

PARADIGM SHIFT IN APPLYING UNDERFILL

Alec J. Babiarz,
Asymtek,
Carlsbad, CA, USA
ajbabiarz@asymtek.com

ABSTRACT

The new advance in applying underfill by utilizing jetting techniques enables the use of more flip chip die sizes in compact packages. Jetting underfill as well as other semiconductor packaging fluids is a paradigm shift in the method of applying adhesives versus traditional needle dispensing. In the past many types of pumps were used to dispense fluids but the common denominator was pushing fluid through a dispensing needle. Jetting eliminates the use of needles, thereby solving all needle related problems and opens new innovative techniques to apply adhesives. Also, new ideas for underfilling large flip chips, making zero (0) width fillets if desired are available if designers are willing to think differently about package design. This paper will cover the new theory and process of jetting capillary and no-flow underfill, a new underfill method for large die which minimizes flow out time, and a review of the basics of underfilling. **Keywords:** Jet, Underfill, Dispensing, Flip Chip

REVIEW: BASIC PRINCIPLES OF UNDERFILL

Using the proper processes for production application of capillary and no-flow underfill is more important today than ever before because it allows the continued growth and applications of flip chips. In any underfill application, first analyze the tolerances of the system to determine the required dispensing parameters. The amount of underfill to dispense is the volume of the fluid under die minus the volume of the bumps plus the volume of fluid in the fillet all around the die. The minimum volume of fluid required occurs when the bumps are highest, the fillet width and height is at a minimum and the die size is at maximum. If less fluid is dispensed in this case, then the die has insufficient underfill or fillet height. The maximum volume of fluid allowed occurs when the bumps are lowest, the fillet width and height is at the maximum and the die size is at its smallest. If any more fluid is dispensed, then the fillet will be out side its keep out area or be on top of the die. See figure 1, 2 and 3.

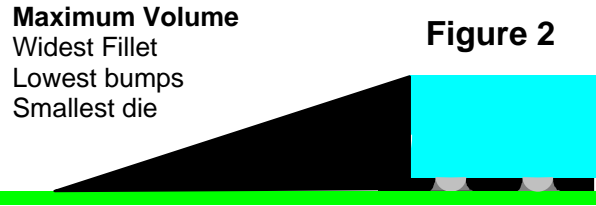
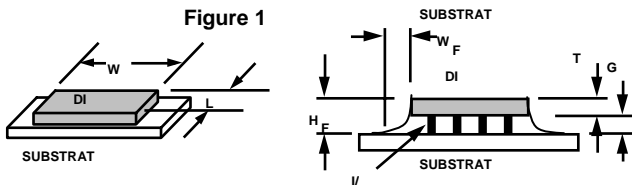


Figure 2



Figure 3

The flip chip calculator available at <http://www.asymtek.com/support/flipchip.htm> may be used to determine the proper amount of underfill to dispense and to determine the fillet width tolerance to produce a robust production process. See figure 4.

