(2)

AD-A278 780

# LIQUEFIED METAL JET PROGRAM AUTOMATION AND ROBOTICS RESEARCH INSTITUTE (ARRL)

## QUARTERLY TECHNICAL REPORT

## REPORTING PERIOD: 15 OCTOBER 1993 THROUGH 15 JANUARY 1994

**Sponsored by:**

Advanced Research Projects Agency (ARPA)
Contracts Management Office (CMO)
Liquefied Metal Jet Program (LMJP)

DTIC ELECTE MAY 02 1994 S G D

ARPA Order No. 9328/03

CLEARED FOR OPEN PUBLICATION

APR 21 1994 4

DIRECTORATE FOR FREEDOM OF INFORMATION AND SECURITY REVIEW (OASD-PA) DEPARTMENT OF DEFENSE

Issued by: ARPA/CMO
Under Contract No.: MDA972-93-C-0035

Subject to the following disclaimer:

~~REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE INDORSEMENT OF FACTUAL ACCURACY OR OPINION.~~

Deliverable Item Sequence No.: 0002AB

R&D Quarterly Status Report

"The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed implied, of the Advanced Research Projects Agency or the U.S. Government."

94-13123

1988

94 4 29 02 8

**Prepared by:**


Texas Instruments Incorporated
Defense Systems & Electronics Group
13500 North Central Expressway
Dallas, Texas 75243


TEXAS INSTRUMENTS

94-S-1422

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

3 March 1994
9093b

## TABLE OF CONTENTS

# LIQUEFIED METAL JET PROGRAM (LMJP)
# AUTOMATION AND ROBOTICS RESEARCH INSTITUTE (ARRI)

## QUARTERLY STATUS REPORT
## DATA ITEM 0002AB
## 15 OCTOBER 1993 THROUGH 15 JANUARY 1994

## 1.0 INTRODUCTION

This report covers the period from 15 October 1993 through 15 January 1994. The Quarterly Technical Reports are organized by the statement of work (SOW) listed in section 5.0 of the proposal. These are listed below:

- Reports and demonstration
- Equipment
- System test and experimentation
- Test coupon evaluation
- Technology transfer

## 2.0 REPORTS AND DEMONSTRATION, SOW 5.1

A requirements definition report has been developed and is included in Appendix A. The report includes a table of the risk assessment and reduction plans developed during this quarter.

## 3.0 EQUIPMENT, SOW 5.2

Section 3.0, Equipment, is divided by the subsystem descriptions used in the proposal.

### 3.1 Fluidizer, SOW 5.2.1

The fluidizer module for the LMJ system converts the solid metal feedstock to liquid. This includes engineering design, fabrication, thermal management integration and functional testing of the fluidizer module to introduce the metal feedstock at a predetermined rate into a high temperature melt chamber. Propelling forces are required to drive the liquid metal jet at the predetermined velocity. The resulting liquefied metal will be transitioned to the droplet generator for subsequent droplet formation.

The fluidizer for the no-lead system has been designed and fabricated. The design is a modification of a previous design used for 63/37 solder which was sponsored by the State of Texas. It is a stainless steel pot which uses heating coils to melt the metal. The system is currently being tested and should be completed by 1 March 1994.

Conceptual design of the fluidizer for the copper system has begun. Due to the much higher temperature needed to melt cooper (2,000°F), a complete redesign will be required for a copper fluidizer. Major areas of evaluation include:

- Melting method; induction, conduction, etc.
- Fluidizer material; titanium, ceramic, etc.
- Sealing options; bolts, flanges, etc.
- Determining the volume of metal needed to be melted.

Interim technical results from these evaluations will be reviewed at the preliminary design review on 17 February 1994.

## 3.2 Droplet Generator, SOW 5.2.2

The proprietary droplet generator for the LMJ system will accept the liquefied metal from the fluidizer and provide the instability required to excite the jet stream into a repeatable droplet formation. In addition, the droplets will have a charge induced by an induction plate as they break away from the jet. A signal level will be provided to the charge plate for each droplet in order to provide deflections for pattern printing. By varying the charge on the droplets the trajectory through an electric field can be controlled. After being charged, the droplets will continue through an electrostatic deflection field, to impact the target at a precise location.

A new version of the proprietary, continuous mode generation has been designed, fabricated, and tested off line. This is a modification of an early design which was used on a 63/37 tin lead solder system developed on an earlier research project. The generator has not been sufficiently parameterized at this time due to its inconsistent performance. Problems include stream instability and a lack of consistent droplet formation. A redesigned continuous mode generator will be required for the no lead system.

