Liquid Metal Paste Jetting for High-Performance Computing Applications in Electronics Assembly

Sunny Agarwal
ITWEAE
Hopkinton, Massachusetts, USA

Miloš Lazić
Indium Corporation
Clinton, New York, USA

ABSTRACT

Metals have long been used as thermal interface materials (TIMs). Due to their high reliability and thermal conductivity, metal TIMs are excellent solutions for heat dissipation in electronic systems, especially for more challenging applications. Thermal conductivity and interfacial resistance are the most important properties of TIM. One of the biggest obstacles for using metal TIMs is interfacial resistance. Most metal TIMs are quite stiff and require compressive force to maintain necessary contact with active components to lower the interfacial resistance. With devices becoming smaller, consuming more power, and producing more heat, finding the right TIM becomes a highly critical step in any electronic systems application. Recently, liquid metal TIMs have gained popularity, especially for thermal management of high-performance computing semiconductor applications such as in central processing units (CPUs), graphics processing units (GPUs), and multi-chip modules (MCMs). Due to their fluid nature, liquid metal TIMs do not need to be compressed to maintain even contact, and they can accommodate imperfections in the neighboring components. The newest metal TIMs are made of liquid metal paste (LMP). These gallium-based, high viscosity materials maintain all the good properties of liquid metals but also offer some improved mechanical properties. A key challenge lies in applying LMPs consistently through various dispensing techniques which could be traditional, like time-pressure versus advanced jetting technology. Both dispensing techniques will be compared based on dispensing quality, weight repeatability on substrates, and valve-hardware stability. This paper addresses the challenges faced during LMP dispensing in high-volume manufacturing, and how to maintain constant volume over the product with good dispense quality leading to higher throughput and process reliability.

Key words – Dispensing, high-performance computing (HPC), jetting, liquid metal (LM), liquid metal paste (LMP), phase change metal (PCM), printed circuit board (PCB), thermal interface material (TIM)

INTRODUCTION

This paper will discuss how novel liquid metal paste (LMP) can be applied in high volume manufacturing (HVM). LMPs can be used in different applications, but here we will present how those materials can be used as thermal interface materials (TIMs). A TIM is a material that is applied between a heat generating device and heat dissipating device to remove heat from the component. Before exploring the materials used for TIMs and their main properties, it is very important to define the classification of TIMs.

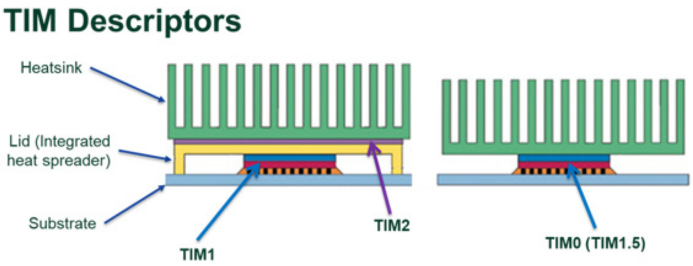

Figure 1: Types of TIMs. [2]

Figure 1 shows a typical semiconductor application. TIM 1, represented as the darker blue line, illustrates the material applied between the integrated circuit (IC) in red, and heat spreader shown in yellow. TIM 2, represented by the violet line, is applied in between the heat spreader and a heat-sink, shown in green. In applications where there are no heat spreaders, a TIM is placed between the IC and the heat-sink, for which the TIM is referred to as TIM 1.5 or TIM 0. LMP is applicable to all TIM1, TIM0 (TIM1.5) and TIM2 applications with a double barrier system explained below. It would be even easier to use this system in the TIM2 application, since there are no passive components like capacitors and resistors nearby, as present in TIM1 or TIM1.5.

Both LM and LMP can be used as TIM in any semiconductor application which could cover consumer devices, data centers, telecommunication systems, automotive, medical, aerospace and many other industries. Generally, the peak junction temperature of control processing unit (CPU) is lowered by up to 3-5°C and 10°C when LMPs and LMs are used respectively as TIM compared to the organic phase change materials and thermal paste. Since the purpose of the TIM is to transfer heat from the heat source to the heat sink, the thermal conductivity of the TIM will play a big role in the overall performance. Metals and alloys have higher thermal conductivity and that is their biggest advantage compared to other types of TIMs. Figure 2 shows thermal conductivity of non-metal TIMs.

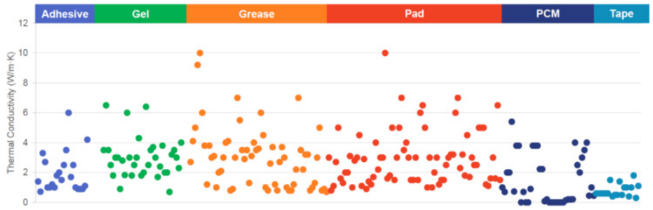

Figure 2: Thermal conductivity of non-metal TIMs. [3]

On the other hand, thermal conductivity of metals and alloys will be in the range of 15-86 W/m*K (Figure 3).

