Self-Alignment and Bonding of Microparts Using Adhesive Droplets

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This paper describes the self-alignment and bonding of microparts using adhesive surface tension to assemble microsystems in air. The alignment and bonding were tested experimentally using adhesive droplets, and the resulting performance was evaluated. The adhesive, which was inorganic and water-soluble before hardening, was diluted with water to a ratio of 10:1 so that its surface tension generated a sufficient restoring force for self-alignment. The experimental results showed that the average of the alignment errors obtained using the adhesive on 1.0 × 1.0 × 0.15-mm microparts was less than 2 μm in the X and Y directions and 0.2 degrees in the θ direction. These alignment errors were almost the same as those obtained using water. The use of a suitable adhesive had no negative effects on the alignment accuracy. The average tensile strength of the adhesive bond after self-alignment was 0.61 N/mm^2.

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1. Introduction

Many types of microsystems have been studied, not only as novel miniature systems that are useful in isolation, but also as microdevices in normal-sized systems. Normal-sized optical and mechanical systems often include many parts that are made from different materials and have different shapes to realize a high level of performance. Advanced microsystems also can consist of several microparts,[1,2] and microsystems that contain parts made from many types of materials can be fabricated using complex batch-fabrication processes. While built-in actuators can be used for the assembly task in these processes,[3,4] a complex process tends to deteriorate the yield ratio; separate fabrication processes are often preferred when fabricating microsystems consisting of separate smaller microparts made from different materials and shapes. A suitable assembly technique for microparts is necessary to realize microsystems that include many parts as industrial products, with alignment being an important task in the assembly procedure.

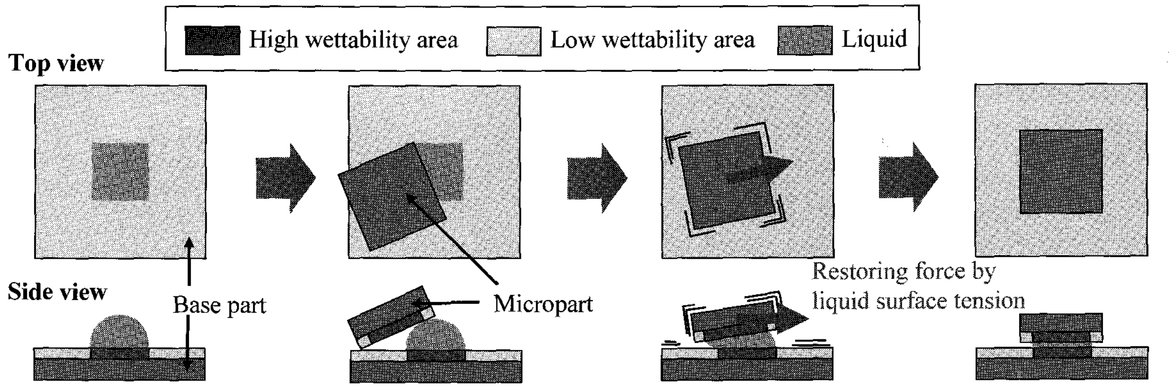
Servomechanisms, such as manipulators, are usually used for the alignment tasks of normal-sized systems,[5–7] and although micromanipulators have been considered for aligning microparts, the use of servomechanisms makes the alignment systems complex and large. The heat generated by the servomechanisms tends to deteriorate the measuring accuracy of the micropart position. To overcome these problems, self-alignment methods have been studied, in which electrostatic forces,[8] surface tensions of liquid in water,[9] and surface tensions of heated molten solder [10] are used as attractive forces for the alignment. These methods do not require servomechanisms, thereby reducing the size and complexity of the assembly equipment.

The purpose of this study was to establish a self-alignment method for micropart assembly using liquid surface tension in air. An alignment based on this method is not influenced by the flow of water, in contrast to the use of liquid surface tension in water, and does not produce thermal deformations of the microparts, in contrast to the heated molten solder technique. It also does not require wires for an electric power supply, unlike the electrostatic force technique. To date, the characteristics of self-alignment have been evaluated with water droplets.[11–13] The effects of the droplet volume and a high wettability area pattern on the alignment accuracy have been examined numerically and experimentally,[11,12] and the self-alignment of a group of microparts at a given instant in time and the self-standing out of the plane of rotational alignment have been described and evaluated experimentally.[13] However, the bonding task was not evaluated in these self-alignment experiments.