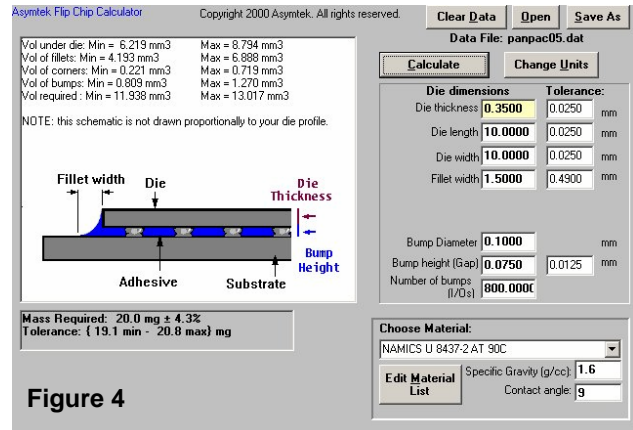


Figure 4

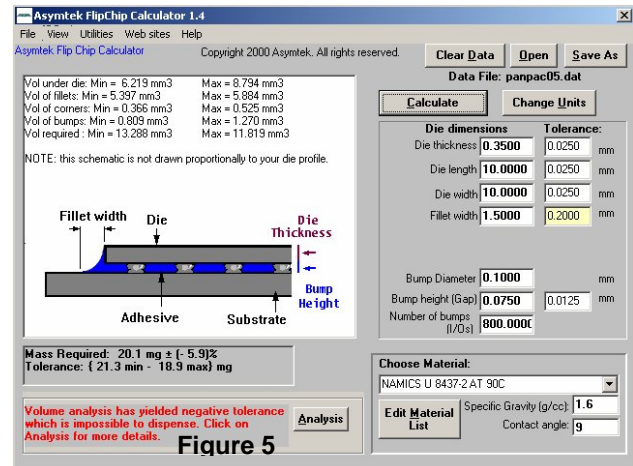
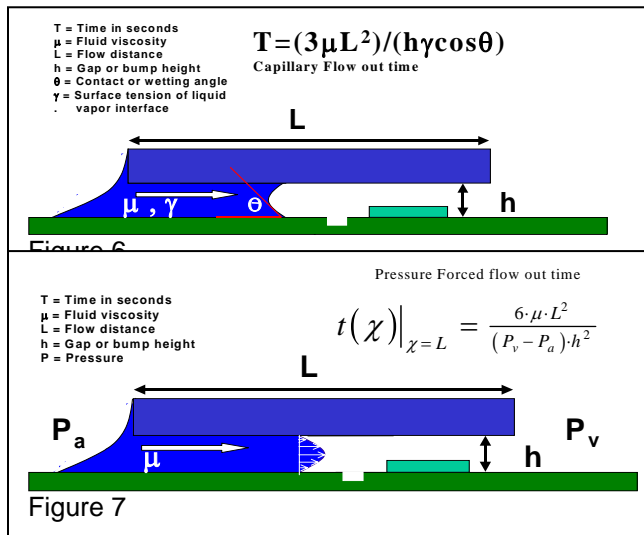


Figure 5

As an example, if the die has the tolerances shown in figure 5, the required dispense volume would be 20.1mg with a negative +5.9%, which is not possible. Since the fillet size was limited to 1.5 +0.2mm, the production process is not viable. The limits on fillet size produced a situation where the minimum volume of fluid necessary to underfill the die in one extreme case is larger than the maximum allowable. (i.e. the case of shortest bumps, maximum allowed fillet size). Therefore, even if the dispensing machine had perfect accuracy, the underfill process would not work. To correct the process, increase the fillet size variation, or gain higher tolerances on the die.

The flow out time equations for capillary and pressurized



underfilling are shown in figures 6 and 7.

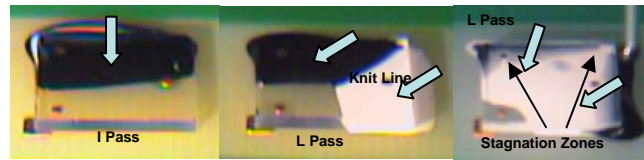
The changes in gap (h) under the die affect the flow out speed and wave front as much as the bump distribution. As the fluid flows around bumps, stagnation zones appear as the underfill flows to the other side of the die. The use of

two colors of underfill and glass die reveal a lot about the flow patterns.

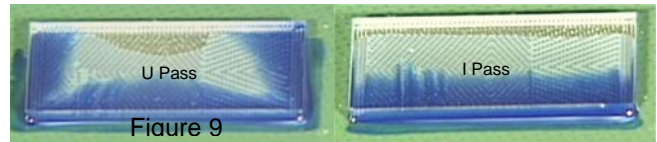
The most commonly accepted dispense patterns are the “I” and “L” passes. See figure 8. The “L” pass will typically provide faster underfill than the “I” pass by the square root two.

$$t_{Line} = \sqrt{2} \cdot t_{L-shape}$$

The difference in speed, knit lines and stagnation zones are apparent in the following photographs shown in Figure 8.



The streaks and flow lines shown in many x-ray and ultrasound images can be attributed to the regular flow of underfill as it works its way through the maze of bumps and channels under the die in a similar manner as fluid flow occurs in a much more macro manner in nature. See figure 9.



The “L” or “I” pass may be dispensed in one pass or multiple passes. Multiple passes are used to minimize the residual wet out area. If all of the material is dispensed along the die at once, the initial amount of material may spread on top of the die or to areas away from the die. As the material wicks under the die, a residual is left behind. If ½ of the material is initially applied, then the wetted fillet area is less and less residual remains after the first pass of material flows under the die. Most applications require that the automated dispenser go back to the die to place the next pass after a certain time. After the required underfill flows under the die, a final “seal” pass may be applied to make the fillet even around the die. Bubbles under the die are rarely caused by application of the underfill. In most cases the root cause of bubbles is improper substrate baking, excess flux, or inadequate flux cleaning.

