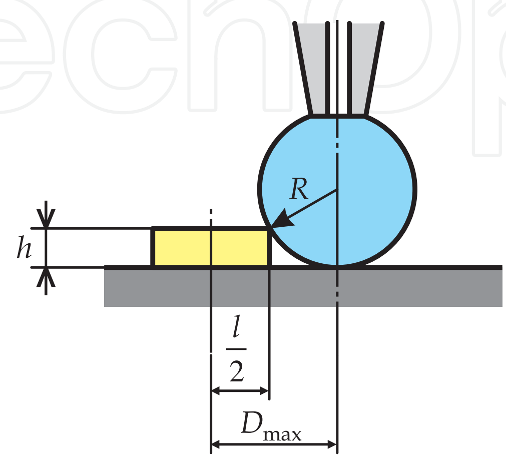


Fig. 13. Maximum deflection

4.4 Picking up accuracy

The positioning accuracy of the chip to the nozzle was estimated. The relative displacements of the gravity center of the chip to the center axis of the nozzle are measured with an optical microscope with a resolution of 1mm in the Y-axis direction and an optical digital measure with a resolution of less than 1µm in the X-axis direction.

Figure 14 shows the measurement results. The average error of the 33 measurements is 24µm. It indicates that the proposed method enables picking up with an accuracy of 24µm for chips displaced by up to 0.2mm.

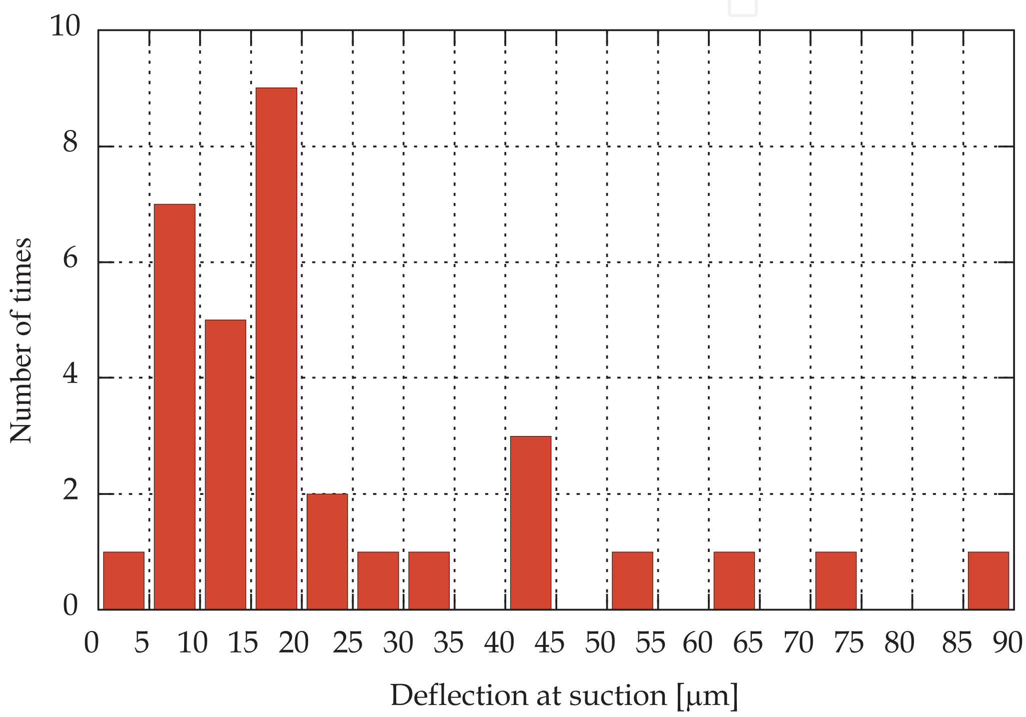


Fig. 14. Deflection at suction

4.5 Effects of vertical misalignment

The effect of misalignment in the vertical directions is investigated. In this experiment, the reference position $D_z = 0$ is defined by the nozzle position just when the drop touches the chip located at the center as shown in Fig.15. Figure 16 shows the results when the nozzle descends by 0.05mm and 0.1mm from the reference. It also shows the distance at which the drop touches the surface of the stage after deformation.

Figure 17 demonstrates the states for various misalignments. In Step 1, the nozzle just touches the chip, which corresponds to $D_z = 0$. In Step 2, the nozzle descends from the reference position a little. The ill effect of misalignment is absorbed by the deformation of the drop. When the misalignment exceeds some limit, the drop starts to move to the side of the nozzle (Step 3) and then touches to the surface of the stage (Step 4), which is similar to Failure 1.

