Statistical Process Control Applied to Automated Dispense of Silver Filled Epoxy for Commercial Millimeter Wave Multi Chip Module

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Abstract

This paper presents the results of continuous improvement from: Designed Experiments, Viscosity measurements, Statistical Process Control, documented operating procedures, , and operator training & certification; on the automated epoxy dispense process. This capability enables the company; M/A-COM, to produce the first volume low cost 28 Ghz Commercial Millimeter Wave Multi Chip Module Receiver.

The Millimeter Wave Multi Chip Module Receiver uses GaAs Phempts measuring 12 by 10 mil length and width by 5 mil thick. This small discrete device required the development of a process for a ten mil diameter silver paste epoxy dot: repeatable, in production, and in volume. Statistically Designed Experiment were used to identify and set the most important process parameters. Viscosity measurements were made which characterized the silver filled epoxy paste. The ASTM methods for measuring viscosity of adhesives were modified to identify the material's sensitivity to shear. A unique Statistical Process Control method was implemented to establish process control over a material which has proven to change flow behavior during processing through an auger type positive displacement pump. The key to the success of this project has been the properly train operators.

Key words: DOE, SPC, Epoxy, Dispense, Viscosity

Introduction

The manufacturing requirements for microwave and millimeter wave microelectronics assembly demand high precision tolerances. This paper is focused on the results of continuous improvement on producing a repeatable small dot of silver filled epoxy in a production environment.

Background

Previous work has been reported on the process capability on the Micro Robotics System Inc. MRSI-170 automated epoxy dispenser.[1] The report identified some of the critical parameter settings on the mentioned equipment in order to produce a 10.5 mil dot with a Cpk of 1.2:

1) The Gap between the needle and the substrate kept at 1 mil +/- .3 mil
2) The dwell time allowed for the epoxy to attach to the substrate from the needle is .1 to .15 seconds. 3) The epoxy dot diameter and the standard deviation both get larger as the time between dots gets longer.
4) The auger on the positive displacement pump is operated in less than the 20% range of its RPM capability (see Figure 1).
5) The pump is pulsed typically for .05 seconds per dot.

The report demonstrated how sensitive this process can be with changing pressures behind the needle. Basically changing the pressure (or altering the time the pump primes) will change the average dot diameter and the standard deviation. Pressure changes behind the needle are seen in production when:

1) The machine sits idle between production batches;
2) While the machine does vision processing and height sensing between parts;
3) Time exceeds 0.6 seconds per dot; or greater than 150 mil pitch.

One conclusion from this work is when a relatively high pressure is maintained behind the

needle; the process will still produce an acceptable dot diameter standard deviation with relatively small changes in pressure. This conclusion led to the following epoxy program guidelines for products requiring 10 mil dots for small components:
1) A set of primer dots will be dispensed prior to the required epoxy dots.2) No program will exceed 0.6 seconds per an epoxy dot dispensed.

Process Design of Primer Dots using DOE

Problem StatementA set of primer dots must be defined to stabilize the 10 mil dot dispensing process.

Objective

Define the least amount of primer dots required without exceeding the 10.5 mil dot diameter average and the 0.8 mil standard deviation.

Definitions:

Gap - The distance between the needle and the substrate.

Motor Time - how long motor is on per dot.

Dwell Time - how long the needle stays at gap position after motor time expires.

Pitch - distance between dots

Flow Control - the amount of volts supplied to the motor to control RPMs

Primer Dots - dots used to build pressure in needle

Total Prime Time - the cumulative time the motor is on while dispensing primer dots

Motor Prime Time - how long motor is on per primer dot.

Factors	Range	Optimal Value
Dwell Time(100 dots)	0.15	0.15
Gap(100 dots)	1	1
Motor Time(100 dots)	0.05	0.05
Flow Control(all)	4.0	4.0
Pitch (0.65 sec) (100 dots)	150	<30
No. of Primer Dots	4 to 10	10
Total Prime Motor Time	1 TO 8	1
Motor Time(Primer Dots)	.1 to 2	.1
Responses		
Average DIA(100 dots)		10.0
Diameter STDEV(100 dots)		1.1

Table 1

Design Matrix

The following is the design matrix used in this experiment. The data represents the statistics per 100 dots dispensed.