The application of no-flow underfill is very similar to the application of die attach adhesives. The material application in a star pattern allows the air to be flushed out as the die is placed. The challenge for no flow underfill remains in the epoxy chemistry. Most no flow underfill epoxies have less filler, therefore the modulus is lower and reliability is less. However, there are low I/O applications where no-flow underfilling is an excellent choice. The no-flow application has a throughput advantage over capillary underfill when the die placement time or other assembly processes are not the bottle neck.

PARADIGM SHIFT IN APPLYING UNDERFILL

Applying capillary or no-flow underfill has been accomplished by using automated needle dispensing processes. As in any new assembly technology, a series of problems and innovative solutions have occurred to allow viable production processes for underfilling. The use of jetting technology for applying underfill instead of needles brings a change in technology similar to the introduction of ink jet versus pin printing years ago.

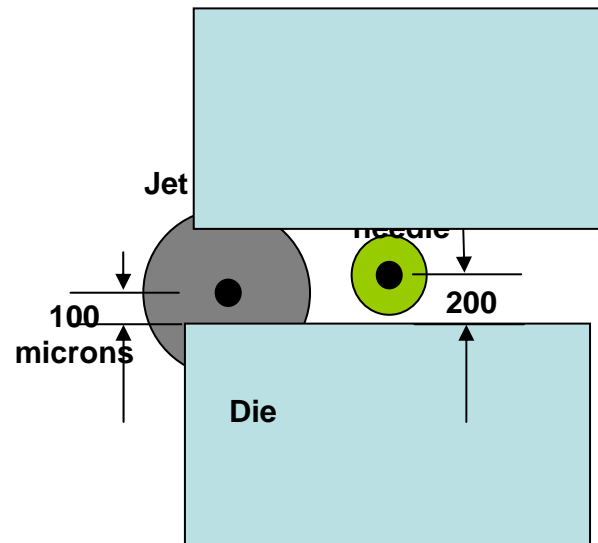
NEEDLE DISPENSING VS. JETTING

Table 1

Problem	Needle	Jet
Die Clipping (chipping die with needle)	1. Higher needle placement accuracy 2. Bent needle detection 3. Fiducial find at each die.	Clipping is not possible because jet is above die.
Maintain dispense gap below die and above substrate	Height sense at each die.	Height sense only once per product because height tolerance is +/- 1 mm.
Make small fillets	Use small needles. (requires low flow rate, therefore low throughput.)	100u stream size at 30mg/sec flow rates allows the smallest fillets in the industry.
Dripping material on die and product	Shut off valves close to needle hub.	Positive zero (0) volume shut off at nozzle for no dripping.
Volume variation die to die due to needle to substrate height variations on first line.	1. Height sense at each die. 2. Minimize residual material on needle.	The amount of material jetted does not depend on distance to surface.
Inaccurate placement due to bent needles	1. Needle sensing 2. Bent needle detection	There is no needle to bend.
Inaccurate placement due to residual material on needle biases fluid flow from needle.	Needle cleaners and wipers	There is no needle to bias fluid break off.
Die spacing under 1 mm.	1. Minimum spacing is needle outside diameter +/- placement accuracy. 2. Small needles (27 gage) limit flow rate to 1 mg/sec	1. Minimum spacing is 100u stream size +/- placement accuracy. 2. 30mg/sec flow rate is possible at minimum stream size.
Keep out area near die to minimize siphoning UF away from die.	Small needles	Small stream size
Maintain high dispense volume accuracy	Utilize positive displacement pumps	1. Discrete jetting of dots as small as 3.5nano liters per

	Mass flow control (MFC)	dot. 2. Calibrated process jetting allows a mass of material to be automatically jetted as a series of dots in a jet on the fly line. (MFC for Jetting)
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Table 1 describes the traditional problems related to automated needle dispensing for underfill and how jetting technology inherently eliminates the problem or the problem is mitigated by another process control. One particular advantage of the jet that is significant for packaging is the small stream size. Since the jet can apply material in smaller spaces, designers can package die closer together.