This paper describes the self-alignment of microparts using the surface tension of an adhesive and evaluates the resulting tensile strength of the adhesive bond after the self-alignment. In the alignment procedure, the bonding of the micropart is achieved in parallel with the alignment. A suitable adhesive and water repellent to produce a low wettability area are identified for the bonding procedure. The alignment errors and tensile strength of the adhesive bond are then evaluated experimentally.

2. Principle of Self-Alignment Using Liquid Surface Tension

Figure 1 shows the principle of the self-alignment method using liquid surface tension. This technique is based on the method described in.[12] The micropart and base part have high and low wettability areas on their surfaces, and the pair of aligned parts has



(a) Putting a liquid droplet (b) Rough positioning a micropart (c) Vibrating the micropart on the base part and aligning the micropart by liquid surface tension (d) Accomplishing the self-alignment

Fig. 1 Principle of the self-alignment method for microparts using liquid surface tension

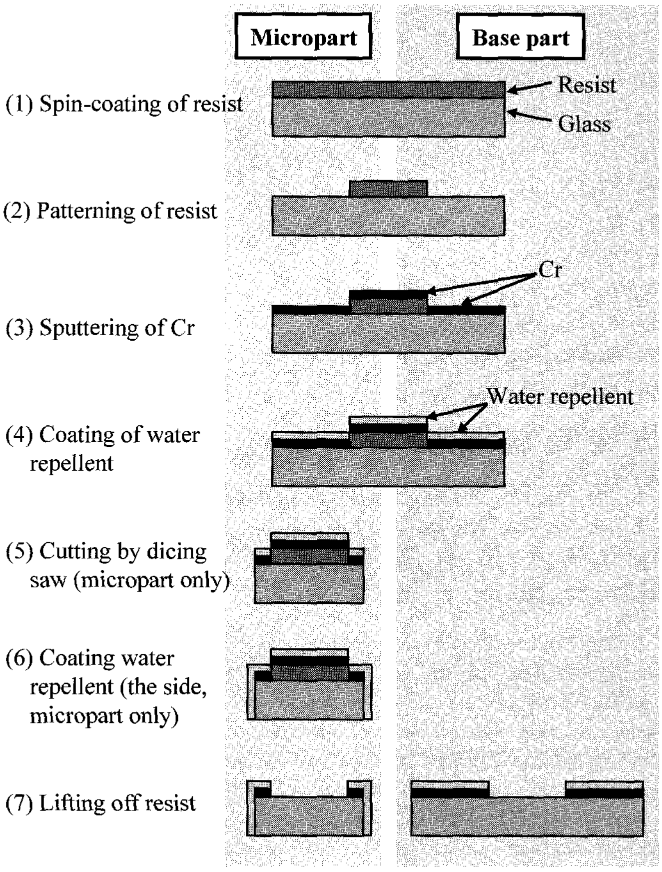
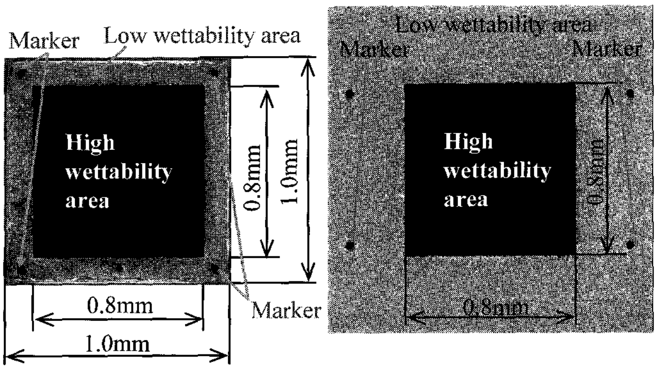


Fig. 2 Fabrication process of the micropart and base part

the same pattern in its the high wettability area. Using these parts, the self-alignment is carried out as follows.