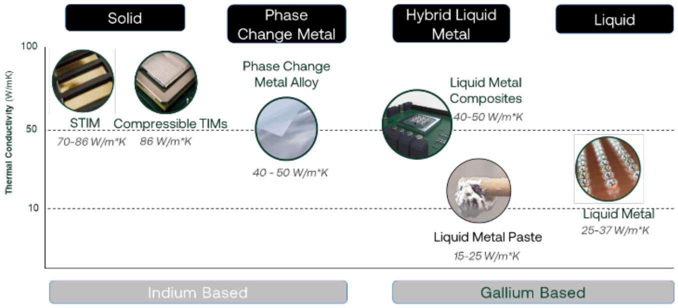

Figure 3: Thermal conductivity of metal TIMs. [1,4]

Liquid Metal vs. Liquid metal paste TIMs

High thermal conductivity would be the greatest advantage of metal TIMs over their non-metal counterparts. However, thermal conductivity is not the only parameter that should be considered when choosing a TIM. Besides thermal conductivity, bond-line thickness and interface resistance play a role in TIM performance, and interface resistance is the biggest challenge for most metal TIMs. Often, metals and alloys are very hard and stiff materials, and it is therefore difficult to ensure the maintenance of the close connection between heat source and heat sink materials. Both LM and LMP TIMs overcome this obstacle since they are in the liquid/paste phase at room temperature, allowing them to adapt to roughness, non-planarity, and any other imperfections in the connecting surfaces. LM has low viscosity as compared to LMP. LM is liquid with viscosity similar to water at room temperature while LMP is pasty and similar to mayonnaise. LM can achieve lower bondline thickness due to their liquid nature which is not the case with LMP. When deciding which material to use, the specific application and properties of the material must be considered. As shown in Figure 3, the thermal conductivity of LMPs is lower than that of LMs. However, despite this disadvantage, LMPs retain other properties that make them advantageous over LMs in certain contexts. LMPs are high-viscosity, pure metal materials made from gallium-based alloys [5]. Due to the presence of gallium, which is corrosive to aluminum, both LM and LMP cannot be applied to aluminum heat spreaders or heatsinks. The typical viscosity of LMPs goes from 5000 to 28,000 Pa-s. Due to this high viscosity, LMPs are not only less prone to leakage than LMs, but they also exhibit better drop shock and stress behavior. Stress behavior is the performance of material when exposed to stress like shaking or bending. Less prone to leakage when exposed to these kinds of stresses. LMPs also perform better during thermal cycling (Figure 4) where they demonstrate more limited spreading as compared to LMs.

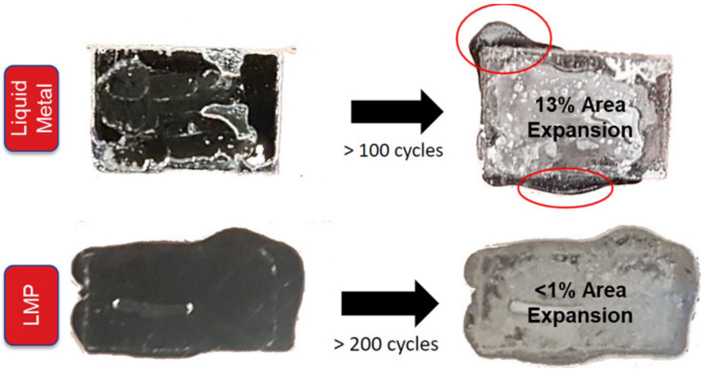

Figure 4: Thermal cycling performance of LM and LMP [6]

Figure 4 shows the material response of LM and LMP samples to thermal cycling. During thermal cycling, gallium-based LM has expanded by 13%, indicating high leak potential (circled in red) if there is no dam or barrier to wall it off. LMP expansion area is less than 1% when thermally cycled with the same temperature range, indicating a notable advantage in shape retention over LMs. LMP can be used for temperatures up to 125 °C which is mostly for any semiconductor application where peak junction temp doesn't go beyond 125 °C. When an LMP is exposed to temperatures of 150 °C or higher for a long period of time like 1000 hours test to mimic constant power-on condition will cause LMP to dry out and degrade.

The wetting performance of LMPs was also exceptionally good. LMPs will wet almost any surface, metal, and non-metal, even if those surfaces are heavily oxidized (Figure 5). Figure 5 shows how LMP wets a bare silicon die surface at room temperature with minimal scrubbing required to wet the die surface. Both LMPs and LMs display good coverage in case of warpage on substrates.