An important test result to be used in the upcoming copper system design is that no temperature-dependent effects have been seen during the testing. This result supports the technical feasibility for developing a high temperature, copper based system.

An initial charging and deflection system has been built and tested for the continuous mode droplet generator. Early problems with electrical fields interference have been identified and are being studied. Other problems include electrostatic buildup and poor response time of the charging ring. These problems are also being studied. The observed deflection has been shown to be larger than theoretically predicated.

Due to the technical problems with deflection and the need to study copper-substrate interactions, a risk reduction effort has identified the need for a simple (i.e., manual) copper jet system to be designed and built. This simplified manual drop system will allow many technical issues (i.e., materials, substrate interaction, heating methods, oxidation) to be tested prior to designing and building the final copper based system. On 27 January 1994, a design effort was initiated for a drop on demand mode, proprietary droplet generator to be used in the manual drop system. This risk reduction effort will have no cost or schedule effect on the program.

## 3.3 Jet/Droplet Stream, SOW 5.2.3

A path for the droplets to be charged and deflected will be provided in the design of the system. The path will also provide for alternative atmospheres for experimentation. Controlling the environment was shown in previous research programs to be critical to jetting success.

The no lead system jet stream and target chamber is a large Plexiglas environmental chamber used to provide an inert gas atmosphere. This is a modification of earlier designs used on earlier research programs.

The cooper system will require a complete redesign because of its higher temperature. Preliminary design evaluations have concluded the continued need to use an inert environment for copper.

## 3.4 Target Chamber, SOW 5.2.4

The test coupons (i.e., samples) on which the experiments will be run, reside in a fixture to hold the coupon and a chamber to provide for controlled inert atmosphere. This chamber will provide controlled heat for coupon preheating, and provide for optical observation and instrumentation. In addition to the chamber, a precision motion control system to position the coupon for pattern writing will be designed, acquired and integrated into the LMJ system. A device to catch and collect the unwanted or "guttered" droplets is included in the coupon chamber.

The required level of environmental control for the jet stream has resulted in the target chamber being included in the jet stream's Plexiglas environmental chamber. A preliminary design of the thermal control for the test coupon and the guttering system has been placed on hold until the deflection system has been characterized.

## 3.5 System Control, SOW 5.2.5

System control addresses all items necessary to control and monitor the process. Subtasks include hardware, software, and integration for process control, environmental control, data acquisition and safety. The system control will include personal computers, programmable logic controller, data acquisition software, Computer Aided Design (CAD) data, Network Control (NC) program interface and custom programming. Facility related substasks will include, fume handling capabilities, safety systems and thermal management equipment.

The system control for the no lead system has been designed and is being procured. The design will be evaluated at the preliminary design review.

The xy table is controlled using COMPUMOTOR software running on a personal computer. Industrial PID controllers are used to control all variable parameters (pressure, temperature). Switches are used for binary control functions. The overall system will be monitored using a National Instruments software program called LABVIEW which runs on a Macintosh computer. Test and evaluation of this system will be performed during the next quarter. The copper based system is expected to use the same basic scheme.

## 4.0 SYSTEM TEST AND EXPERIMENTATION, SOW 5.3

This task consists of planning and executing all tests and experiments. Several testing requirements have been identified and included in the Requirements Definition Report. A test coupon preparation procedure for handling copper coupons has also been developed. Additional testing requirements will be added as the program progresses. A requirements definition report is given in Appendix A.

# Appendix A

# REQUIREMENTS DEFINITION REPORT
# LIQUID METAL JET TECHNOLOGY:AN ALTERNATIVE PRINTED WIRING BOARD PROCESS

## 1. Introduction

The Requirements Definition Report is submitted to Texas Instruments Inc. as a deliverable for the research project titled, *Liquefied Metal Jet Technology:An Alternative Printed Wiring Board Process*. This report establishes design targets for the research prototypes funded by this project and for future production equipment. The report is a working document that will be updated as additional information is identified. In addition, a risk analysis and avoidance plan is included.