The results indicate that misalignment less than 0.1mm can be absorbed by the deformation of the drop. It is also found that the limit do not depend on the diameter of the drop. It is to be noted that the limit of horizontal misalignment depends on the diameter given by Eq.(1).

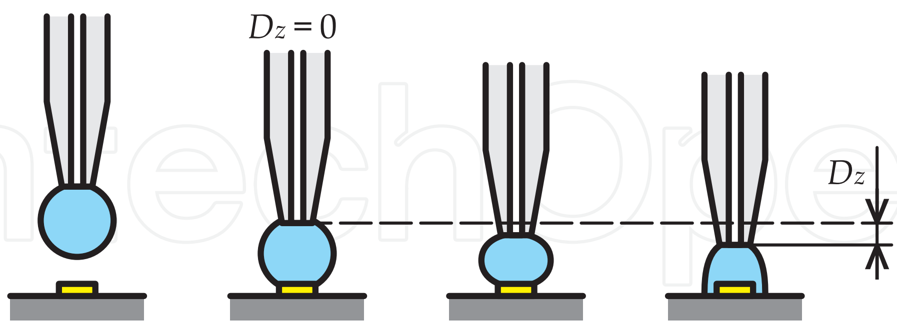


Fig. 15. Definition of deflection in Z-direction.

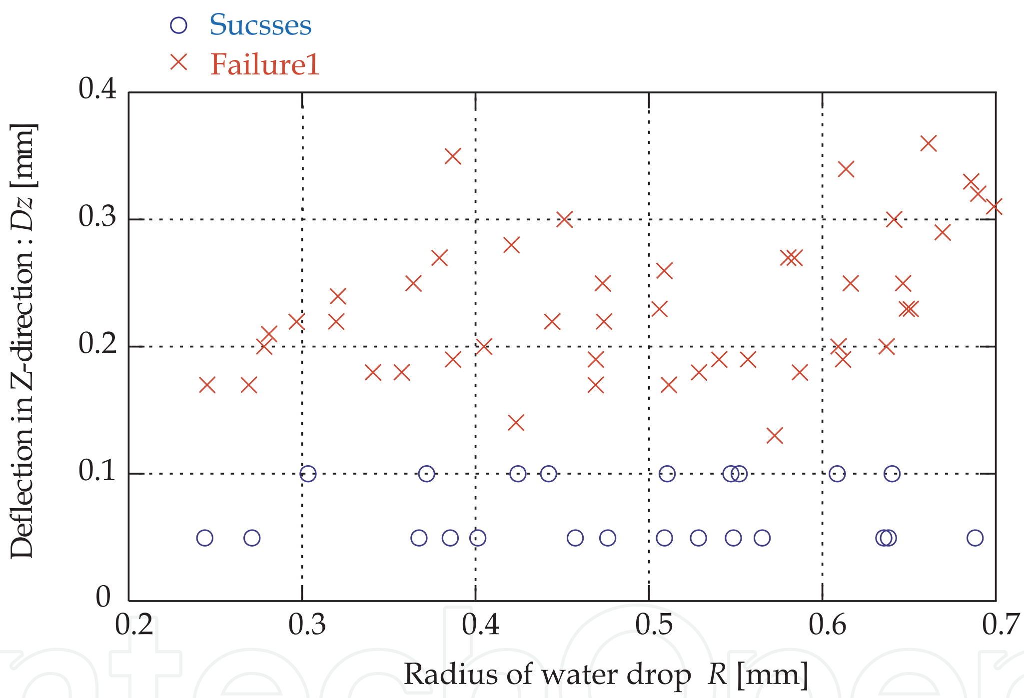


Fig. 16. Effects of deflection in Z-direction

5. Picking up cylindrical object

In the previous section, it has been demonstrated that the method using water drop is effective in picking up box-shaped objects. In this section, a cylindrical object is treated (Kato et al., 2010). The self-centering effect is also expected.

5.1 Object for picking up

Figure 18 shows a new object. It is made by cutting a wire of a multicore cable. The X-, Y-, and Z-axes are defined as shown in Fig.18.

