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CAPILLARY UNDERFILL PHYSICAL LIMITATIONS FOR FUTURE PACKAGES

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ABSTRACT

The capillary underfill (CUF) although a well established manufacturing assembly process, is being challenged as die thickness diminishes, the interconnection (bumps) get smaller and their number increases. Denser populated packages demand very tight tolerances for keep out zones (KOZ); the total package thickness challenges the process throughput since die contamination from underfill fluid is not allowed and multiple fluid dispense passes may be needed. All this challenges translate in lower capillary surface energies, increase in fluid flow drag, smaller particle size fluid that often results in increase in viscosity and therefore slow flow-out-times. The present work addresses these issues. A series of mathematical models based on surface energy evolution for CUF accounting for these new geometries and processes is proposed. In particular the problem of component proximity is and the gap topology issues are studied. Experimental data for CUF in the presence of these future assembly demands is shown. Although there are practical physical limitations for the CUF as experienced today if one were to implement it for future packages, new hybrid CUF methods that overcome such shortcoming are recommended.

INTRODUCTION

The capillary action occurring in small ducts has been studied by several disciplines of science. Molecular forces of particles in a fluidic matrix are just an instance. In the electronic packaging the fluid dispensing for various applications including, potting, filling, component underfilling is of common knowledge. The c capillary kinetics plays an important role in several of these applications. Contrary to the traditional injection molding, where the fluid is mobilized by an induced relatively high pressure differential at the surface of the fluid wave front, the capillary action is a result of adhesion forces overcoming the cohesive forces of the moving fluid. A Variational approach to determine the fluid-air-solid surface shape of the moving front will guide us in determining various geometric boundary conditions including gaps sizes, and steps occurring in the corresponding capillary ducts.

THEORY AND BACKGROUND

The analytical approach to solve the problem of surfaces is that of Mapertuis principle. These solutions, coupled with mechanical adhesive and cohesive forces hat include Vander-Wall forces and London forces due to oscillation of electron clouds in molecules that are in close proximity, can give us a good description of the kinetics that takes place for slow fluid flow under capillary action. Given a definite integral with boundary conditions, its stationary value can be found by minimization of a functional using Variational calculus tool [1].

$$\delta F(y,y',x) = F(y+\varepsilon\phi, y'+\varepsilon\phi', x) - F(y,y',x) = \varepsilon\left(\frac{\partial F}{\partial y}\phi + \frac{\partial F}{\partial y'}\phi'\right) + O(\varepsilon^2)$$

The Variational of the definite integral can be computed as follows:

$$\delta\int_a^b F(y,y',x)\,dx = \int_a^b \delta F(y,y',x)\,dx = \varepsilon\int_a^b\left(\frac{\partial F}{\partial y}\phi + \frac{\partial F}{\partial y'}\phi'\right)dx$$

Dividing by ε ad integrating by parts the second term of the r.h.s. of above equations we obtain

$$\int_a^b \frac{\partial F}{\partial y'}\phi'\,dx = \left[\frac{\partial F}{\partial y'}\phi\right]_a^b - \int_a^b \frac{d}{dx}\left(\frac{\partial F}{\partial y'}\right)dx$$

We define I as the definite integral and since the $\phi(x)$ vanishes at the limits of integration (boundary conditions are satisfied exactly, $x=a$ and $x=b$)

$$\frac{\delta I}{\varepsilon} = \int_a^b\left(\frac{\partial F}{\partial y} - \frac{d}{dx}\left(\frac{\partial F}{\partial y'}\right)\right)dx$$

We now define the function $\xi(x)$ as

$$\xi(x) = \frac{\partial F}{\partial y} - \frac{d}{dx}\left(\frac{\partial F}{\partial y'}\right)$$

Combining above expression we can then write the stationary value of the corresponding definite integral as

$$\frac{\delta I}{\varepsilon} = \int_a^b \xi(x)\phi(x)\,dx = 0$$

It can be easily seen that the above expression would be satisfied for any arbitrary $\phi(x)$ if and only if $\xi(x)$ vanishes everywhere in the space [a,b]. We can, on the other hand make $\phi(x)$ vanish everywhere except in 'a small neighborhood around a point say, $x=\zeta$. Within this "small interval," $\xi(x)$ is "practically" constant and can therefore, be taken out of the sum (integral operation) as a simple multiplier factor

$$\frac{\delta I}{\varepsilon} = \varepsilon(\xi)\int_{\xi-\mu}^{\xi+\mu}\varnothing(x)\,dx$$