## 2. Background/Program Summary

The objective of this project is to create a demonstrable prototype system capable of manufacturing printed wiring boards (PWBs) via an additive process. The project is based on the liquid metal jet (LMJ) process which is capable of printing very precise droplets of molten metals including solder and copper. This proposal is a teaming effort among Texas Instruments Incorporated (TI), and the Automation & Robotics Research Institute of The University of Texas at Arlington (UTA/ARRI)

The primary technical challenge to be met under this proposal is the development of a print head and system capable of precisely forming and 'printing' extremely small droplets (100 to 1μm) of higher melting point metals such as copper and nonlead-based solder. Unlike current processes, the high precision liquefied metal jet (LMJ) technology will be capable of printing a PWB much like an ink jet printer would print a document or label. This printing capability will eliminate many of the ecological problems or by-products associated with the photolithography masking electroplating and chemical etching processes used in PWB manufacturing. In addition to the environmental impact, the liquefied metal jet process will favorably impact DoD manufacturing cost, capability and flexibility. With a direct CAD interface, the proposed alternative manufacturing technology will excel in one-of-a-kind rapid prototyping and replication type PWB board production. The proposed process can produce PWB patterns with circuit lines smaller than existing technologies. This just-in-time (JIT) fabrication and replication fits directly into such DoD agency missions as the Logistics Command Depot support for the line of battle.

This project represents the first of two steps necessary to develop and implement LMJ technology throughout industry. The demonstration prototype developed in this project will establish the viability of the technology as a significant improvement in PWB affordability, flexibility, and environmental concerns. The next step (i.e., future proposal) would be to convert the prototype into a robust, industrial hardened PWB process which can be used throughout the defense and commercial industrial base.

Two test coupon patterns for this research program have been selected. The first pattern will be used for process validation and is shown in Figure 1. The process validation coupon includes lines, ball grid arrays, vias and symbols/characters. The size of these features will vary depending on the size of the metal spheres being jetted. The second test coupon will be used to investigate the capability of LMJ to meet future production requirements. This coupon represents the state of the art for each application. The state of the art pattern includes different sizes of straight lines, six channel routing, vias, plated through holes, ball grid arrays, and symbols/characters. For this contract, the process validation coupon is a program requirement, whereas, the state of the art coupon will be used as a program goal if time permits.

## 3. Requirements Definition

### 3.1 Introduction

Four test applications have been identified to establish the viability of the LMJ process in PWB manufacture. The four applications are applying:

1. pure tin for pretin PWB applications
2. pure tin as an etch resist to produce circuit paths/pads/vias
3. pure tin solder bumps on PWB substrates for ball grid arrays
4. copper for printed circuit paths

Major requirements and important parameters to be measured for each application are described in this report. When available, each parameter includes metrics and methods for its measure. Some of the design targets are undefined at this time and shown as "to be determined" (TBD). In addition, important process parameters to be measured in the LMJ test and evaluation phase are listed. Many of the measurement methods will also to be defined at a later date. As a research project, both performance based and scientific based parameters are included.

### 3.2 Pure Tin

**3.2.1 Description of tin, fluxes, and coupon substrate.** The metal selected to be applied for the first three applications is pure tin. This was selected for its environmental friendliness, low cost, stability, widespread use in electronics, and widespread knowledge of its material properties.

The test coupons will be 12" × 12" oxygen free, high conductivity (OFHC) copper clad substrates. Since the substrate base is not a critical parameter, FR-4 will probably be used. The copper will be degreased and lightly acid etched prior to testing. The coupons will be prepared in a similar procedure used by Sandia National Labs Solder Research Center (see section 10.1). Four fluxes will initially be used. These are RMA1, RMA2, OA1, and OA2 which will be mixed 1:1 with alcohol. For more information on coupon preparation, see section 10.

**3.2.2. Application No. 1 Pretin - applying pure tin that wets to a copper clad substrate to pretin circuit pads/paths.** The purpose of test application no.1 is to simulate the pretin requirements found in PWB manufacturing. Pure tin will be applied in a pattern on the copper clad, non pre-etched, test coupon. Test patterns were selected which represent typical PWB patterns and are shown in Figures 1 and 2. The prototype will be a single shooter (assume one layer of balls, various sized diameter balls)

To minimize the placement accuracy required for this first test application, the pattern will be applied in a non-registered position on the test coupon where the entire coupon is covered with copper. This differs from pretining etched circuit paths/pads found in a typical PWB application.