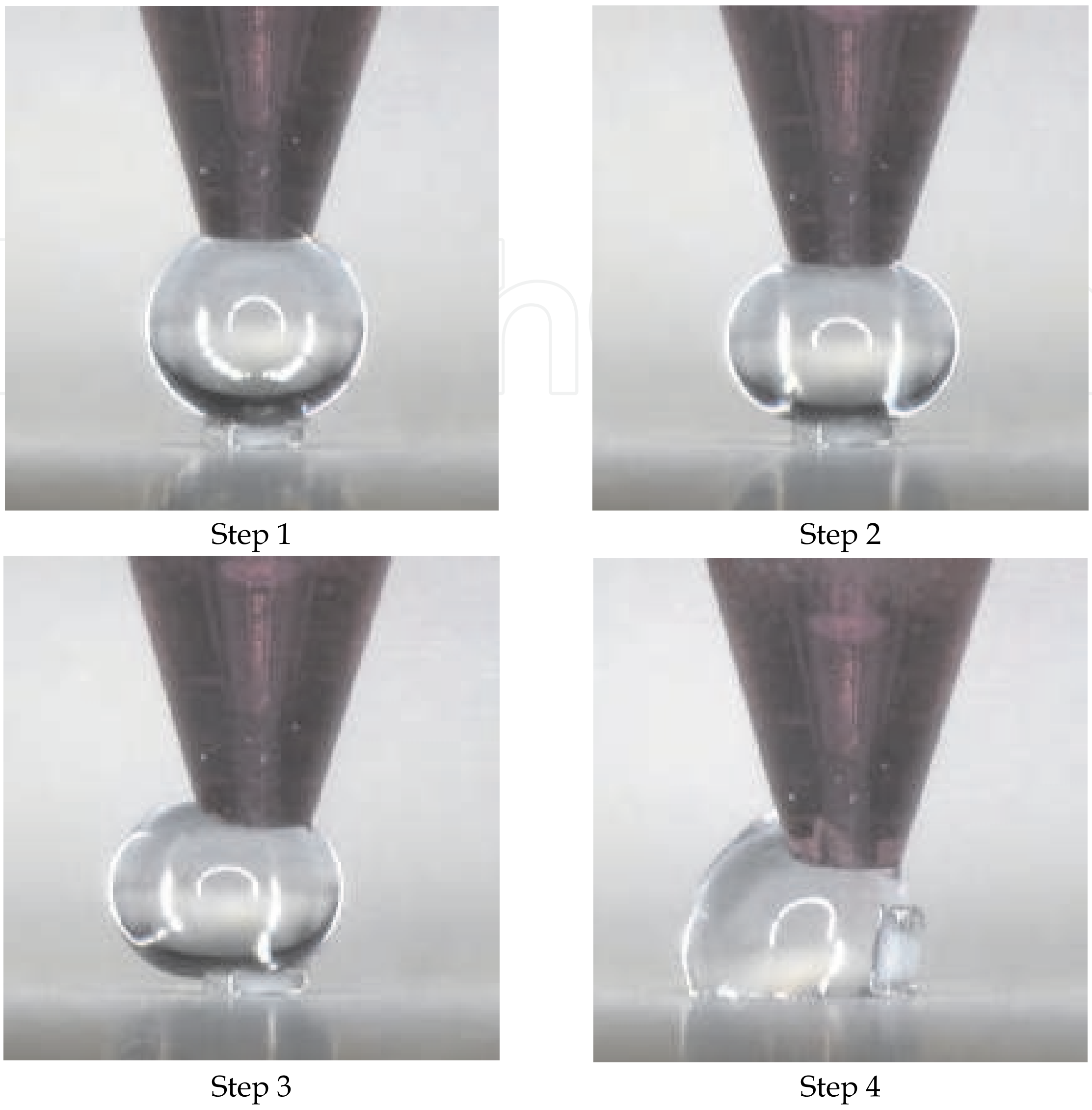


Fig. 17. Vertical deflection.