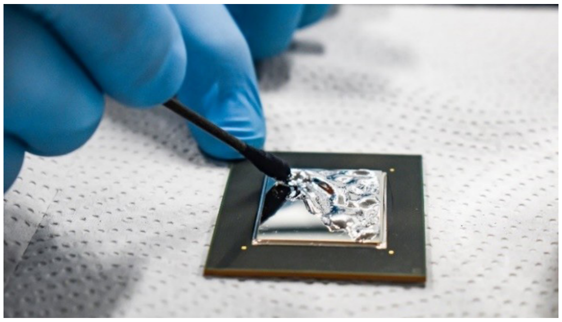

Figure 5: The wetting and spreading performance of gallium-based LMP on a silicon die.

While overall thermal performance of LMPs will not be as good as thermal performance of standard gallium-based LMs, both materials will have higher thermal conductivity than most of the non-metal TIMs. The combined thermal and mechanical properties of LMPs make this category of metal-based TIMs a better choice in some applications than LMs. During post accelerated stress testing, there was no delamination or minor cracks observed on LMP after initial application. The X-ray machine was used to check if there were any voids, and no huge voids were observed. During the production process of LMPs, some oxides will get trapped in the material, but those are not big enough to be imaged by X-ray.

Dispensing Techniques - Jetting vs Time Pressure Dispensing

Dispensing techniques have evolved from needle contact dispensing methods to non-contact (jetting) dispensing technology. Early dispensing approaches were used for reworking applications on components with deficient fills of adhesives onto the substrates or die surfaces. More recently, researchers have proposed the use of dispensing for independent operation of fluids application, such as epoxies, onto the PCB for securing components [8]. Needle contact applications like time-pressure, and rotary auger screw dispensing fall under the same application to dispense the fluid through the needle contact to the printed circuit board. Jetting, as shown in Figure 6, is termed as a technology where material is dispensed as individual droplets onto the PCB through a jet dispenser without any needle contact with the PCB. Jetting technology uses the "ball and seat" mechanism to supply the fluid to the ball seat area with the application of pressure. For this method, as the ball moves in the downward direction to strike the seat, it dispenses the fluid in the form of a droplet onto the substrate [8].

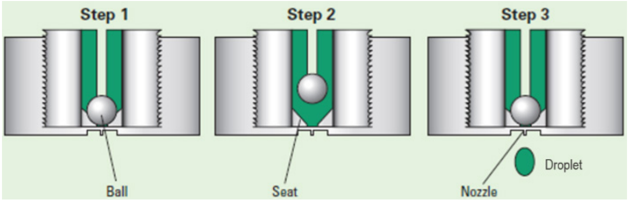

Figure 6: Jetting technology [8]

The time-pressure dispensing mechanism as shown in Figure 7 (a) drives the fluid out of the needle through application of pressure onto the syringe. The fluid will stop dispensing from the needle as the applied pressure is switched off from the actuator. Jetting works mostly on the principle of positive-piston displacement fluid dispensing (Figure 7 (b)) which involves a mechanism of pushing the fluid along the cylinder chamber through the reciprocating motion of the piston which forces the material out of the needle. Herein, the piston and cylinder are the two essential components in this driving mechanism.

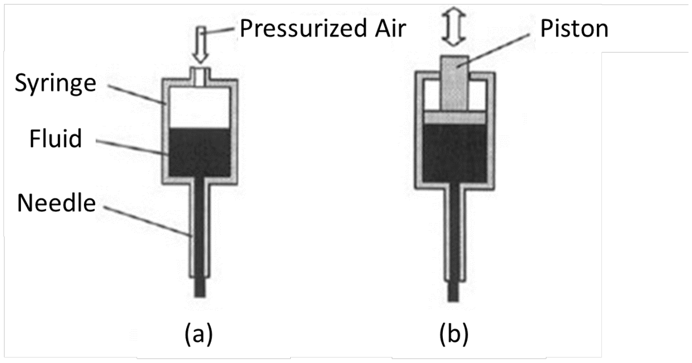

Figure 7: Schematic Diagrams of the Fluid Dispensing Systems: (a) Time-Pressure, (b) Positive-Displacement [10]

Although both the time-pressure and positive displacement systems dispense fluids, each uses a slightly different approach and so is better suited for some applications than others. The time-pressure mechanism is used for a higher variety of situations due to its low maintenance, cost, and ease of operation. However, it is difficult to control due to the amount of pressure variability in the syringe, which can affect the dispensing quality and consistency. Also, the fluid looks to drool from the needle tip due to build up residual back pressure from the fluid. Time pressure has no inbuilt mechanism to seal the fluid chamber at the needle end in comparison to jetting where ball sits onto the seat to seal the fluid chamber.

The dispensing of fluid volumes in short bursts of applied syringe pressure makes the application process unpredictable as the flow rate of the fluid is time dependent. Time-pressure dispensing has been the main area of attraction for the past twenty years, but to mitigate the drawbacks must evolve from needle contact dispensing to jetting technology. Jetting involves tapping the piston with a ball end onto the conical seat opening to eject a droplet at a constant volume in a more repeatable and precise manner resulting in good dot quality at a particular syringe pressure [9]. Jetting is very much adaptable to different sizes and shapes of substrate given the adjustability on the droplet size with change in the process settings or the jet valve hardware like nozzle and piston.