### 3.2.3 Application No. 1 Pretin - requirements and process parameters to be measured.

Solderability

- There are two distinct issues:
  1. How well tin (Sn) wets the substrate during deposition of liquid metal
  2. How solderable the tinned surface remains for subsequent soldering operations
- The techniques used for assessing solderability on the substrate should include cross-sectional analysis by optical microscopy (OM), SEM and possible TEM, XEDS, area-of-spread measurements, wetting angle, and peel testing. In the second case, solderability is a function of oxide formation on the tinned surface. The SERA technique has been used to measure solderability in this case.

Process Parameters to be measured (surface profile and edge definition)

Line Width and Thickness

- line width tolerance (mils)
- line thickness tolerance (mils)

Surface and Edge profile (See Figure 3)

- indentation/mouse bites (mils)
- overall slope of top height (degrees)
- wetting angle (degrees)
- surface color (subjective classes), visual

X/Y Placement Tolerance; Centerline measure

- initial placement accuracy (mils)
- average overlap accuracy (mils)
- overlap repeatability (mils)
- maximum off pattern (mils)

Material Behavior

- oxide inclusion content

### 3.2.4. Application No. 2 Etch Resist - applying pure tin to a copper clad substrate to be used as an etch resist

The purpose of test application no.2 is to simulate the use of tin as an etch resist for producing copper circuit paths by printing circuit paths in tin and then etching away excess copper. Pure tin will be applied on the copper clad test coupon in the same pattern as application no.1 (see Figures 1 and 2). Unlike application no.1, more than one layer of depositions may be required. After the pattern is printed on the test coupon, excess copper on the coupon will be etched away. Tests will then be performed on the remaining copper circuit paths that remain. The prototype will be a single shooter, assume one layer of balls, TBD x/y diameter balls, TBD placement overlap.

