Self-alignment of silicon chips on wafers: the effect of spreading and wetting

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ABSTRACT

3D integration is the key to advanced microelectronic systems. Die-to-wafer assembly is a necessary step to reach full integration. Self-assembly methods are promising due to their parallel aspect which overcomes the main difficulties of the current techniques. The aim of this work is the understanding of the mechanisms of self-alignment. In a preceding work, the stable and unstable modes have been investigated, assuming that the fluid completely wets the surfaces of the chip and the fixed pad. In this work, we focus on the mechanism of spreading and the motion of the chip during the spreading. We use again the Surface Evolver software to analyze the mechanisms of the chip motion.

Keywords: 3D microelectronics, self alignment, pinning, spreading

INTRODUCTION

3D integration appears as the key to advanced microelectronic systems. While robotic methods experience difficulties to accommodate fabrication speed and alignment accuracy, self-assembly methods are promising due to their parallel aspect, which overcomes the main difficulties of the current techniques. We investigate a self-assembly method based on capillary alignment of a chip on a fixed pad. Capillary forces are used to align the chip and evaporation of the liquid droplet eventually leads to contact and direct bonding of the chip on the fixed pad [1-5] (fig.1). In a preceding paper we have focused on the alignment in a quasi-steady state, assuming that the liquid droplet has spread to the chip and pad boundaries and remains pinned along the edges of the chip and pad [6,7]. A similar approach has also been followed by Lambert et al. [8]. It has been shown that the fully wetted, stabilized state produces a precise alignment. However, recent experiments have shown that this quasi steady state is an ideal case which is not always reached due to defects in spreading or overspreading. In this work we focus on the progressive spreading of the liquid and wetting of the two surfaces and analyze the consequences on the alignment.

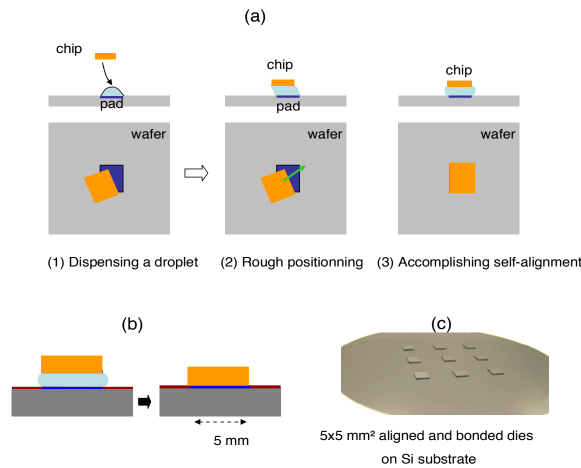

Figure 1: Principle of capillary alignment. (a) sketch of the droplet and the die; (b) sketch of the die before and after evaporation; (c) view of aligned dies on a wafer.

Our approach is both experimental and numerical, with an emphasis on the numerical modeling.

1 MATERIALS AND METHODS

The experimental setup is composed of a pad and a chip of exactly the same surface area. In order to reinforce a good pinning on the chip and pad boundaries, reliefs with sharp edges have been added to the two surfaces (fig.2). This is why two "borders" appear on the photograph of figure 3. The chip is gently deposited on top of a water droplet initially pipetted on the pad. The motion of the chip is then followed with a fast camera.

Two series of experiments have been performed: in the first one, the Young contact angles of both surfaces are 60° and in the second one, 30°. A perfect alignment—to the tolerance of the chip and pad dimensions—is always obtained in the first series of experiments. On the other

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hand, a rate of 30% only of success is obtained when the contact angle is 30°.

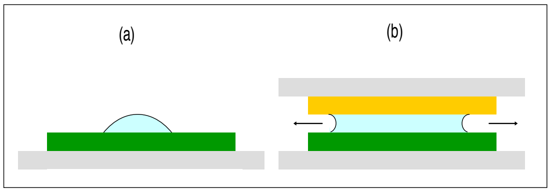

Figure2: Schematic of the experiment

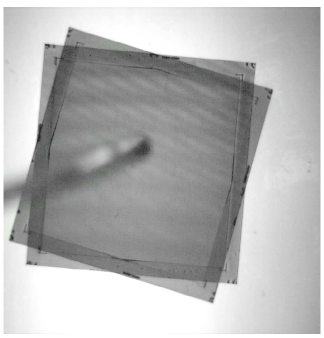

Figure 3: View of the pad and chip. The chip is still held by a suction tube.