(a) A liquid droplet is placed on the high wettablity area of the base part.
(b) The micropart is placed on top of the base part so that the droplet comes in contact with the high wettability areas of the two parts.
(c) The liquid acts so that its surface energy becomes small. Thus, the micropart is moved by the liquid surface tension so that the high wettability area pattern of the base part overlaps with that of the micropart. If necessary, the micropart is vibrated on the base part for a certain period so that it can be easily moved by the liquid surface tension.
(d) Self-alignment is achieved.



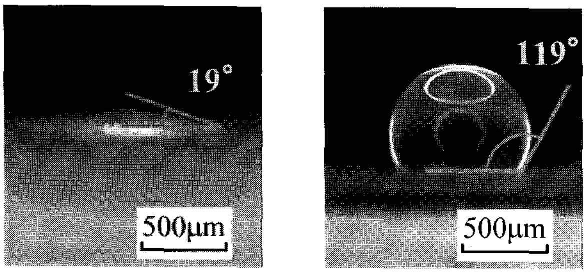
(a) Micropart (b) Base part

Fig. 3 Micropart and base part used in the experiment

In this study, an adhesive was used as the liquid for the self-alignment, and the bonding of the micropart was performed in parallel with the self-alignment. Although it was not always necessary to vibrate the micropart, it tended to come in contact with the base part directly and the friction between the parts could deteriorate the resulting alignment accuracy. In addition, the high wettability area on the micropart might not be in contact with the liquid. To overcome these problems, the micropart was vibrated during the self-alignment procedure.

3. Micropart and Base Part

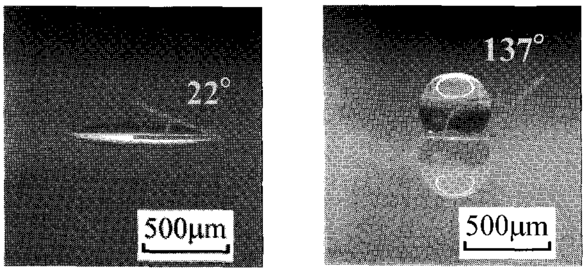
Figure 2 shows the fabrication process used to produce the micropart and base part. They both had high wettability areas made of glass and low wettability areas on which a water repellent was coated. The water repellent was made from a commercial coating. The adhesive used was water-soluble before hardening and tended to spread over the glass surface but not areas coated with the water repellent. The characteristics of the adhesive are described in the next section. A Cr layer was added under the water repellent so that the high wettability area was distinguishable from the low wettability area, allowing the corresponding behavior of the micropart to be



(a) Glass surface

(b) Surface coated with water repellent

Fig. 4 Contact angle of the adhesive



(a) Glass surface

(b) Surface coated with water repellent

Fig. 5 Contact angle of water

Table 1 Contact angle

	High wettability area		Low wettability area	
	Average (°)	Standard deviation (°)	Average (°)	Standard deviation (°)
Adhesive	19	4.6	119	12.9
Water	22	2.9	137	8.3

observed.

Figure 3 shows the micropart and base part used in the experiment. The size of the high wettability areas of the two parts were both 0.8 × 0.8 mm. The micropart was 1.0 × 1.0 × 0.15 mm in size. Figure 3(b) shows one of the high wettability area patterns on the base part, which contained 16 similar patterns on its surface. In each self-alignment test described later, one micropart and one of the patterns on the base part were used. The circular makers in the low wettability areas of both parts were used to measure the position and the inclination angle of the micropart with an image processing unit.

4. Adhesive

The adhesive required for the self-alignment method must have the following characteristics:

(a) a surface tension sufficiently large to generate a large restoring force and

(b) a large contact angle with the surface in the low wettability area to keep the adhesive attached to the high wettability area.

In the self-alignment method that is achieved in water,[9] the surface tension of the water around the micropart is used for the alignment. Thus, a high surface tension of the adhesive is unnecessary. However, in the method described in Section 2, characteristic (a) is necessary. Therefore, a water-soluble adhesive was selected that can attain a large surface tension when it is diluted with water. It can also form a large contact angle with a surface that is coated with a water repellent. The water-soluble adhesive was inorganic and diluted with water to a ratio of 10:1 so that the surface tension of the diluted adhesive generated a sufficient restoring force for the self-alignment.