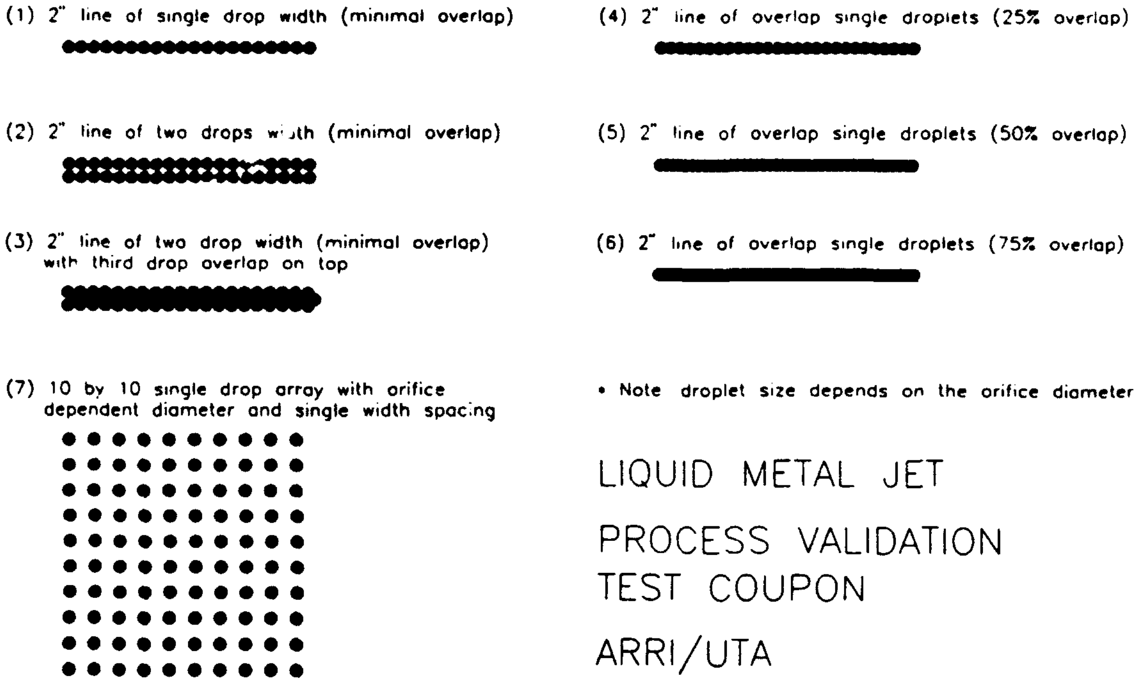


**Figure 1**
**Process Validation Test Coupon Pattern**

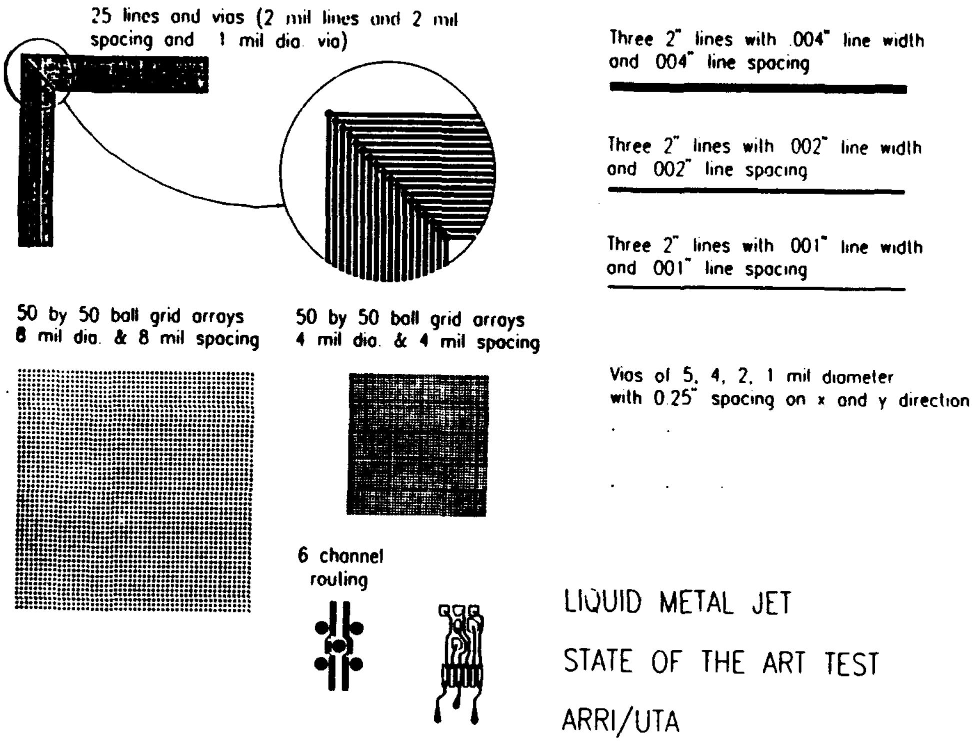


**Figure 2**
**State of the Art Test Coupon Pattern**

**3.2.5. Application No. 2:Etch Resist - requirements and process parameters to be measured (mean, standard deviation, and distribution)**

Etch Resistance (to be determined)
Surface Profile and Edge Definition
Line Width and Thickness Tolerance; Microscopic Measurement

- line width tolerance (mils)
- line thickness tolerance (mils)

Surface and Edge Profile (see Figure 3)

- indentation/mouse bites (mils)
- overall slope of top height (degrees)
- wetting angle (degrees)
- surface color (subjective classes), visual

X/Y Placement Tolerance; Microscopic Measurement

- initial placement accuracy (mils)
- average overlap accuracy (mils)
- overlap repeatability (mils)

Electrical Performance Characterization of Etched circuit paths
Conductivity/Resistivity
Thermal Conductivity (w/m °K)
Material Behavior