As the radius μ tends approaches zero, our "error' also tend to vanish. The first' variation or linear term of the expression must vanish, hence we can write the expression known as the Euler-Lagrange Equation

$$\varepsilon(x) = 0 = \frac{\partial F}{\partial y} - \frac{d}{dx}\left(\frac{\partial F}{\partial y'}\right)$$

About two centuries ago Poisson wrote the equation for the free energy of a solid elastic membrane

$$F = \frac{k_c}{2}\int_M (2H)^2\sqrt{2}\cdot dS$$

Where H and dS are the mean curvature and infinitesimal area element of the surface respectively, and k_c is the bending elastic modulus. The energy Euler-Lagrange equation corresponding to these functional can be written as

$$\nabla^2 H + 2H(H^2 - K) = 0$$

And the solution for such functional satisfying the minimization of surface energies is the critical curve known as the Willmore surface F, written as

$$W(f) = \int_M H^2 dS = C + \int_M (H^2 - K)dS$$

NUMERICAL AND ANALYTICAL RESULTS

We carry out some solution for the formulation presented above and using boundary conditions corresponding to the flow of a fluid in a capillary action, between two parallel plates, and in the presence of various surface topographies. The geometry to be treated consist of parallel plates

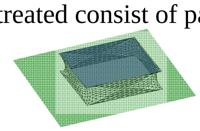


Figure1. Drawing of the geometry of two parallel plates separated by a gap in the presence of a fluid flowing by capillary action between them.

The capillary motion results, in the presence of a step, i.e., a sudden increase in the gap between the parallel surfaces, (see figure2) resulted from the numerical analysis is depicted in the sequence of pictures shown in figure 3.

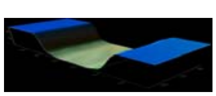


Figure 2. A sudden step on the organic substrate.

There one can observe that the fluid front has a tendency to behave in a way that preserves state of symmetry about a virtual horizontal plane parallel to the surfaces, thereby avoiding the creation of voids in the fluid path. The assumption here of course is that all surfaces in contact with the fluid are wettable to it, and that the adhesion is about the same for all of them. This flow behavior is very different from that of the case where induced pressure differential (as it is in the case of injection molding) for instance, the propensity to create voids is rather high in similar geometries. For the case of holes, the flow around them is the primary cause of void formation and it is governed by the flow velocity field around the hole, tangent to the circumference of the hole, and the fluid velocity as the fluid goes to a larger gap.

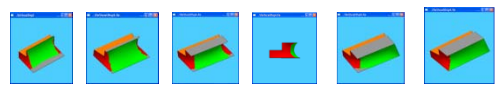


Figure 3. Capillary fluid flow in the presence of sudden step where the gap increases.

Other geometries analyzed can be depicted in figure 4, including grooves crossing and different grooves directions.

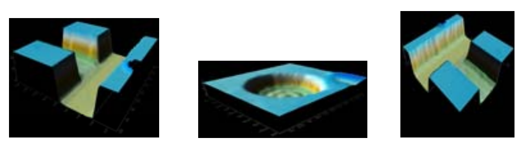


Figure 4. Various laser profile-meter geometries treated as spatial boundary conditions: grooves, hole and grooves intersections.

The case for underfilling components where the distance between them is comparable to the gap to be capillary underfill poses a whole new set of complications [3]. Aside from the fact that perhaps only jetting technologies can be of use (see figure 5) given that the needle dispensing requirements do not physically permits its use, there are other limitations imposed by the physics of the underfill and capillary equilibrium principles.

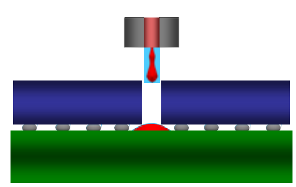


Figure 5. Jetting fluid from a distance above the components allowing for small distance between components.

Solutions to above problem indicate that when the distance between the components is the same as the gap or less, then capillary underfilling does not take place, this can be depicted in figure 6.