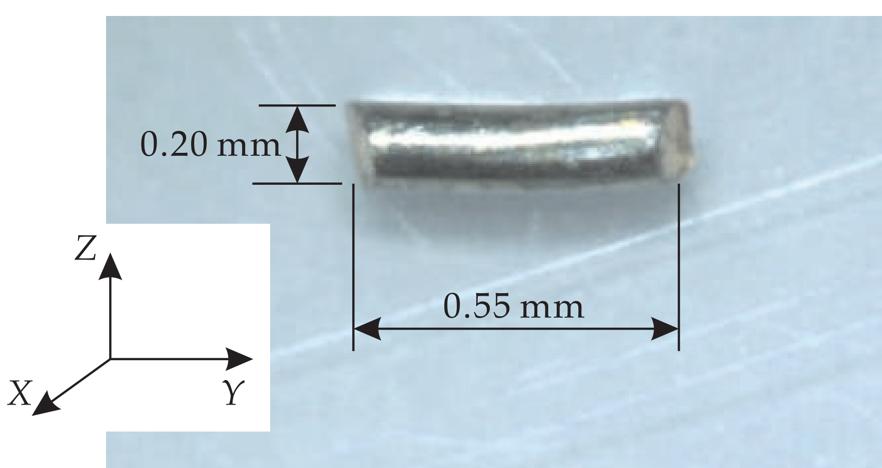
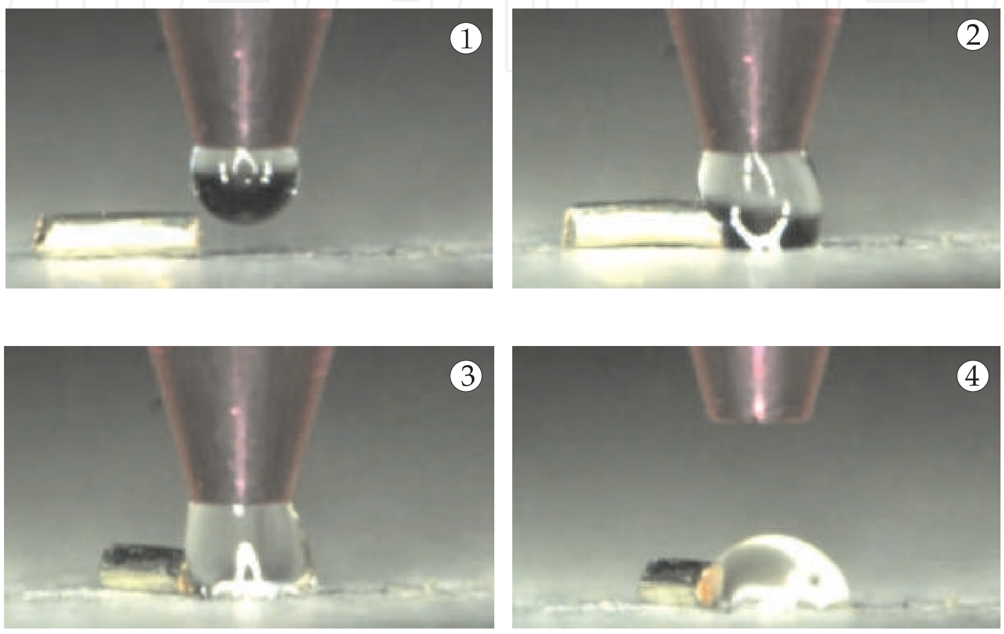


Fig. 18. Cylindrical object.

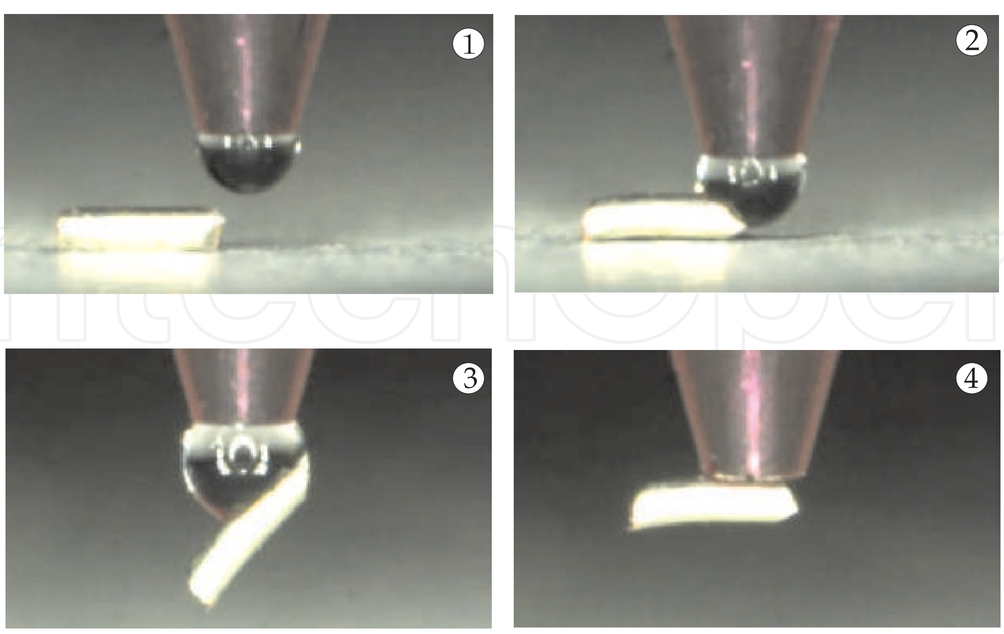
5.2 Effects of misalignment

The results of picking up and sanction are classified into three types. Two of them, Success and Failure 1 are similar to those in the experiments on the 0402 chip. Another type, Failure 4, was observed:

Failure 4: With a large misalignment in the Y-direction, the drop touched edge of the cylindrical object, as shown in Fig.19(b-2). Thus, the center of the nozzle was not aligned to the center of the cylindrical object.



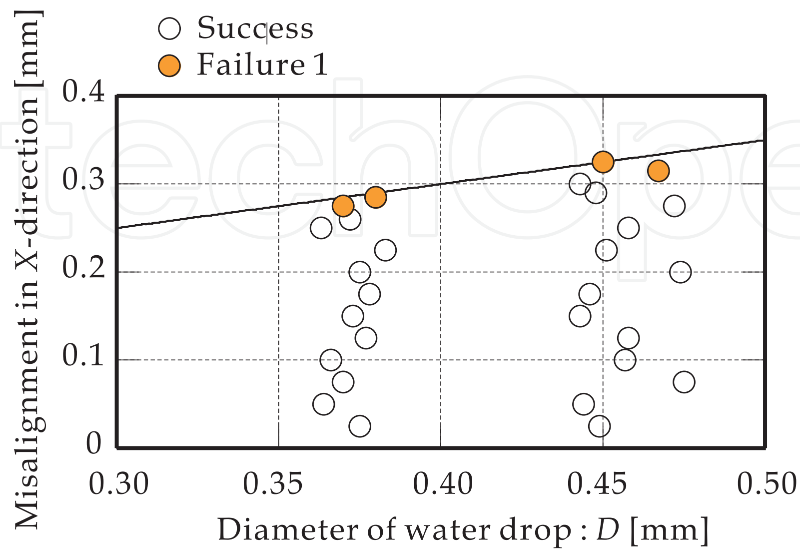
(a) Failure 1



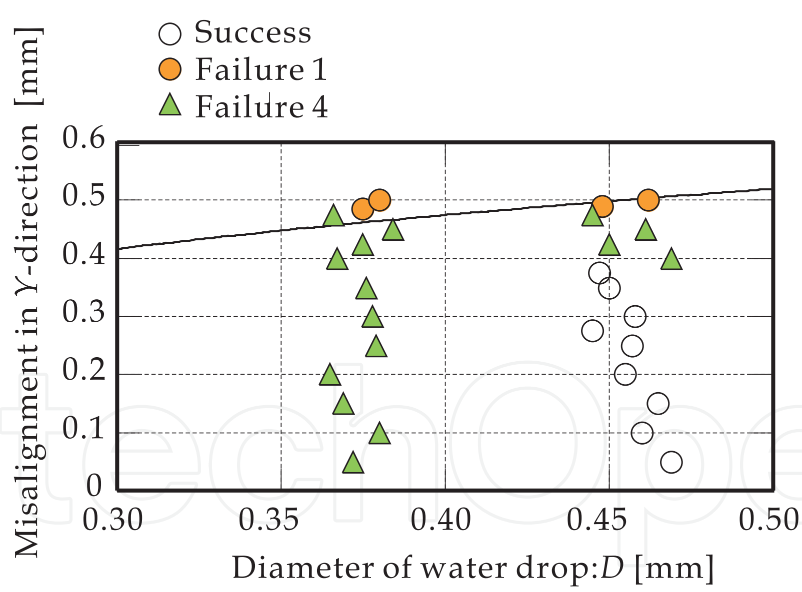
(b) Failure 4

Fig. 19. Classification of results for picking up a cylindrical object.

Figure 20 shows the results of picking up with the nozzles of external diameters of 0.37 and 0.46 mm. The prescribed deflection was given (a) in the X-direction and (b) in the Y-direction.



(a) X-direction



(b) Y-direction

Fig. 20. Relation between the diameter of the hemispherical drop and the misalignment for picking up a cylindrical object.

The lines in Fig.20 are the maximum deflection, where a drop contacts with both the cylindrical object and the stage at the same time. In the XZ section, the object is circular. Therefore, the maximum deflection in the X-direction is similar to that of the spherical object

(Kato et al., 2010). Similarly, it can be considered that the maximum deflection in the Y-direction is similar to that of the 0402 chip.