It is observed that the shift (horizontal translation of the chip relative to the pad) is very quickly resolved, and then the twist (rotation of vertical axis) is progressively reduced to reach alignment—when alignment is reached. In the cases of misalignment the twist is not resolved.

2 PHYSICAL ANALYSIS

The physical analysis is summarized in figure 4. In a first stage, the droplet spreads under the action of the capillary forces (and the weight of the chip). During this stage, there is no motion of the chip relative to the pad, due to the nearly perfectly circular shape of the spreading triple line. This stage ends when the triple lines reach the first edge, either that of the chip, or of the pad. The analysis of the forces on the chip edges show that there is a translational restoring force that tends to zero out the shift. Figure 5 shows the capillary force acting on the moving chip depending on which edge the pinning first occurs.

In a third stage, there is a restoring torque that brings the chip to alignment (fig.4.c).

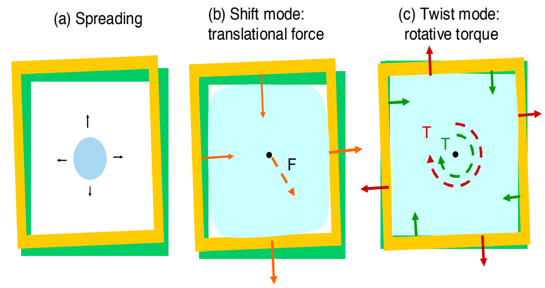

Figure 4: Sketch of the spreading. The chip only appears through its frame, for easier visualization.

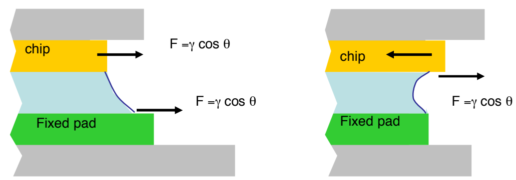

Figure 5: The two different situations of pinning: left, pinning on the pad edge; right, pinning on the chip edge.

It is extremely important that the spreading is uniform. Consider the two following cases shown in figure 6: (i) symmetric wetting defect in a corner, (ii) asymmetric wetting defect in a corner. In the first case, the restoring shift is blocked at some point when the resultant of the forces vanishes: during the translational motion, the shift is progressively reduced, but the opposing force caused by the wetting defect still acts on the chip, it even increases because the length of the triple line corresponding to the dewetted area increases. The chip cannot reach its aligned position. In the second case, the same mechanism occurs for the shift; moreover the asymmetry induces a small torque which causes a twist of the moving chip. The resultant of the capillary forces along the dewetted section does not intersect the center of the chip. A shift plus a twist remain preventing alignment.

It has been observed that in the case of 30° contact angle, the pinning on the edges is not systematically achieved resulting in a liquid overflow; when the overflow is important, the restoring forces and torques are not sufficient, or they are asymmetrical and a misalignment occurs.

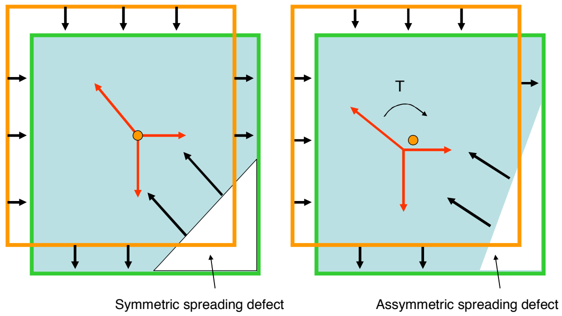

Figure 6: Left: a symmetric wetting defect in a corner blocks the restoring motion; right: an asymmetric wetting defect blocks the restoring motion and creates a twist.

3 MODELING RESULTS

Although Surface Evolver cannot take care of the dynamics of the spreading, the model becomes relevant when the interface reaches the pad and chip edges [9]. In such a topology, the surface tension forces are dominant under the condition that the chip has been dropped gently, i.e. the fluid is not flushed violently by the inertia of the falling chip. From a numerical standpoint, the difficulty in such a case is to specify constraints that can adapt to the moving edges during chip motion.