EXPERIMENTAL METHODOLOGY

The main objective of this research is to conduct a detailed study to repeatedly dispense a commercially available LMP TIM material to understand the dispense characteristics like weight repeatability and dispense performance. The study involves the use of a high-speed dispensing system with either a time-pressure or a positive displacement jetting pump installed which can dispense material in a repeatable manner without affecting the dot quality. Material packed in syringe sizes of 10cc is used for this study.

The experiment was conducted in two stages: first with a time-pressure pump and then with a high-speed, pneumatically actuated jetting pump. The sample fire-resistant (FR4) substrate as shown in Figure 8 was first pre-weighed, then a spiral or rectangular pattern was dispensed onto the sample substrate before post-fabrication weighing was finally carried out to determine the net weight of the dispensed material. An offline weigh scale was used for pre- and post-fabrication weighing of the sample. Control charts are used to determine the variation in the process for analysis purposes.

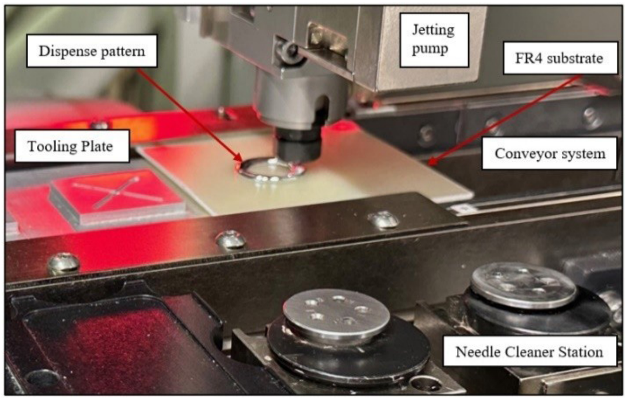

Figure 8: Experimental set-up of FR4 Substrate with Dispensed Pattern

Figure 9 shows two different control charts created on Minitab statistical software to illustrate the difference between the common and special cause variation. Minitab statistical software determines the centerline ($\bar{X}$) based on the average of all the individual samples collected. X-axis displays the number of samples. Lower control limit (LCL) and Upper control limit (UCL) are defined as 3 standard deviations on each side of the determined centerline (CL). A process is said to be in control when the control chart does not indicate any out-of-control condition (a point outside the control limit or matching one or more of the criteria in defined rules) and only contains common cause variation. If common cause variation is small, then a control chart can be used to monitor the process. If the common cause variation is too large, the process will need to be modified or improved to reduce the amount of inherent variation to an acceptable level [7].

A moving range measures how variation changes over time when data are collected as individual measurements rather than in subgroups. Moving range average ($\overline{MR}$) is the average of all the moving average for all the individual samples collected. Each Moving Range point is calculated as $X_n – X_{n-1}$ and hence we will have one data point lesser than that in the Individual Chart. When Minitab calculates the average of a moving range, the calculation also includes an unbiasing constant. The table of unbiasing constants is available within Minitab. The MR Chart helps in assessing the stability of the process caused by the variation between consecutive individual data points. Whenever the points are out of Control Limits, it indicates that the process is unstable. This helps in identifying the Special/Assignable Cause that triggered the process to become unstable. After exploring the reason for the cause of outlier, the same should be fixed and removed from both I and MR Chart. Whenever the variation is found to be huge in MR chart, one should refer to the I-Chart and determine the cause of the variation as the I-Chart will have the exact individual data points against the time period which had caused the high variation.

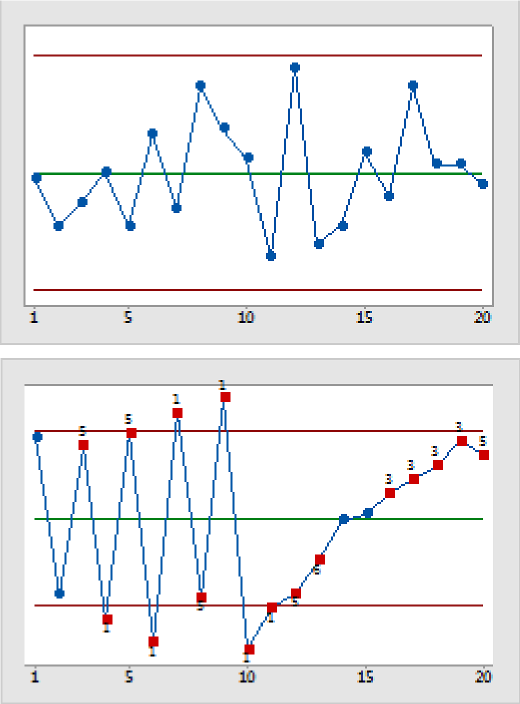

Figure 9: Common Cause Variation (a) vs Special Cause Variation (b) example [7]

In Figure 9 (a) the process is stable because the data appears to be distributed randomly and does not violate any of the 8 control chart tests. In Figure 9 (b) the process is not stable; several of the control chart tests are violated. The specific number above the datapoints relates to which test was violated by each individual data point. Minitab provides 8 different tests as shown in table 1 to detect special cause variation. Users can make each test more or less sensitive by changing the value of K which is a constant number.