Total Motor Time	Dot Motor Time	# Primer Dots	Dia AVE (100 dots)	Dia STD (100 dots)	Miss Dots per 100
1.00	0.25	4	9.52	1.38	0
8.00	2	4	14.87	0.1	0
4.50	0.643	7	11.01	1.55	0
4.50	0.643	7	13.12	0.82	0
4.50	0.643	7	13.25	1.02	0
1.00	0.1	10	8.22	1.55	0
8.00	0.8	10	12.2	1.41	0
1.00	0.1	10	9.96	0.07	0
8.00	0.8	10	11.78	1.35	0
4.50	1.125	4	13.36	2.66	3
4.50	1.125	4	11.25	3.51	7
1.00	0.25	4	10.13	3.23	6
1.00	0.25	4	10.76	1.17	0
8.00	2	4	14.83	4.32	5
8.00	2	4	16.62	2.08	0
8.00	1.143	7	13.9	1.7	1
8.00	1.143	7	13.48	1.37	0
8.00	1.143	7	14.21	1.17	0
8.00	1.143	7	14.33	0.93	0
1.00	0.143	7	10.01	3.91	9
1.00	0.143	7	10.5	4.01	9
5.00	0.5	10	12.19	1.28	0
5.00	0.5	10	11.89	1.03	0

Conclusions of Designed Experiment

The following conclusions are drawn from the statistical model graphically shown in the contour plot of figure 2. It should be noted; the dot ave and dot stdev are the statistics calculated on the 100 dots measured. There were no measurements taken of the primer dots. First, more primer dots has a negative effect on the dot diameter and standard deviation. Although, the model points in the direction of preferring more dots; there was no attempt to design a process requiring more. Ten dots can represent a problem in production. It is sometimes difficult to find a convient place to dispense these undesirable dots on the product while not impacting the circuit performance. The second conclusion, the cumulative amount of motor time during the primer dot dispensing has a positive effect on the dot diameter of the 100 dots even though the machine settings are held constant for the 100 dots (see Table 1).

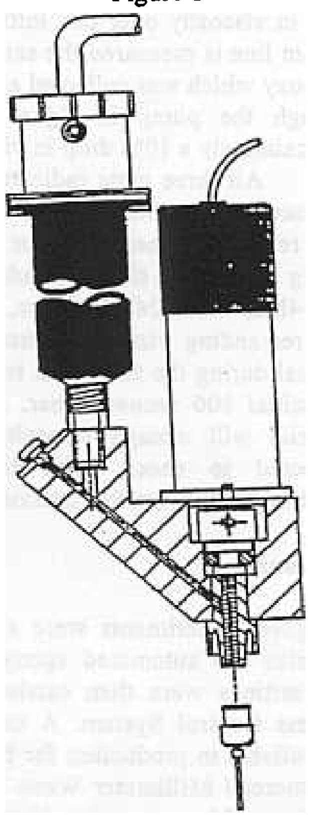
Implementing a SPC System

No off-line experimentation can show cost savings to the product without a production process control method. The machine settings established from the off-line experimentation has become the standard for verifying every four hours the process is in control (see table 1). The SPC program dispenses the 10 primer dots then the 100 dots at the optimized machine settings except for the pitch between dots. The work has shown the results to be better when dispensing dots at a fast rate or <30 mil. However, not to many products place descrete die that close. Therefore, the standard has been set at a pitch of 150 mil (or 0.6 sec/dot). Although this standard will not cover all products; it is usually easy to find a place to dispense an unneeded dot every 150 mil or so. The operators are trained to operating procedures stating the following:

1) None of the 100 dots can be missing
2) Measure column 1 of the 10X10 dot array; this has the first and last dot of the 100 dispensed in it.
3) The upper limit of the 10 dot average must not exceed 13 mil and lower limit must not go below 8 mil.
4) Take the appropriate corrective action and document the fix of an out of control condition, such as; adjust the RPM, change a clogged needle, or re-calibrate the x-y-z position of the needle.

POSITIVE DISPLACEMENT PUMP WITH A ROTARY FEED-SCREW

Figure 1



Viscosity Analysis

The auger type positive displacement pump has been known to be sensitive to changes in material viscosity. A quick look at the SPC charts show constant adjustments to the RPM of the pump to maintain a constant process performance.

Although, temperature is a known culprit to viscosity change; close monitoring of the lab has shown temperature to be extremely stable.

A Brookfield Viscometer was used to gather preliminary rheological data to determine what type of flow behavior is characteristic of this system.[2] Two viscosity test methods were performed to reveal the shear thinning behavior of the silver epoxy paste. The first method displayed in figure 3 is a plot of the "Up Down Curve". Since the two curves do not coincide the material is time-dependent. This "Up Down Curve" was performed by allowing ten minutes to elapse at each RPM then a reading was taken. It should be noted when only one minute is allowed to elapse at each recording; the "Up Down Curve" will coincide and the material and would be classified as time independent. The method used is similar to ASTM D2196 Test Method B.