- oxide content inclusion

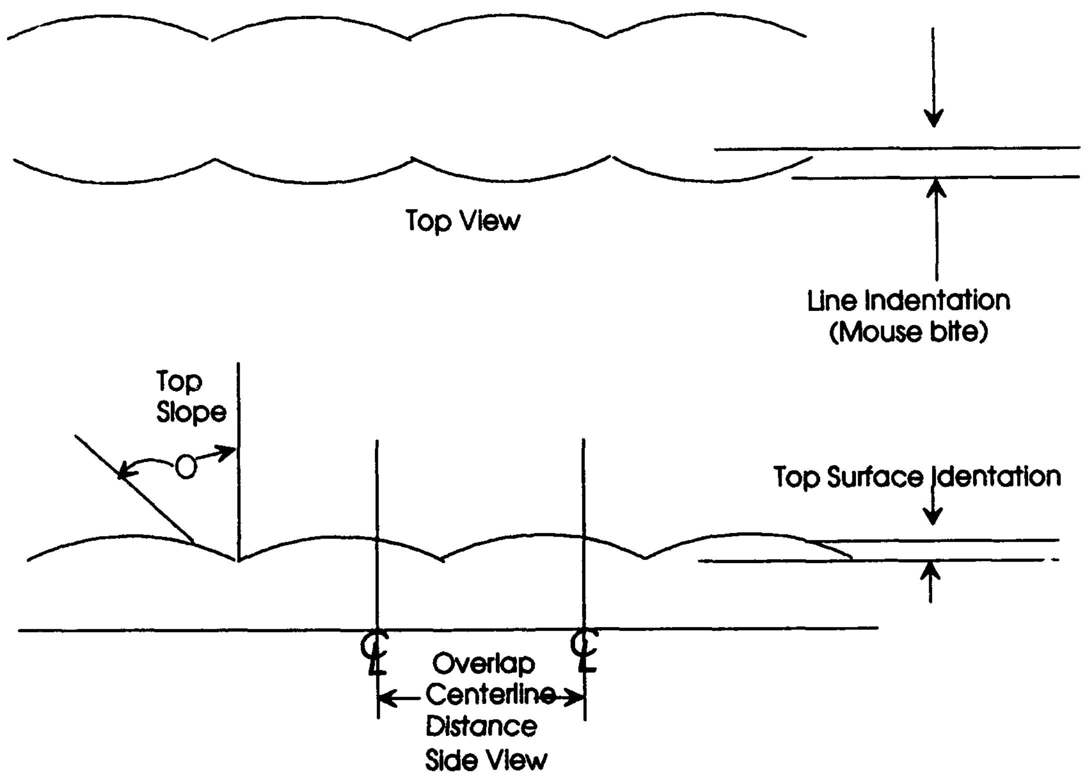


**Figure 3**
**Surface and Edge Profile Description**

**3.2.6 Application No. 3:Ball Grid Array description: - applying tin and no lead solder for solder bumping of PWB's for ball grid array applications**

The purpose of test application no.3 is to simulate the solder bumping process on printed wiring board (PWB) for ball grid arrays (flip chips). Pure tin will initially be used for the solder bumps. Since pure time is not being used in this application, no lead and solders will only be use if time and resources permit. Some of the alternatives includes: 67Bi-37In (109C), 50In-50Sn (118-125°C), 40In-40Sn-20Pb (121-130°C), 58Bi-42Sn (138°C), 97In-3Ag (143°C), 80In-15Pb-5Ag (142-149°C), 95Sn-5Sb (232-240°C) and 96Sn-4Ag.

**3.2.7 Application No. 3 Ball Grid Array - requirements and process parameters to be measured (mean, standard deviation, and distribution)**

Surface Profile and Edge Definition
Thickness Tolerance

- minimum (mils)
- maximum (mils)

Individual Splat Surface and Edge Profile Tolerance

- edge diameter (mils)
- overall slope of top height (degrees)
- wetting angle (degrees)
- surface color (subjective classes), visual

X/Y tolerance
Initial Placement Accuracy (mils)

Array Repeatability

- average edge distance (mils)
- minimum/maximum edge (mils)
- minimum/maximum centerline (mils)
- average centerline distance (mils)

Mechanical Characterization
Strength (kg/mm$^2$)- Pull Test
Reliability - Fatigue, Thermal, Vibration
Material Behavior

## 3.3 Copper

**3.3.1. Description of copper and substrates.** Pure Copper (OHTC) will be used in test application no.4. This was selected for its superior electrical characteristics, low cost, and widespread use in electronics manufacturing.

The test coupons will be 12" x 12" substrates of different materials. Materials to be evaluated will include FR-4, polyimide, BT, A1O, BeO, A1N, plastic, and any other readily available material. Various materials will be evaluated for pre cleaning, fluxing, and post processing the various substrates.

### 3.3.2 Application No. 4:Copper Circuits description: - applying liquid copper to form circuit paths on various substrates.

The purpose of test application no.4 is to simulate the printing of copper circuit paths on various substrates (i.e. additive process). Pure copper will be applied in the same pattern as defined in Figures 1 and 2. The tests to be performed for this application will be similar to those for copper paths produced in typical etch processes.