There are several types of jet technologies available in the market. Piezo, pressure, thermal, and continuous flow jets are limited to low viscosity materials. See Figure 10. The mechanical jet imparts high energy to a small volume of material that allows jetting high viscosity materials. The typical viscosity range of the mechanical jet is 300 cps to 900,000 cps. See Figure 11.

Figure 10

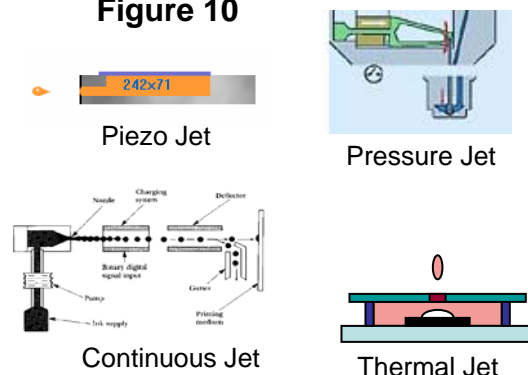
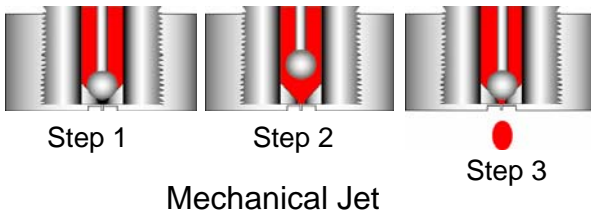


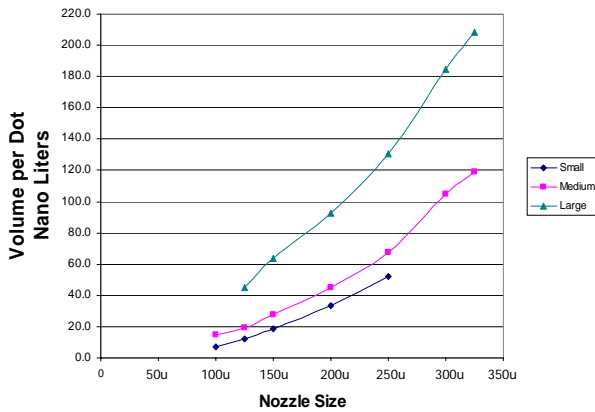
Figure 11



OPERATION OF THE MECHANICAL JET

The mechanical jet operates in the following manner. Initially a ball shaped “needle” is held against a nozzle seat by a spring loaded air piston. The fluid in the chamber is under low pressure (less than 0.2MPa). To create a dot, air pressure is applied quickly to move the ball off the seat. After a set time, the air pressure is released and the ball is moved down at a controlled rate determined by the spring. At close to the point of closure of the ball against the seat, the fluid directly between the seat and ball has a lower flow resistance path out the nozzle than back into the fluid chamber. Pressure increases rapidly and a jet of adhesive is extruded from the nozzle at the last moment. At the point of impact, a shock wave helps snap the fluid from the nozzle. The action is simple however the seat, nozzle and ball geometries are varied to optimize different volume and fluid velocity requirements. In addition, the nozzle has temperature control by means of resistive heater and air cooler to hold the fluid at an optimum viscosity. Figure 12 shows the variation of dot sizes for various nozzle/seat/ ball sizes at a constant temperature.

Figure 12 Nozzle Size vs Volume/Shot with Underfill



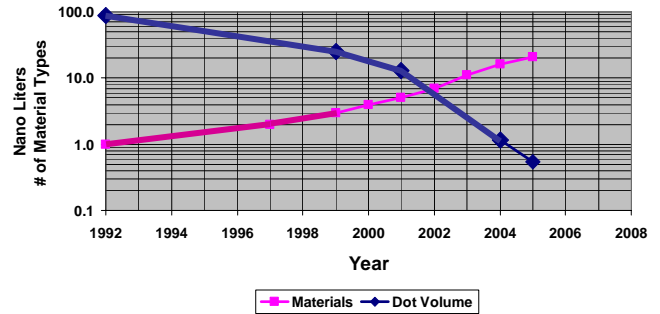
Material can be jetted at 200 dot/sec to achieve up to 120 mg/sec.