Figure 20(b) shows that the drop of an approximate diameter of 0.38 mm picked up the cylindrical object with a deflection between the center of a cylindrical object and the center of the nozzle. The initial misalignment between the cylindrical object and the nozzle remained after the pickup. It is supposed that the size of the drop was smaller than the size of the cylindrical object.

To verify this expectation, a cylindrical object was picked up with misalignment in the Y-direction using one of the nozzles, as shown in Fig.21. For water drop with a diameter less than 0.45mm, almost all the trials resulted in Failure 4. However, when the drop size was larger in diameter than 0.45 mm, Success was observed more often as drop size increased. As a result, a drop whose size was about 80% of the cylindrical object was required for obtaining the self- centering effect.

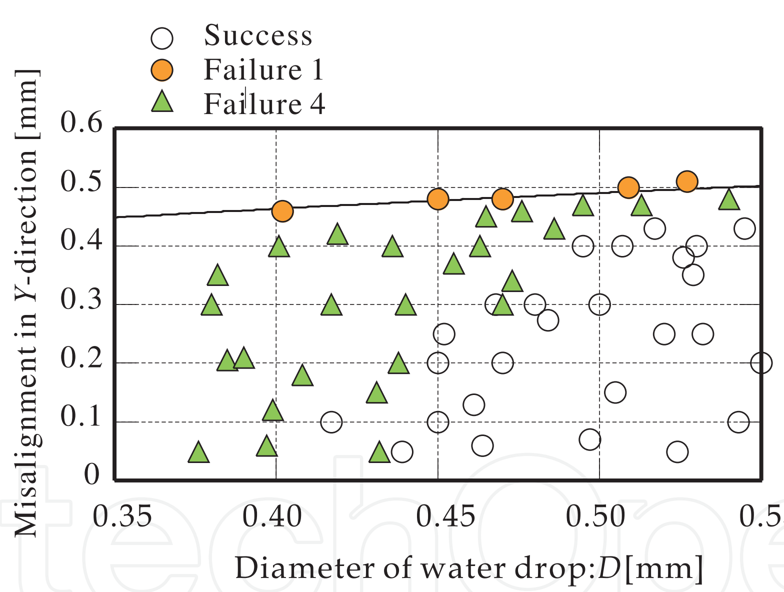


Fig. 21. Relation between the diameter of the drop and the misalignment in the Y-direction for picking up a cylindrical object.

6. Conclusions

A new method of microassembly using water drop for µm-order electric components was proposed. This method is characterized by combining surface tension with negative pressure produced by vacuum.

An experimental apparatus was fabricated for its experimental study. Experiments targeting actual industrial chips with a width of 0.4mm and a depth of 0.2mm were carried out. It was confirmed that the proposed method enables picking up chips displaced by up to 0.2mm due to self-centering effect. The average positioning error was 24μm even for such displaced objects. In addition, vertical misalignment can be absorbed by the deformation of the liquid.

A cylindrical object was also picked up with the proposed method. It was shown that drop with a size of about 80% of the cylindrical object was required for obtaining the self-centering effect.

This chapter described the experiments in which the working liquid was pure water. Haga et al. (2010) have studied the effect of liquid surface tension by using isopropanol (IPA) and its water mixture. The adsorption force of a drop was measured for IPA-water mixtures. It was found that the adsorption force of a drop was sufficient to lift up for the microchip.

7. References

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The book "New Technologies - Trends, Innovations and Research" presents contributions made by researchers from the entire world and from some modern fields of technology, serving as a valuable tool for scientists, researchers, graduate students and professionals. Some practical applications in particular areas are presented, offering the capability to solve problems resulted from economic needs and to perform specific functions. The book will make possible for scientists and engineers to get familiar with the ideas from researchers from some modern fields of activity. It will provide interesting examples of practical applications of knowledge, assist in the designing process, as well as bring changes to their research areas. A collection of techniques, that combine scientific resources, is provided to make necessary products with the desired quality criteria. Strong mathematical and scientific concepts were used in the applications. They meet the requirements of utility, usability and safety. Technological applications presented in the book have appropriate functions and they may be exploited with competitive advantages. The book has 17 chapters, covering the following subjects: manufacturing technologies, nanotechnologies, robotics, telecommunications, physics, dental medical technologies, smart homes, speech technologies, agriculture technologies and management.