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Stabilization of the tilt motion during capillary self-alignment of rectangular chips

J. Berthier[a,*], K.A. Brakke[b], S. Mermoz[c], C. Frétigny[d], L. Di Cioccio[e]

[a] University Grenoble Alpes F-38000 Grenoble, Department of Biotechnology, CEA, LETI, MINATEC Campus, F-38054, Grenoble, France
[b] Mathematics Department, Susquehanna University, 514 University Avenue, Selinsgrove, PA 17870, USA
[c] STMicroelectronics, 850 rue Jean Monnet, 38926 Crolles Cedex, France
[d] UPMC/CNRS/ESPCI PPMD UMR 7615, Physico-Chimie des Polymeres et des Milieux Disperses, 10 rue Vauquelin, 75231 Paris, Cedex 05, France
[e] University Grenoble Alpes F-38000 Grenoble, Department of Microelectronics, CEA, LETI, MINATEC Campus, F-38054, Grenoble, France

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ABSTRACT

Capillary self-alignment (CSA) has emerged as a convenient technique to assemble solid objects. In this technique a liquid droplet forces a mobile solid plate or chip to align with its counterpart on a solid substrate. It has been widely investigated for applications such as 3D microelectronics and assembly of optical components. It is now thought that it could be a solution for surface mounting and packaging technologies. For 3D microelectronics, where square or rectangular chips are used, it has been found that amongst the four displacement modes, i.e. shift, twist, lift and tilt, only the tilt mode was unstable (not restoring). In particular, tilting of a floating square or rectangular chip may trigger a direct contact between the plate and the pad that impedes alignment. In this text, an analysis of the tilt mode is first presented. Second, it is demonstrated that tilt can be stabilized by incorporating specific geometrical features such as lyophilic bands patterned on the substrate.

1. Introduction

Capillary self-alignment (CSA) of mesoscopic objects emerged in the early 1990s as a convenient technique to assemble solid objects [1–4]. It has been recently widely investigated for applications such as 3D microelectronics [5–7] and assembly of optical components [8–10]. It is now thought that it could be a solution for packaging technologies [11]. In this technique the capillary forces exerted by a liquid sandwiched between the two plates forces the mobile solid plate or chip to align with its counterpart on the solid substrate. More specifically, surface tension forces associated to capillary pinning create restoring forces and torques that tend to bring the moving part into alignment [12–14]. Later, evaporation—when the liquid is water—or solidification—when the liquid is a solder—immobilizes the chip in the aligned position.

In the particular case of 3D microelectronics, where square or rectangular chips are used (Fig. 1), it has been found that amongst the four displacement modes—shift, twist, lift and tilt—the three first were stable (restoring). On the other hand, the effect of the tilt mode has been lengthily debated. Using sophisticated calculation, it appeared that this mode is slightly unstable (not restoring) [13]. Fig. 2 shows the tilting of a LED deposited on a solder. The instability of the tilt mode may bring serious drawbacks on the capillary alignment technique [13–19]. For 3D microelectronics, where small amounts of liquid are used, the distance between the two solids is small, and tilting may trigger a direct contact between the moving plate and the fixed pad that impedes alignment. Avoiding tilt requires achieving perfect horizontality of the chip at the instant of the drop-off, which complicates substantially the robotics that brings the chip above the pad [20].

Self-alignment of mirrors uses the same capillary principle as microelectronic chip alignment [7–9]. In the alignment process of mirrors for optical applications, a solder is used, then gelled, and tilt cannot be tolerated. Fig. 2 shows an example of tilt instability during the alignment of mirrors.

Other approaches for the control of the tilt have been done: mechanical stops and hinges for the guidance of the pieces to assemble have been shown to be effective against rotational undesired motion [21,22]. However, due to their 3D structure, such devices require complicated fabrication, not compatible with the requirements of microelectronics. Note that for very small objects to align—in the range from 50 to 200 μm where random agitation is efficient—hydrophobic patterns on the objects have been used to improve the alignment [23]. This type of solution is not effective

* Corresponding author.
E-mail address: jean.berthier@wanadoo.fr (J. Berthier).

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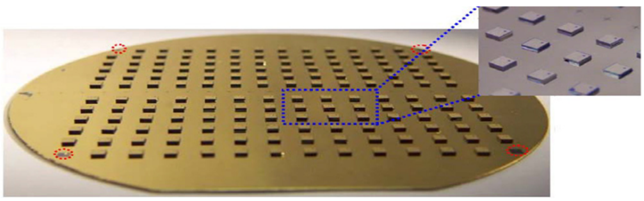

Fig. 1. Chips self-assembled on a wafer.

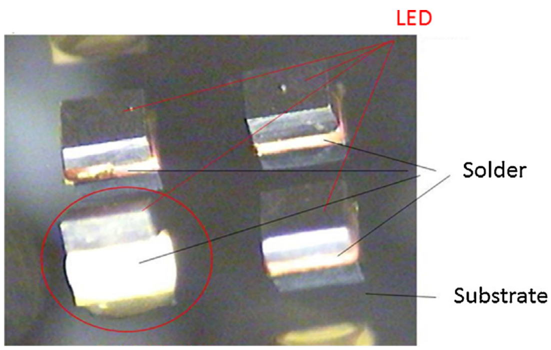

Fig. 2. Left: tilting of a LED deposited on a liquid solder.