MATERIAL CAPABILITY

The low viscosity jets have been limited to inks, reagents and some UV curable adhesives. Since the development of the mechanical jet in 1992, the number of different fluids has been expanding logarithmically. Figure 13 shows the relationship of jetting different types of materials used in electronics assembly versus time and the smallest size dot jetted with the technology. The following materials have been identified as jettable: SMA, Silver, Flux, UF, Silicone, No Flow UF, Conformal Coating, UV, Phosphor, Wax, Hot

Melt, Liquid Crystal, Desiccant, Liquid P-Type material, Solder Mask, Solder Paste, Paint, Lubricants, Reagents, Thermal Grease, and Dam epoxy. However, each type of material has a number of formulations that work. For instance, underfill material is one type of material, but most underfill materials from several vendors like Loctite, Namics, Shinetsu, Cookson, etc are jettable formulations.

Figure 13 DJ-9000 Capability



CHALLENGES TO JETTING TECHNOLOGY

Underfill adhesives are highly filled and abrasive materials. There are various wear areas in the jet mechanism. With the use of carbide, hardened steels and chrome plating, the wear issues have been reduced to a level acceptable as normal wear and tear. The wear parts are designed for low cost of ownership, and easy replacement.

As new materials are tried with the jet, new issues arise. Jetting low viscosity materials brings up the possibility of splashing. Analyses have been done on droplets splashing on solid surfaces, thin liquid films on solid surfaces and liquid interfaces. For underfilling and jet on the fly, the most relevant analysis is for droplets onto thin liquid films. An empirical relationship has been established for this case called the “Sommerfeld Parameter” given by the following formula:

$$K = We^{0.5} Re^{0.25}$$

Where **We** is the Weber number and **Re** is the Reynolds number.

$$We = \rho U^2 D / \gamma$$

$$Re = \rho U D / \mu$$

And where:

- ρ = fluid density
- U = drop velocity
- D = drop diameter
- γ = fluid surface tension
- μ = fluid viscosity

Splashing occurs when the dimensionless parameter K is greater than about 50. This also depends on the surface roughness when impact is occurring on a solid surface. Rougher surfaces will cause an earlier onset of splashing¹.

Strong impacts are exhibited by high **We** numbers and high **Re** numbers indicate that the viscosity has less of an effect. Low impact velocity and high viscosity fluids do not splash but result in depositions. The dots go from deposition to spreading to splashing with decreasing viscosity, higher velocity and larger dot mass. See Figure 14. The maximum velocity recorded for the mechanical jet is about 5 meters per second.

Figure 14 Velocity Dependence on Splash Onset: $K = 50$
Underfill Fluid: 47 dynes/cm, 1.5 specific gravity
Dot Mass = 0.06mg

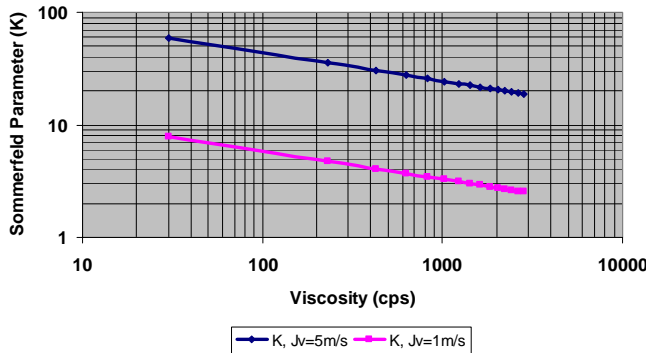
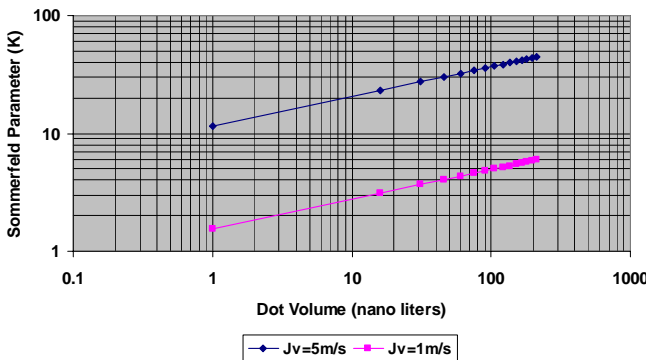