Figure 4 and 5 are similar to ASTM D2196 Test Method A. In these figures, the viscometer was allowed to rotate for 800 seconds. A measurement was taken every ten seconds. The top line; of figure 4, shows a drop of approximately 10% in viscosity over this initial time period. The bottom line is measured the same way on a sample of epoxy which was collected after it was processed through the pump in figure 1. It also shows approximately a 10% drop in viscosity.

All three plots indicate the material drops in viscosity the more it is worked. The viscosity was repeatedly measured for 800 seconds after letting the sample sit for an additional 15 minutes, 1hr, 4hrs, 8hrs, 24hrs, 32hrs, 4days, and 5days. The remanding viscosity changes were relatively gradual during the follow on test when compare to the initial 800 second shear. All data shows the material will change viscosity over time when subjected to shear; with the largest change occurring in the first 800 seconds.

Summary

Designed Experiments were successfully used to optimize the automated epoxy dispense process. The settings were then carried to the Statistical Process Control System. A ten mil dot must be controllable in production for the low cost 28 Ghz Commercial Millimeter Wave Multi Chip Module Receiver. This process is critical while placing thin and small discrete devices. Guidelines have to be followed in the epoxy programming. One, 10 primer dots have to be dispensed prior to production dots. Two, a dot should be placed at a minimum of every 150 mil. Three, the optimized machine settings for a ten mil dot must be used. The material and pump used showed a constant need for RPM adjustment. One potential reason for this was the shear thinning nature of the epoxy used.