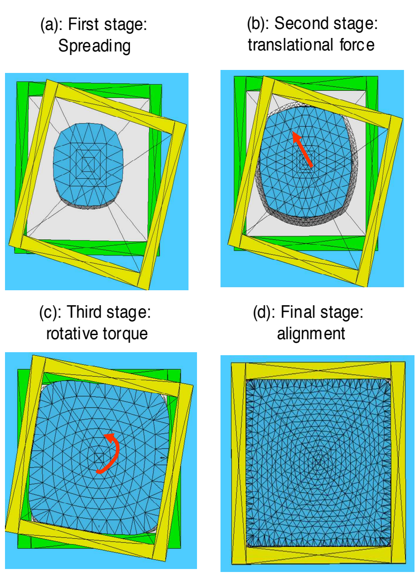

Figure 7: Evolution of water spreading and wetting on the two surfaces (Evolver). Note that the chip has been dematerialized for easier visualization.

The numerical results agree with the physical analysis presented in section 2, i.e. the shift is first reduced, then the twist (fig.7). This results is in agreement with our previous work [6,7]: the shift restoring force is by far dominant in the process.

The numerical method can be used to investigate the case where the spreading is incomplete—for example if the substrate is not perfectly clean. We show here that self-alignment is impossible in such a case. When looking closely at the corner, it is observed that wetting cannot be complete: a curvature radius always remains in the corners, even for extremely hydrophilic cases. These small, symmetrical dewetted areas do not prevent alignment because they have a very small extent and they are completely symmetrical relatively to the pad center. However, as we have seen in the preceding section, a real wetting defect results in an incomplete alignment.

In the case of figure 8, different spreading defects are investigated: a band along on side of the pad, a large corner and an asymmetrical large corner. The liquid spreads to reach the edges, but cannot wet the part of the pad with the defect. All these configurations result in a misalignment with a remaining shift and twist of the chip.

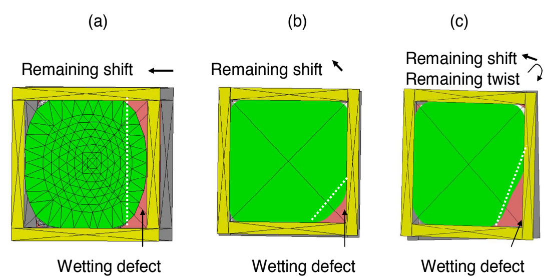

Figure 8: Analysis of the behavior of the chip in the case of wetting defects: (a) non-wetted band, (b) non-wetted corner, (c) asymmetric non-wetted corner

In conclusion, self alignment is achieved when the spreading is total on the two surfaces—to the exception of the extremity of the corners which can never be totally wetted.

It appears that the condition of spreading is not sufficient: the pinning along the pad and chip edges is also important. Figure 9 shows that a large overspread linked to the rupture of the pinning result in a misalignment.

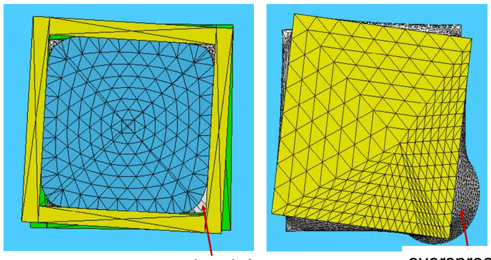

Figure 9: Alignment not reached due to a wetting defect or an overspread in a corner.

4 CONCLUSION

A first condition for chip self-alignment is that the spreading is total on the two surfaces—to the exception of the extremity of the corners that can never be totally wetted. Defects in spreading result in non-resolved shifts and twists.

A second condition is that the pinning on the edges is efficient. It is not yet clear to what extend a good pinning is required; but a large overflow definitely ruins the alignment. In the case of a Young contact angle of 60°, the pinning on the edges was found to be efficient due to the very accommodating canthotaxis condition (fig.10). On the other hand, in the case of a contact angle of 30°, overflows resulting from pinning defects occur. These large and/or asymmetrical overflows are a cause of misalignment.

In order to obtain a satisfactory bonding of the chip on the pad, more hydrophilic surfaces must be used ($\theta < 10°$). The pinning of the liquid on the edges must then be reinforced. It is planned to use a scalloping effect (Bosch fabrication process) for increasing the canthotaxis effect (fig.10).

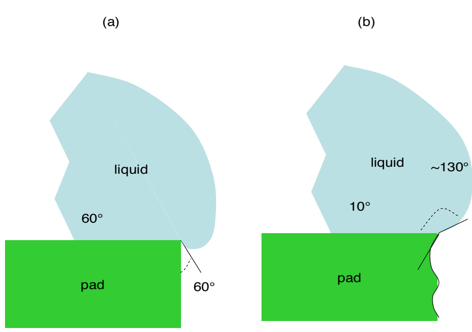

Figure 10: Canthotaxis limit for a contact angle of 60°.

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