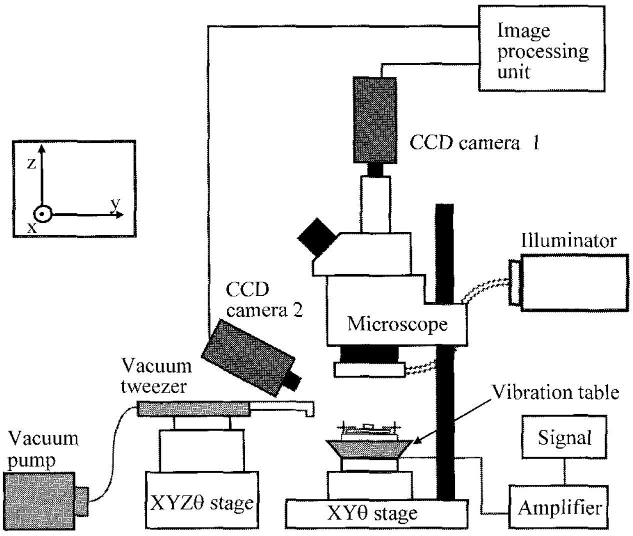


Fig. 6 Experimental apparatus

Figure 4 shows side views of droplets of the diluted adhesive on the two wettability areas. The high wettability area is presented in Figure 4(a) while the low wettability area is shown in Figure 4(b). The diluted adhesive droplets were observed after ultrasonic cleaning of the areas with acetone and pure water. White rings on the adhesive droplets are reflected images of the microscope ring illuminator, not voids. The diluted adhesive droplets were placed on the two areas 10 times. The contact angles of the diluted adhesive on the glass and the water repellent were measured, and the averages of the contact angles were 19° and 119°, respectively. Figure 5 shows side views of water droplets on the two wettability areas. The contact angles of the water on the glass and the water repellent were measured for comparison, and the averages of the contact angles were 22° and 137°, respectively. The average values and standard deviations of the contact angles of these liquids are listed in Table 1. The difference between the average contact angles of the adhesive and water was small, and thus, the alignment accuracy obtained using a droplet of the diluted adhesive was expected to be similar to that obtained using a water droplet.

5. Self-Alignment Tests

5.1 Setup

Figure 6 illustrates the experimental apparatus used to observe the micropart and liquid and to measure the alignment errors of the microparts. The position and inclination angle of the microparts were measured using an image processing unit with CCD camera #1 connected to a microscope. The measuring accuracy, which was calibrated with a capacitance displacement sensor, was better than 0.35 μm and 0.04°. CCD camera #2 was used to provide a side view of the micropart behavior.

The position and the inclination angle of the microparts could be adjusted using an $XY\theta$ fine stage. A vibration table was placed on the stage, and a rectangular wave voltage was applied to the vibration table so that the micropart essentially vibrated in the Z direction on the base part. The base part was fastened to the vibration table with four clips, as shown in Figure 7. The vibrating plate was adjusted so that its tilt was statically zero, and the micropart was carried by a vacuum tweezer system on the $XY\theta$ fine stage.

5.2 Alignment

The alignment tests were carried out as follows.