### 3.3.3 Application No. 4 Copper Circuits - requirements and process parameters to be measured (mean, standard deviation, and distribution)

Thermal Cycling - TBD

Adhesion (pull off)

- LMJ copper to resin/substrate; 6 lb./in. min. 0-12 lb./in. preferred, on a 1/2 T-Pell (ASTM D-1876) (1972)
- LMJ copper to copper; ≥ 10 lb./in., on a 1/2 T-Pell (ASTM D-1876) (1972)

Final Shape Characterization (surface profile and edge detection)

Line Width and Thickness Tolerance

- line width tolerance (mils)
- line thickness tolerance (mils)
- indentation/mouse bites (mils)

X/Y Placement Tolerance

- initial placement accuracy (mils)
- average overlap accuracy (mils)
- overlap repeatability (mils)
- maximum off pattern (mils)

Surface and Edge Profile

- indentation/mouse bites (mils)
- overall slope of top (degrees)
- wetting angle (degrees)
- surface color (subjective classes), visual

Electrical Performance Characterization

Conductivity/Resistivity (ohm.cm)

Thermal Conductivity (w/m deg k)

Electron Mitigation

Tensile Strength

Material Behavior

Metallic/Grain Structure (size/geometry)

Amount of Oxide/Copper Inclusion (% of cross section)-Electron Microscope $\geq$ 99.98%

## 3.4 Future Process Requirements/Measures

### 3.4.1 Environmental Performance (for each application)

Amount of Non-Reusable Wastes (lbs)

Amount of Reusable Wastes (lbs)

Environmental Costs ($)

### 3.4.2 Production Placement (for each application)

Placement accuracy (mils)
Overlap Accuracy (for each application)

- average (mils)
- minimum/maximum centerline (mils)

Repeatability (mils)

### 3.4.3 Machine Reliability (MTBF) - number of failures/process hours

MTBF (hrs)

### 3.4.4 Quality (meet all performance criteria see previous section )

No Stray Balls (number of satellites per-balls) (%)

Ability to Identify Problems

Percentage of Products Requiring Rework (%)

### 3.4.5 Set up time (when system is cold)

Warm Up (minutes)
Change Nozzle (minutes)

### 3.4.6 Repairability (when system is hot)

Change Nozzle (minutes)
Time to Change Metal/pot (minutes)

### 3.4.7 Cost of production (for each application)

Life Cycle Cost ($) - LCC model
Cost Per Board ($) - LCC model
Cost Per Pad ($) - LCC model
Cost To Prepare Surfaces ($) - LCC mode
Cost To Package Finished Product ($) - LCC model

### 3.4.8 Test Requirements (see section 9)

### 3.4.9 Facility Requirements

TBD

### 3.4.10 Safety Requirements

Meet all OSHA/electrical standards
Emergency Stops

### 3.4.11 Production Process Using an Array of Jetting Mechanisms

## 4. Summary of Major Process Related Targets

### 4.1. Pure Tin Applications

| | Application 1 Pretin copper | Application 2 Etch resist | Application 3 Ball grid array |
|---|---|---|---|
| Metal | Pure tin | Pure tin | Pure tin |
| Substrate | Copper clad | Copper clad | Copper clad |
| Solderability | | | |
| Surface profile | | | |
| Edge definition | | | |
| Etch resistance | Not applicable | | Not applicable |
| Adhesive strength | | Not applicable | |
| Accuracy | | | |
| Repeatability | Not applicable | | Not applicable |

## 4.2. Copper Application

| | Application 4 Circuit Paths |
|---|---|
| Metal | Copper |
| Substrate | Various |
| Thermal cycles | |
| Adhesion (pull off) | 10-12 lb./in. |
| Surface profile | |
| Edge definition | |
| Conductivity | |
| Thermal conductivity | |
| Tensile strength | |
| Copper purity | ≥ 99.98 |
| Elongation | 6% |

## 5. Technical Risk Analysis Summary

### 5.1 Technical Risk Assessment And Control

| Risk Areas | Areas of Impact | Control Options and Actions |
|---|---|---|
| 1. Precision Placement Requirements and System Design | • performance characteristics | (a) Incorporate systems design discipline into process.<br>(b) Purchase precision optic table with dampening and X/Y controller.<br>(c) Parameterize deflection using old existing system.<br>(B/U) Assume that precision will be improved in later research. |
| 2. Copper to Substrate Interaction | • non-wetted droplets<br>• integrity of substrate | (a) Develop manual drop system to study interactions in 1994 rather than waiting until 1995.<br>(b) Bring on a materials company partner in 1994 (DuPont).<br>(B/U) Try every known substrate material in every known test condition. |
| 3. Orifice | • leaks<br>• unstable jet | (a) Continue larger .004 orifices until filtering is reliable.<br>(b) Try titanium orifice holder.<br>(B/U) Cast ceramic orifice.<br>(B/U) Plumbing includes orifice. |
| 4. New Head Technology | • function (oscillation)<br>• reliability | (a) Test on water.<br>(b) Test prior to implementing into system.<br>(c) Measure as many parameters as possible to characterize process.<br>(B/U) Use piezoelectric crystal for shooting tin.<br>(B/U) Use piezoelectric crystal for shooting cu → modified design of shooter. |
| 5. Metal Filtering | • clogging<br>• oxide particles (solder) | (a) Try various filters and holders.<br>(B/U) Accept occasional clogging during this contract. |
| 6. Tubing/Pot/Nozzle Materials for Copper | • metal impurities | (a) Try tubing materials on manual drop system in 1994 rather than 1995.<br>(B/U) Subcontract for a customer designed and built system. |