References

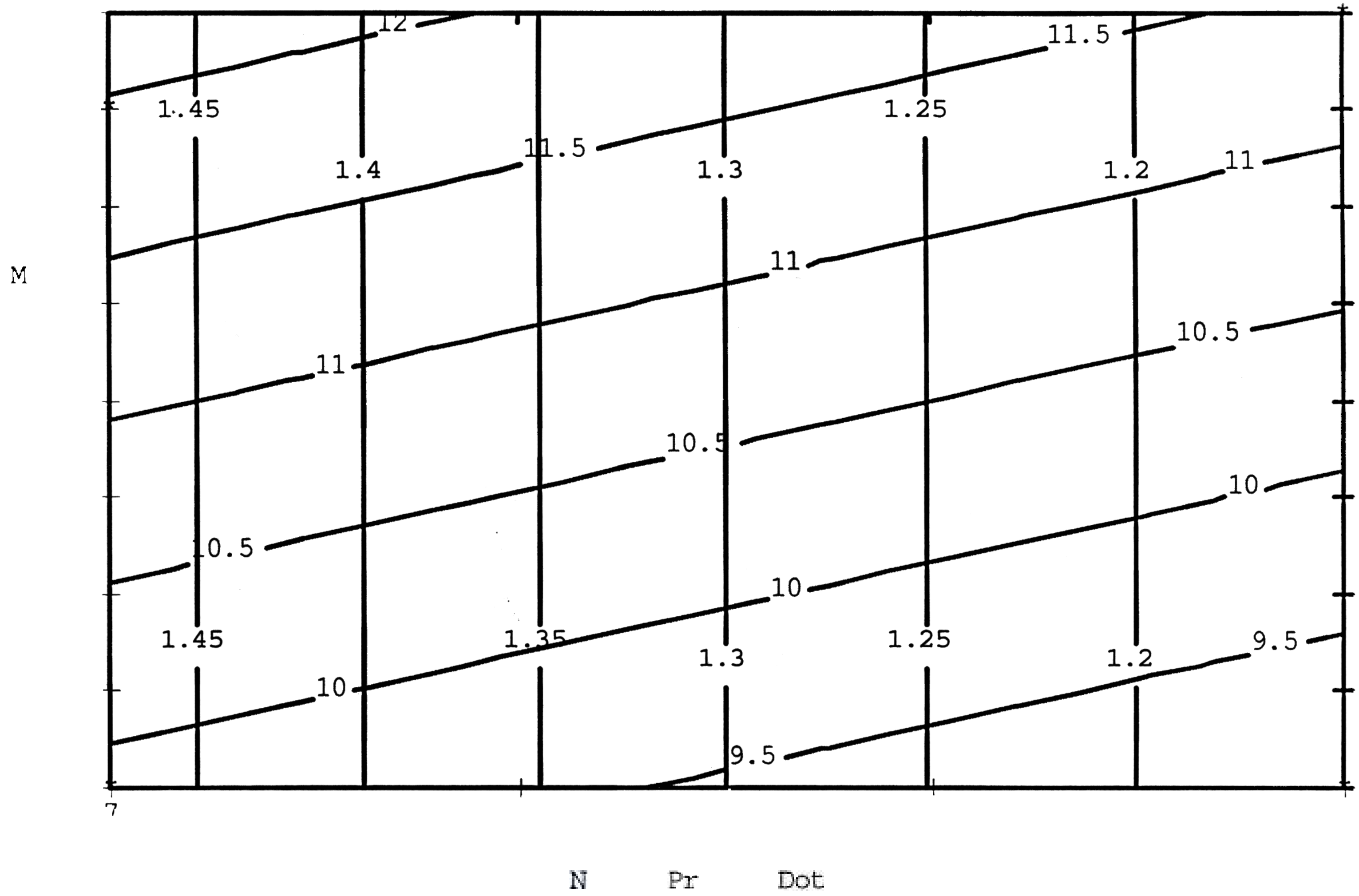
Presented Paper

[1] Robert Spinazzola, "Automated Epoxy Dispense Process Capability", Proceedings of the 1996 NEPCON West Conference, Feb. 25-29, 1996, Anaheim, CA

Guideline for Viscosity Measurements

[2] Brookfield Engineering Laboratories Inc., "More Solutions to Sticky Problems", Stoughton, MA

No o Prim r Dot V Moto T m Ov r Dot Av ane TD V



Dot A
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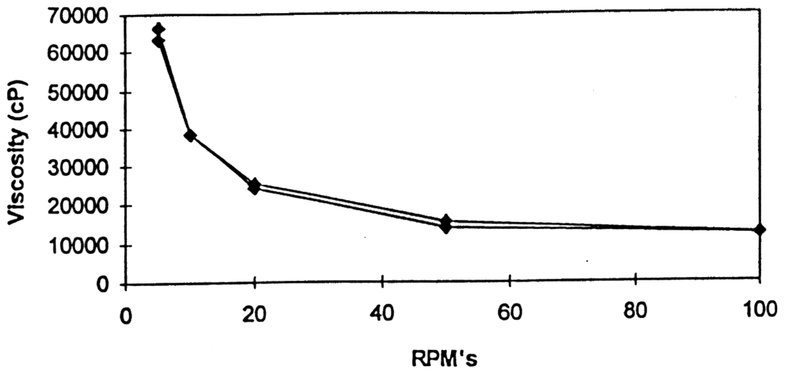
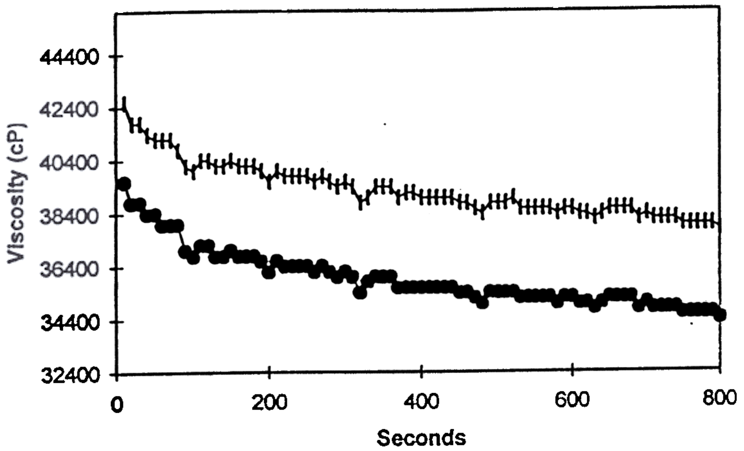
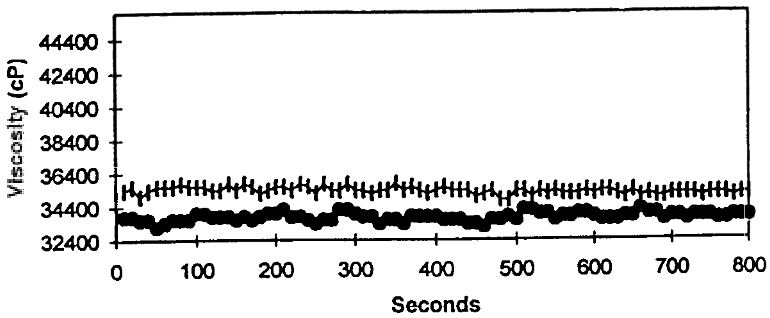
Viscosity vs RPM's (H35-175)



SC4-15/7R 20 RPM (purged first run) H35 lot95
10/20/96



SC4-15/7R 20 RPM (Purged, after 32 hours) H35 lot95
10/20/96



Top: Figure 3 **Middle: Figure 4** **Bottom: Figure 5**

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