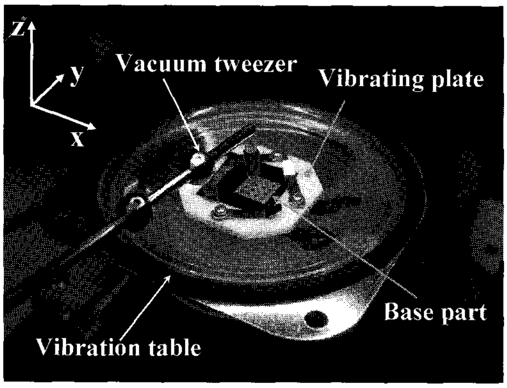
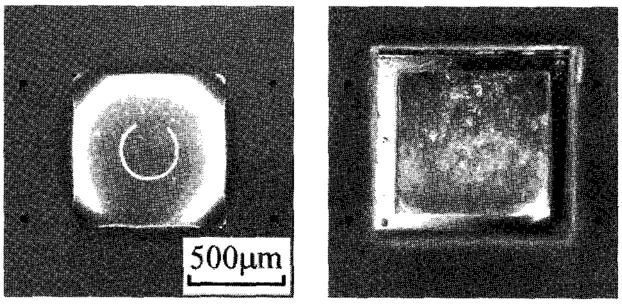
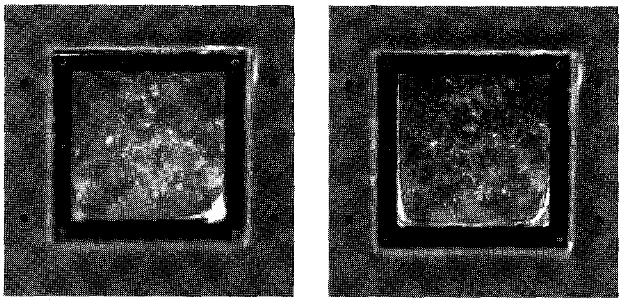


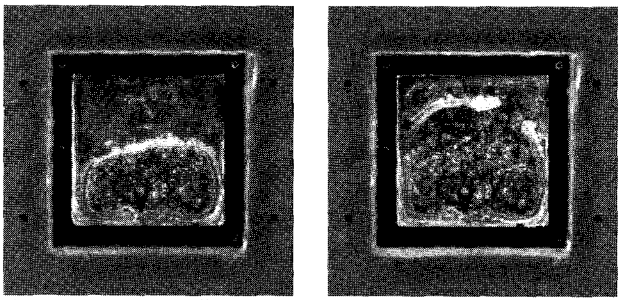
Fig. 7 Vibration table



(a) Putting a droplet of adhesive (b) Dropping a micropart



(c) Vibrating the micropart on a base part (d) Stopping vibration



(e) Evaporating the liquid content of the adhesive (f) Accomplishing the alignment and the bonding

Fig. 8 Top view of the micropart and adhesive droplet during the self-alignment tests

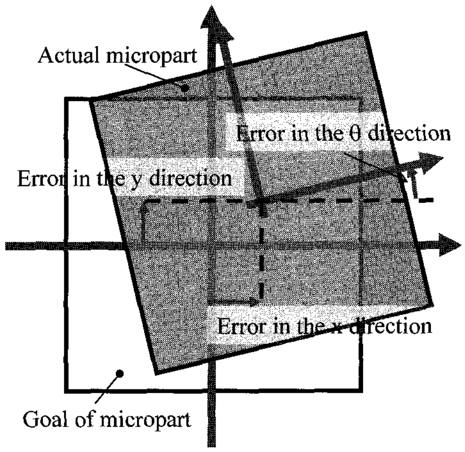
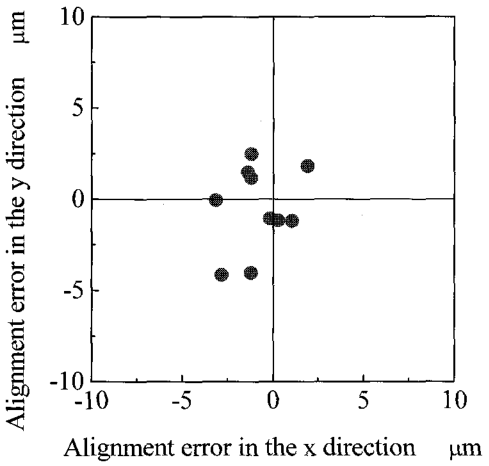
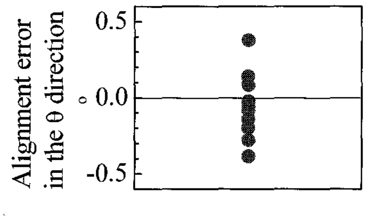