## 6. Technical Risk Plan Avoidance

## 7. Glossary

Droplet - molten drop in flight
Splat - solidified droplet after impact
Solder/Metal bump - partially wetted, solidified droplet after impact placed in an array configuration for ball grid arrays (flip chips)

## 8. Referenced Specifications and Bibliography

IPC, NCMS, ASTM, SMTA, etc.

## 9. Test Requirements for a Copper Circuit

| Test Description | Copper Circuit | Specification Number |
|---|---|---|
| Bulk Resistivity | $1.7 \times 10^{-6}$ Ohm cm | IPC TM-650 2.5.13 |
| Sheet Resistivity | $0.75 \times 10^{-3}$ Ohm/square | IPC TM-650 2.5.14 |
| Tensile Pull Strength | 300 $Kg/cm^2$ | IPC TM-650 2.4.1.2.T |
| Peel Strength | 200 $Kg/cm^2$ | IPC TM-650 2.4.1.2 |
| Chemical Resistance | pass | IPC TM-650 2.3.2 |
| Isopropyl alcohol | | |
| Toluene | | |
| MEK | | |
| Methylene chloride | | |
| Hydrochloric acid | | |
| Sodium Hydroxide | | |
| Solderability, Edge Dip | 100% | IPC TM-650 2.4.12 |
| Through-Hole Adhesion | – | IPC TM-650 2.4.21 |
| Rework Simulation | 86.1% of Original | IPC TM-650 2.4.36 |
| Current Carrying Capacity | pass | IPC TM-650 2.5.4 (2-AMPS) |
| Service Temperature | > 150°C | IPC TM-650 2.6.21 |
| Hydrolytic Stabiltiy | pass | IPC TM-65- 2.6.17 |
| Moisture and Insulation Resistance | pass | IPC TM-650 2.6.3 |
| Thermal Shock | | IPC TM-2.6.7 |
| (adhesive strength) | – | |
| (sheet resistivity) | – | |
| Temperature Cycling | | IPC TM-650 2.6.6 |
| (adhesive strength) | | |
| (sheet resistivity) | | |
| Ionic Cleanliness | | Mil-Spec P-55110 3.10.4.1 |
| Solder-Float Thermal Stress | pass | Mil-Spec P-55110 4.8.2.7 |
| Insulation Resistance | pass | Bellcore TR-NWT-00078 13.2.6 |
| Electromigration Resistance | pass | Bellcore TR-NWT-00078 13.2.7 |

**10.1.** Tin Application Experiments No. 1, No. 2, and No. 3.

Oxygen free, high conductivity copper (OFHC Cu) is the surface material for the 18" × 12" test coupons. The copper can be clad to any type of substrate such as FR-4. The Cu coupons will be degreased in trichloroethylene, rinsed in isopropyl alcohol, lightly etched for one minute in a 1:1 solution of hydrochloric acid and deionized water, rinsed in hot tap water and then deionized water, rinsed in isopropyl alcohol, and finally blown drip with technical grade nitrogen gas. This procedure is to produce a uniform, reproducible, baseline surface condition to evaluate.

Four solder fluxes are selected for the tin jetting portion of the study. Two rosin, mildly activated chemistries (RMA1 and RMA2), and two water soluble, organic acid based (OA1 and OA2) are used. The fluxes are diluted 1:1 with isopropyl alcohol. Remember that flux activation is a problem at temperatures below 150°C. The Cu substrates are fluxed and allowed to dry approximately 5-10 minutes before testing.

**10.2.** Copper Application Experiment No. 4

Various substrate materials will be used for 12" × 12" test coupons. These will include FR-4, polyimide ceramics, (ALO, BeO, A1N) plastics, and other potential materials.