Figure 15 Dot Volume Dependence, Splash: $K=50$
Underfill Fluid: 47 dynes/cm, 1.5 specific gravity
Viscosity = 500cps

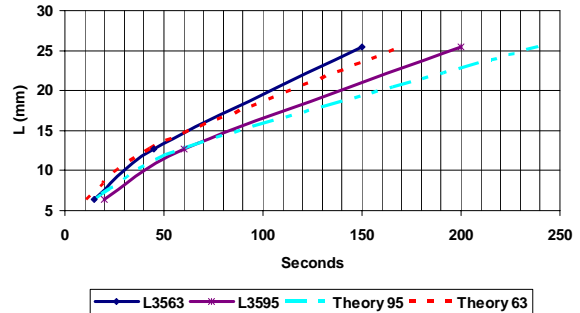


As can be seen in the calculations and in production, underfill materials will not splash due to their high viscosity. The onset of splashing does not occur even with a 500 cps material at maximum velocity of 5 m/s and a large dot volume of 0.3 mg per dot (60mg/sec). There is significant margin in the process of jetting underfill materials.

NEW METHOD OF UNDERFILLING

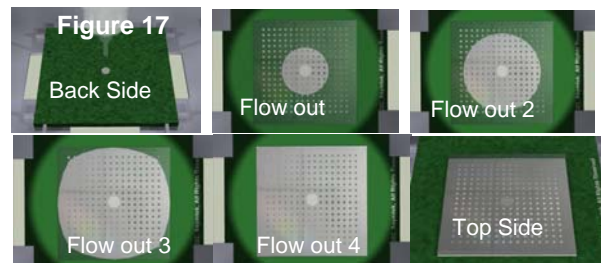
Capillary underfill of large die is perceived as a problem as bump heights decrease. Figure 16 shows the dependence of flow out time on die length for a gap of 25 microns. The dashed lines show the predicted curves by using the equation in Figure 6 and the viscosity, contact angle and surface energy of the materials. ..

Figure 16 Flow Out Time of Some Typical Underfill Materials



A new method of underfilling would be to fill the gap from the back side of the die. This could be accomplished by having a through hole in the substrate under the center of the die. See Figure 17. The highest stress on flip chip bumps occurs at the edges of the die. Also many die are not fully populated and the center of the die is void of bumps. A small hole in the substrate of about 1 mm is all that is required. The hole does not have to be directly in the center but can be offset as required. By using back side filling of a flip chip, the effective length can be cut in half. Therefore the flow out time will be 4 times less. For instance, if material L3595 were used on a 20mm square die, it would take 140 seconds to complete flow out. By using backside filling, the effective length of the die would be 10mm, so it would take approximately 35 seconds versus 140.

Since the material is flowing from the center of the die to the outside edges, there is no wet out area. The fillet width is dependent upon the wetting characteristics of the fluid at the die edges. Also, by observing the flow characteristics under a glass die, it can be seen that there are no knit lines.



CONCLUSIONS

By using the tools for defining underfilling volumes and fillet sizes, underfilling has become a robust manufacturing process. The process engineer can use clear die and different color underfills if flow analysis is required. I and L pass techniques followed by seal passes are utilized throughout the industry,

Jetting technology has brought a new level of robustness to the underfill process. By eliminating needles from the dispensing process, problem areas due to needles are mitigated. Therefore, jetting increases the throughput and yield of the underfill process. Today many materials can be jetted. The wear problems associated with highly filled

underfill materials are solved by hardened parts and low cost of ownership. As more fluids are used with the mechanical jet, even the low viscosity range of 500cps may be used without splashing at very high jet velocities. The range of the jet is very robust.

One of the key objections to underfilling is the long flow out time for large die. By putting one via through the substrate underneath the die, the flow out time can be reduced by a factor of 4. This process would effectively eliminate the underfill process as the bottleneck in the production line.

REFERENCES

1. Christophe Josserand and Stephane Saleski, "Droplet splashing on a thin liquid film", *Physics of Fluids*, Volume 15, Number 6, June 2003
2. C. Mundo, M. Sommerfeld, and C. Tropea, "Droplet wall collisions: Experimental studies of the deformation and breakup process," *Int. J. Multiphase Flow* 21, 151 (1995)

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1. Quinones, Horatio, Chief Scientist, Asymtek, Carlsbad, CA, USA
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