Table 1: Test criteria for special cause variation

Test	Criteria	Description
Test 1	1 point > K standard deviations from center line	It identifies subgroups that are unusual compared to other subgroups. Test 1 is universally recognized as necessary for detecting out-of-control situations. If small shifts in the process are of interest, the user can use Test 2 to supplement Test 1 in order to create a control chart that has greater sensitivity.
Test 2	K points in a row on same side of center line	It identifies shifts in the process centering or variation. If small shifts in the process are of interest, the user can use Test 2 to supplement Test 1 in order to create a control chart that has greater sensitivity.
Test 3	K points in a row, all increasing or all decreasing	Test 3 detects trends. This test looks for a long series of consecutive points that consistently increase in value or decrease in value.
Test 4	K points in a row, alternating up and down	It detects systematic variation. You want the pattern of variation in a process to be random, but a point that fails Test 4 might indicate that the pattern of variation is predictable.
Test 5	K out of K+1 points > 2 standard deviations from center line (same side)	It detects small shifts in the process.
Test 6	K out of K+1 points > 1 standard deviation from center line (same side)	It detects small shifts in the process.
Test 7	K points in a row within 1 standard deviation of center line (either side)	It detects a pattern of variation that is sometimes mistaken as evidence of good control. This test detects control limits that are too wide. Control limits that are too wide are often caused by stratified data, which occurs when a systematic source of variation is present within each subgroup.
Test 8	K points in a row > 1 standard deviation from center line (either side)	It detects a mixture pattern. In a mixture pattern, the points tend to fall away from the center line and instead fall near the control limits.

Time-pressure is set up by dispensing 1450 milligrams of material with a 15-gauge precision needle tip onto the sample FR4 substrate. A sample size of 31 was chosen for data analysis. Weight sampling into the weight scale precision cup prior to dispensing onto the FR4 substrate cannot be performed with the time-pressure pump due to material stringing at the needle tip and lack of proper detachment for actual weight measurement. With no weight measurement from the weight scale, there is no feedback to perform the automatic weight scale compensation with time pressure system prior to dispensing on FR4 substrate. The standard process program involves a clean needle, height sensing of the FR4 substrate, and subsequent dispensing of a spiral pattern on FR4 substrate excluding dispensing twenty shots into the weight measuring cup. Only the dispensed volume on the FR4 substrate is evaluated while weigh repeatability evaluation is not possible.

RESULTS

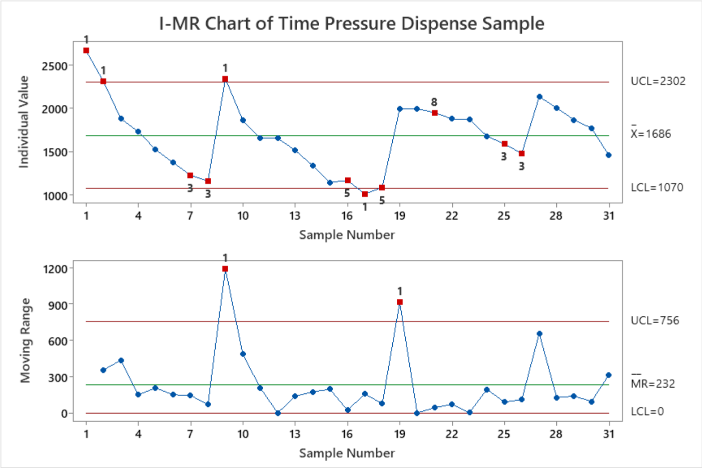

Figure 10: I-MR Chart of Time-Pressure Dispense Sample on FR4 Substrate

Table 2: Results for I-MR chart of Time-Pressure Dispense Sample

	I Chart	MR Chart
Test 1	One point > 3 std deviations from CL	
Test Failed	1, 2, 9, 17	9, 19
Test 3	6 points in a row all increasing or decreasing	
Test Failed	7, 8, 25, 26	-
Test 5	2 out of 3 points > 2 std deviations from CL	
Test Failed	2, 8, 16, 17, 18	-
Test 6	4 out of 5 points > 1 std deviation from CL	
Test Failed	17, 18	-
Test 8	8 points in a row > 1 std deviation from CL	
Test Failed	21	-

Control chart for time-pressure dispensed sample in Figure 10 shows 4 points beyond the 3 standard deviation control limit and more than six points in a row steadily in a falling trend which reveals a different aspect of process instability on the individual value (I) Chart. Two test points fall outside the control limits on the moving range (MR) chart therefore the process variation is not in control. This indicates special cause defects which may be due to the compressible nature of the material and the limited number of controllable process parameters for time-pressure dispensing. The current feed mechanism on time-pressure does result in inconsistent dispensing results even with a constant reservoir pressure; natural variation occurs despite constant air pressure being applied to a syringe. The syringe pressure remains constant regardless of other factors like fluid variation, reservoir level and plunger stiction which leads to occasional material drip from the needle tip. Weight scale compensation is not an option due to the material not separating from the needle tip because of its viscous nature.