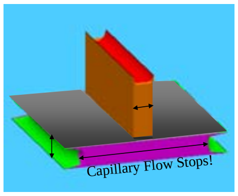


Figure 6. No capillary flow takes place for this geometry (gap same as distance of separation).

For cases where the distance separating the components is larger than the gap to be underfilled, (see figure 7), the solution indicates that capillary underfill occurs to completion, i.e., the fluid reaches the sides of the smaller of the two plates (in this case the glass plate).

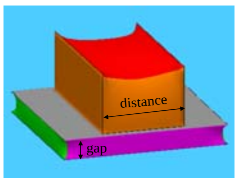


Figure 7. Drawing of two components side-by side separated by distance larger than the gap to be underfilled.

As depicted in figure 8, the fluid flows until it reaches equilibrium, a fillet around the plate including that area in between the components is formed. In figure 7 a sequence of event throughout time is shown where the fluid is moving under the influence of capillary effects.

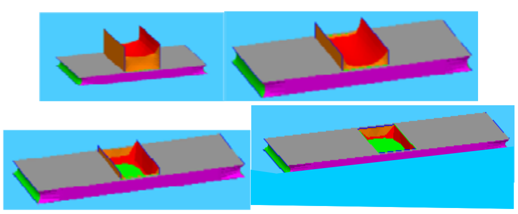
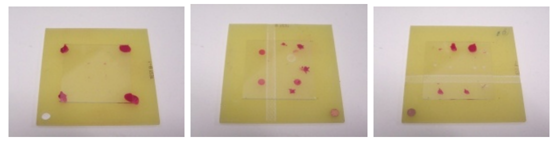


Figure 8. Sequence showing time slices of the fluid moving in a capillary manner in between the gap that is smaller than the distance separating the components.

EXPERIMENTAL RESULTS

Glass plates were mounted on organic boards with gaps varying from 75 to 300 μm. The surface of the board had different topographies including, grooves of different depth and widths as well as holes drilled to different diameters and depths from 250 μm to 1.5mm. Figure 9 depicts some of the samples used for the experiment.



(a) (b) (c)

Figure 9. Samples used for capillary underfilling: (a) Drilled holes on organic substrate; (b) grove aligned parallel to the fluid flow direction; (c) Groove normal to the capillary fluid flow direction.

Underfill material was jetted along a side of the glass plate using Asymtek DJ9K jet[4]. Figure 10 depicts the capillary flow of the underfill in the presence of a hole with diameter about three times larger than the gap and about 1mm deep. It is noticed that a void is present, this resulted from thee fact that the fluid flows along the peripheral of the hole following a near perfect tangential direction to its circumference.

Figure 10. Capillary flow in the presence of a large hole on the organic substrate, void formation resulting from fluid flow tangential to the hole.

In the case of grooves present on the organic substrate the fluid flow in a capillary fashion without allowing void formation. When the groove is parallel to the direction of the flow void could be formed if such groove is very narrow (compared to the gap) and in particular, if its depth varies. However, for the case of grooves normal to the fluid flow, voids are not formed independent of the groove geometry. For a very deep groove, the flow will simply cease to continue, this can be understood from the point of view of pure equilibrium mechanisms, i.e., it can be simply seen as a boundary condition similar to the starting edge of the glass plate. In figure 11 depicts the case where both grooves, normal and parallel to the fluid flow direction were present.

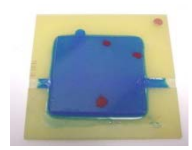


Figure 11. Grooves are present in the organic substrate in both directions, normal and parallel to the fluid flow direction; no voids are formed during the capillary underfill.

CONCLUSIONS

A comprehensive analysis of capillary fluid flow has been presented and validated by actual data. The coupling of molecular forces adhesion and cohesive in nature and the minimization of surfaces, as in the case of elastic membranes that yield Willmore critical surfaces in the differential geometry scheme gives an adequate way to model capillary fluid flow. These solutions were obtain in a way by perturbation theory where Variational of the functional derived from Poisson integral formulation mimic very closely the observation of capillary fluid flow under various boundary conditions that included several different geometries. For dispensing in presence of tight spacing and high density packages, the Jetting technology lends itself in a very transparent and practical manner. Above results can be used as guidelines in situations where uneven surfaces and arrays are present and capillary flow is used. Design rules for packaging design need to include the capillary physics present during underfilling and fluid dispensing in general.

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