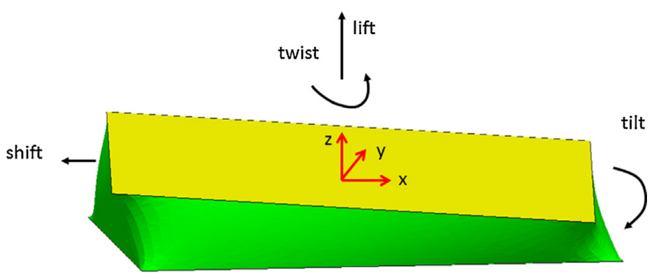

Fig. 3. The four displacement modes during alignment process.

for microelectronic chips whose size is much larger—in the range 1–5 mm—and for which random agitation is not conceivable.

Based on a computational approach, a completely passive method is described in this work that impedes the tilt motion for square and rectangular chips.

First an analysis of the tilt mode is presented: it shows that the tilt mode is slightly unstable in the case of square or rectangular chips [13]. Second, it is demonstrated that tilt can be eliminated by incorporating specific geometrical features such as wetting bands patterned on the substrate. These wetting bands allow for a controlled spreading of the liquid.

The solution is completely passive and does not bring complication in the microfabrication process. It just requires drawing a patterning mask that includes the wetting bands.

2. Alignment modes

In the process of alignment of square or rectangular chips, four displacement modes have been defined: (1) shift, which is a horizontal translation of the plate, (2) twist, corresponding to a rotation of the plate in the horizontal plane, (3) lift, corresponding to a vertical motion of the plate, and (4) tilt and roll, which are respectively rotations around the horizontal y-axis and x-axis (Fig. 3).

An analysis of the restoring forces and torques has been done analytically [13,20] and in addition numerically by using the program Surface Evolver [24]. Fig. 4 shows the restoring of alignment for shift, lift and twist modes, but not for the tilt mode. In the following, we investigate the physics of the tilt mode and propose a geometrical solution to render the tilt mode stable for chips of sufficiently light weight.

3. Analysis of the tilt mode

By definition, tilt is a rotation around the y-axis and roll a rotation around the x-axis. Basically, tilt and roll share the same behavior. In the case where the chip has a square shape, tilt and roll are exactly identical. Tilt is a complex phenomenon because the variation of the surface area is difficult to intuitively predict.

If we make the very simple reasoning presented in Fig. 5, comparing horizontal and fully tilted chip positions, we deduce that the problem is indeterminate. For the same volume of liquid, we assume the simplest form of surfaces: flat interfaces in the case of parallel-to-pad chip, and in the case of the dihedral position, a cylindrical interface for the largest surface area, and flat interfaces for the two lateral surfaces. The surface energy E in the horizontal configuration is

$$E = \gamma S = \gamma\,(4 L h) = \gamma\left(4\frac{V_l}{L}\right), \tag{1}$$

where V_l is the liquid volume, L the dimension of the pad—and chip—edge, and γ the liquid–air surface tension. In the dihedral morphology, the surface energy is

$$E = \gamma S = \gamma\left[2\left(\frac{\alpha L^2}{2}\right) + \alpha L^2\right] = \gamma\left(4\frac{V_l}{L}\right), \tag{2}$$

where α denotes the dihedral angle.

The two calculated energies are equal. Hence, it is the distortion of the surfaces that can make the difference and pinpoint the stable position. It is a second order problem that requires a careful numerical approach. This remark leads to serious complications: from a numerical standpoint, the meshing of the surface should be sufficiently fine and the numerical method should be sufficiently elaborated to produce a precise value of the energy. In return, the computation time is long. From a physical standpoint, the roles of the parameters—like the weight of the chip, or the surface tension of the liquid—are difficult to predict.

In the investigations presented in this work, we have considered a square chip of horizontal dimensions 5 × 5 mm, with a weight of 0.07 g (corresponding to a chip height of approximately 400 μm). The liquid is water, with a surface tension γ = 72 mN/m.

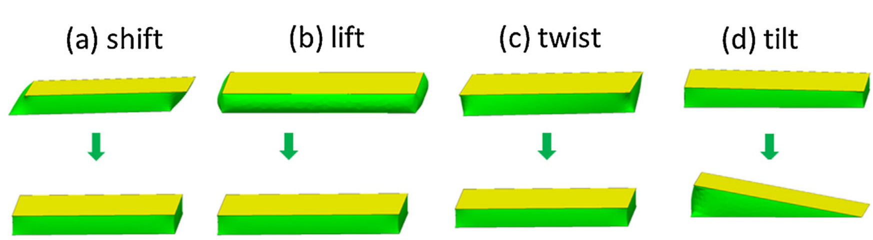

Fig. 4. (a)–(c): Shift, lift and twist modes are stable; tilt mode (d) is unstable (from Evolver).