A high-speed, pneumatically actuated jetting pump, which works on the principle of positive displacement, is used to jet the LMP material onto the FR4 substrate in small quantities. The experiment is intended to repeatedly dispense the material into a weight-measuring cup placed on a precision scale installed in the high-speed dispensing system. Gage R&R analysis considers data from the weight measuring scale which has the weight measuring cup installed to measure the amount of weight dispensed by the fluid dispensing system into the cup. Gage R&R only evaluates the precision of the measurement system, and it considers the P/T ratio which is the ratio of the precision of the measurement system to the tolerance of the manufacturing process on which it is being incorporated. A P/T ratio less than 0.1 indicates that the measurement system is satisfactory and can determine whether the measured part follows the desired tolerance specification, while a P/T ratio between 0.1 and 0.3 indicates the measurement system to be merely acceptable depending upon the importance of application and cost of gage. Generally, for our testing purposes, we accept the gage system to be acceptable for P/T ratios below 0.3 because of minor vibrations introduced due to the gantry motion too fast in the entire three axes X, Y and Z.

The pump makes an adjustment based on the target total weight with defined specifications to adjust the number of extruded dots to dispense the correct amount of material into the weight-measuring cup followed by deposition onto the FR4 substrate. The standard process program involves dispensing twenty shots into the weight measuring cup, cleaning the needle, sensing the height of the substrate, and then dispensing a spiral or rectangular pattern onto the FR4 substrate. Target total weight for weigh repeatability on the weight precision scale on the machine was defined as 40 milligrams with process tolerance of ±10 percent while the pattern weight on FR4 substrate was 1450 milligrams. Target total weight is often chosen as a less amount of material to avoid any wastage of material and help with the weight correction to automatically adjust the number of extruded dots to ensure the correct volume of spiral pattern is dispensed on the FR4 substrate. Flow rate of the jet valve is constant so it provides good weight control for both lower and higher weights.

Figure 11: I-MR Chart of High-Speed Jetting Pump Weight Repeatability

Table 3: Results for I-MR chart of Jetting Pump Weight Repeatability

	I Chart	MR Chart
Test 1	One point > 3 std deviations from CL	
Test Failed	-	15, 16
Test 5	2 out of 3 points > 2 std deviations from CL	
Test Failed	16	-

The I chart in Figure 11 indicates a test point failure at point 16 on Test 5 which is identified as a small sudden shift from the average like a one-time occurrence of a special cause may be due to a small air bubble present in the syringe. Moving Range (MV) chart also indicates the same phenomenon at similar points. Point 16 could be counted as a one-time occurrence or outlier in the process. LMP is a compressible material which can observe random spikes depending upon the kind of plunger assembly used in the syringe. This could be eliminated in future trials with use of different plunger assembly which flows smoothly on the inner walls of the cartridge.

Data was also collected for the jet dispensed sample on the FR4 substrate in which a total target weight of 1450 milligrams was deposited. Jet dispensing as a method is promising due to the non-contact nature of technology allowing for easy material separation from the needle tip without any contamination. The I-chart in Figure 12 has all points within the 3 standard deviation control limits and no failed tests for any of the dispensed samples collected through the high-speed jetting pump. The process resulted in highly controlled deposition with no variation in the resulting data.

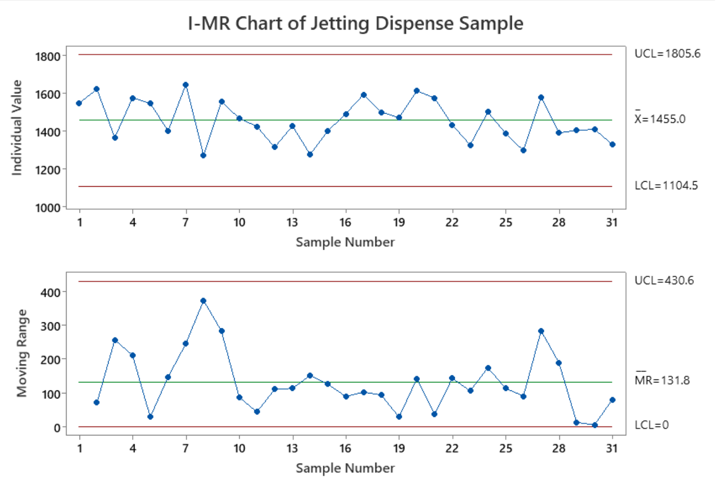

Figure 12: I-MR Chart of High-Speed Jetting Pump Dispense Sample on FR4 Substrate

Dispense Quality

Visual inspection of the dispense pattern quality was performed under an optical light microscope to capture any satellite formation during the dispense cycle. Visual inspection also helps to determine whether the dispensing pattern is misaligned. Dispense quality seems to degrade with material skipping as the dispense progresses from sample 1 to 20 with the time-pressure dispense system as shown in Figure 13 below. Dispense sample 1 starts good but quality looks to degrade with little skip on dispense sample 13 which eventually degrades as it progresses to dispense sample 20.