Fig. 9 Definition of alignment errors



(a) Errors in the X and Y directions



(b) Error in the θ direction

Fig.10 Experimental self-alignment errors using the adhesive

Table 2 Overall alignment errors obtained using the adhesive

	Error (absolute value)	
	Average (°)	Standard deviation (°)
X	1.44	0.96
Y	1.86	1.32
Horizontal	2.53	1.30
θ	0.18	0.13

(a) An adhesive droplet was placed on the base part using a syringe so that the droplet came in contact with the high wettability areas on the base part.
(b) The micropart was dropped from a height of 500 µm above the base part. The air under the micropart disturbed its falling motion so that the position and inclination angle of the micropart tended to change after it was dropped.[14]
(c) The micropart was vibrated on the base part for 20 s.
(d) Alignment and bonding were achieved after the liquid content of the adhesive evaporated. The solid content of the adhesive droplet was 4.8%.

A top view of the micropart and adhesive droplet during the alignment tests is shown in Figure 8.

Figure 9 illustrates the definition of the alignment errors in the X, Y, and θ directions. The errors in the X and Y directions are shown in Figure 10(a) and the error in the θ direction is given in Figure 10(b).

The same alignment procedure was repeated 10 times using the adhesive, and the averages and standard deviations of the errors are shown in Table 2. Table 3 gives the averages and standard deviations of the experimental alignment errors obtained using water. The alignment errors using the adhesive surface tension were similar to those obtained using the water surface tension. Thus, the use of the adhesive did not deteriorate the alignment accuracy. The averages and standard deviations of the errors shown in Table 2 are smaller than those listed in.[12] We attribute this to the facts that we vibrated the micropart on the base part and used a water repellent to increase the water shedding ability of the low wettability areas.

5.3 Tensile strength of the adhesive bond

The tensile strength of the adhesive bond between the micropart and base part was measured after they were aligned. Figure 11 shows the apparatus used to measure the tensile strength, which consisted of a Z stage on which the base part was fixed and a tension gauge to which the micropart was bonded. The gauge resolution was 0.025 N. The Z stage was moved downward and the tension force required to separate the micropart from the base part was measured. The tensile strength measurement was performed 10 times. The average and standard deviation of the tensile strength after alignment was 0.61 N/mm^2 and 0.15 N/mm^2, respectively.

When the diluted adhesive used in the above experiments was applied between the glass plates manually, the tensile strength of the resulting adhesive bond was about one-third of that obtained after the self-alignment tests. This was because a larger volume of adhesive was used in the self-alignment tests.

Table 3 Alignment errors obtained using water

	Error (absolute value)	
	Average (°)	Standard deviation (°)
X	1.54	1.38
Y	2.03	1.71
Horizontal	2.91	1.63
θ	0.10	0.10

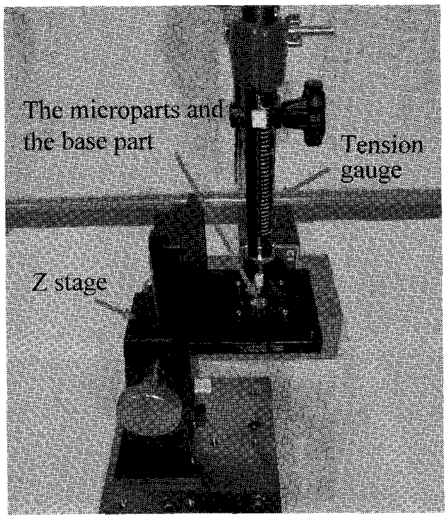


Fig. 11 Tensile test apparatus

6. Conclusions

Self-alignment and bonding of microparts using an adhesive was attained and the resulting performance was evaluated experimentally to establish a suitable method for micropart assemblies using liquid surface tension in air. The adhesive was inorganic and water-soluble before hardening. The adhesive was diluted with water so that its surface tension generated a sufficient restoring force for the self-alignment procedure. The experimental results demonstrated that the average alignment error in the X and Y directions was less than 2 μm and the average alignment error in the θ direction was less than 0.2 degrees. The alignment errors obtained using the adhesive were almost the same as those using water. Applying a suitable adhesive had no negative effects on the alignment accuracy, and the average tensile strength of the adhesive bond after self-alignment was 0.61 N/mm^2.

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