Sample 1 Sample 13 Sample 20

Figure 13: Time-Pressure Dispense Pattern Samples

The jetting pump exhibited more consistent volume deposition across the dispense pattern due to the weight correction applied during weight sampling into the weight cup installed on the high-speed dispensing machine. Weight correction refers to auto adjusting the number of extruded dots before dispensing a spiral pattern on the FR4 substrate. Weight correction is only possible with jetting as the dots look to separate cleanly from the needle tip while time pressure doesn't allow good separation. Liquid Metal paste constitutes of metal alloy which is less viscous in nature mixed with the metal paste. Dispense quality on sample pattern 6 and 16 is little different from sample pattern 25 and 30 as shown below in Figure 14 due to the little bit more volume of metal alloy present in the dispense pattern. Metal alloy, due to its less viscous nature tends to sit down close to the exit point of the syringe, it will be on a higher side on initial patterns as compared to subsequent patterns. Dispense volume stays the same for all 31 dispense sample patterns.

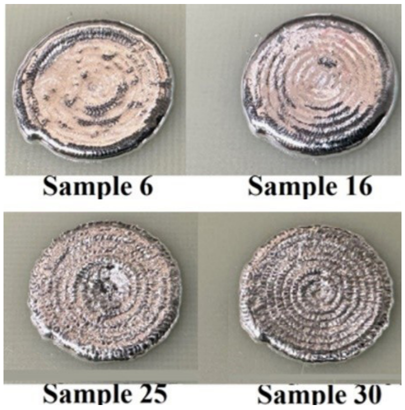
Sample 6 Sample 16
Sample 25 Sample 30

Figure 14: Jetting Pump Dispense Pattern Samples

Double barrier system for LMP application

LMP is a next generation liquid metal-based thermal paste designed specifically for thermal management of high-performance computing (HPC) semiconductor applications, such as CPU, GPU, and MCM. Depending on the chosen pattern and specific die dimensions, a more uniform spread can be achieved when attaching the heat-sink. If using a jetting system, it is possible to jet dots so close together that the liquid metal will combine immediately after the jetting process.

A bare silicon die is placed over the substrate. LMP must be applied with the jetting pump over the bare silicon die within the inner barrier. Inner barrier also helps to prevent leakage and moisture intrusion into the stack-up. The inner barrier bead height must be less than the height of the applied LMP over the silicon die while the outer dam barrier must be higher than the inner barrier bead height to prevent LMP from spreading onto adjacent components. Inner barrier bead height was lower than outer barrier helping LMP to spread out evenly to cover the die. Excess LMP can spread out between the inner barrier and outer barrier boundary. A variety of gasketing materials can be used for both inner and other barrier boundaries to hold their shape after dispensing to enclose the LMP. A compression test with a glass slide is performed to demonstrate that liquid metal paste spreads isotopically leaving behind no major voids. A glass slide could be imagined equivalent to a heat sink or heat spreader shield to dissipate the heat out of the package.

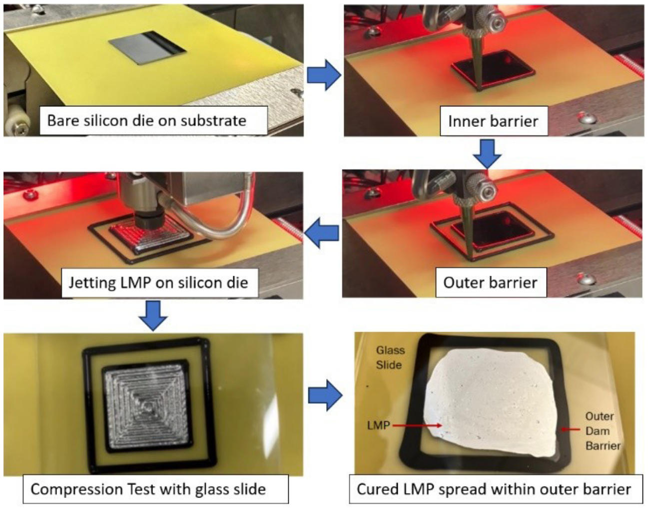

Figure 15: Process flow for Double barrier system in LMP application

CONCLUSION

Based on the individual and moving range control charts, jetting is a more promising dispensing method compared to the time-pressure dispensing. Weight repeatability of 40 milligrams dispensed weight is within process tolerance of ±10 percent. Due to easier and cleaner separation of liquid metal paste from the needle tip, jetting results in a much better dispense quality as compared to time-pressure dispensing for liquid metal paste. Various formulations of LMPs were tested with both time pressure and jetting to find the appropriate formulation that could be used for this study. Jetting also promises tighter weight control due to the weight correction feedback loop which ensures correct material volumes are dispensed on the substrate. Choosing advanced jetting technology helps to maintain the deposit volume of LMPs more consistently on the final product in high volume production for better yields. Another good thing about liquid metal paste is that it is reclaimable which can be recycled to regenerate liquid metal paste again. This may lead to less waste subject to sustainable solutions for the electronics assembly industry. Also, soapy water solution is recommended to clean the jet valve hardware instead of harmful chemicals which have high volatility content which are prohibited at worldwide manufacturing sites under OSHO standards.

Future improvement would be to test another LMP formulation to have more uniform spread of metal alloy in the metal paste for consistent dispense quality across the bigger cartridge sizes.

ACKNOWLEDGEMENT

We would like to thank our partner Ricky McDonough at Indium Corporation for providing material samples and support for the evaluation trials required to perform this study.

REFERENCES

[1] M. Lazić, (2021, Jan 25-27). "Solid Liquid Hybrid TIMs", IPC APEX EXPO Technical Conference 2021, San Diego, California, United States.

[2] Agarwal, S., Lazic, M. (2025, March 15-20). "Liquid Metal Paste High-Speed Dispensing for High-Volume Manufacturing – Part II," IPC APEX EXPO Technical Conference 2025, Anaheim, California, USA.

[3] J. Edmondson, "Thermal Interface Materials 2021–2031: Technologies, Markets and Opportunities", IdTechEx, 2019.

[4] M. Lazić, et al, (2022, Jan 25-27). "Solid Liquid Hybrid TIMs—Part II, The Power of m2TIMs™", IPC APEX EXPO Technical Conference 2022, San Diego, California, United States.

[5] M. Lazić, et al, (2023, Jan 24-26). "High-Performance Phase Change Metal TIMs", IPC APEX EXPO Technical Conference 2023, San Diego, California, United States.

[6] M. Lazić, Dr. A. Mackie, T. Jensen, D. Socha, "Solid Liquid Hybrid TIMs", PCB Carolina

[7] S. Agarwal, 2024. "Optimized Performance of Piezo-Driven Jet Actuator for Thixotropic Epoxies in Electronics Assembly." Journal of Microelectronics and Electronic Packaging 21 (4): 86–92. https://doi.org/10.4071/001c.127407.

[8] S. Agarwal, 2024. "Improved Throughput with Dynamic 'Real-Time' Dual Head Dispensing in Electronics Assembly" Journal of Microelectronics and Electronic Packaging 21 (2): 50–57. https://doi.org/10.4071/001c.119027.

[9] Agarwal, Sunny, and Miloš Lazić. 2025. "Jet Dispensing of Liquid Metal as a Thermal Interface Material." Journal of Microelectronics and Electronic Packaging 22 (4): 85–92. https://doi.org/10.4071/001c.147767.

[10] S. Agarwal, "Low Volume Dispensing with High-Speed Dispensers," Master's Thesis, State University of New York at Binghamton, December 2012.

BIOGRAPHIES

Sunny Agarwal is a Senior Applications Engineer at ITWEAE Camalot Electronic Dispensers group in Hop¬kinton, Massachusetts, with over 15 years of experience working on product develop¬ment and validation of high-speed adhesive dispens-ing equipment for printed circuit board assemblies. He completed his master's degree in industrial and sys¬tems engineering from Binghamton University, New York with specialization in electronic packaging and his bachelor's degree in mechanical En¬gineering from India. His current research interest lies in industrial au¬tomation for electronic packaging, adhesive dispensing, electromechanical systems, advanced motion control, product innovation, machine vision and image processing. He has authored 16 publications and holds 3 patents. He has been a featured speaker at various national and international forums and is a Certified Lean Six Sigma Green Belt professional. He has been an active tech¬nical program committee member organizing IPC and IMAPS technical conferences.

As a Senior Product Specialist for Thermal Interface Materials (TIMs), Miloš is responsible for developing new thermal materials and products and providing solutions for customer challenges and applications. He also develops new testing methods to evaluate power and thermal products and gathers data on new and existing products for marketing presentations. Miloš joined Indium Corporation in March 2018 as a Technical Support Engineer, primarily responsible for servicing customers, troubleshooting and application needs in the Northwest, California, and Rocky Mountain regions. In 2018, he took on the role of Coordinator for the Live@ Program—a global initiative designed to align Indium Corporation and its industry partners in promoting agile response, resource management, and efficiency improvement.