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| PROJECT TITLE: i-DISC |
| Document Title: Specification for a Prototype Plating Imaging and Etching Plant for the Manufacture of Metal Patterned 3D Parts of Convex Shape |
| Document Reference | - |
| Document Version |  |
| Document Status | Draft |
| Document Date |  13 February 2017 |
| Document Author | Oliver Leisten  |
| Document Classification | commercial in Confidence |

Scope:

This specification sets out the requirements for a prototype volume electro-chemical plant for 3D patterning of metal coatings on convex 3D dielectric cores using a subtractive process with the Dow Chemicals/Rohm&Haas/Shipley/Eagle chemical system.

Distribution:

|  |  |
| --- | --- |
| DISC Management Team | Yes |
| DISC Steering Board | No |
| DISC Advisory Panel | No |
| Catapult Executive Management Team | Yes |
| InnovateUK | Yes |
| UKSA | No |
| Other | No |
| Public | No |

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|  |  |  |
| --- | --- | --- |
| Version | Date | Amendment Summary |
| draft | 1st Feb 2017 | First draft: Oliver Leisten |
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# Introduction

This specification sets out the requirements for a prototype wet-bench system to enable development of a process for making metal patterned 3D parts of convex shape. The plant is conceived of as being comprised of three linear wet-bench configurations of chemical cells having specific electrochemical functions as will be defined in this specification. These have the following functions:

* Electro-less and electrolytic plating bench (defined in section 2)
* Electro-phoretic etch resist coating (defined in section 3)
* Develop, etch and strip processing (defined in section 4)

The electro-chemical plant is a major part of production system for the manufacture of metal patterned 3D parts of convex shape. The processing stages that these parts pass through are defined in figure 1.1:



Figure 1.1 from left to right: bare ceramic insulator cylindrical substrate, copper coating, etch-resist coating, after exposure and development, after copper etching and resist stripping.

The plant shall catalyse the surface of the ceramic blanks to render them receptive to electro-less copper plating; which shall be deposited to a depth of approximately 5μm. The parts shall then be electro-plated to a depth of 20 μm and then coated with EP-resist. The parts shall be unloaded from the plating/resist line and loaded into a laser imaging machine which is the subject of a separate specification. Still mounted on the special stacked carousel carrier the parts shall then be passed through a “develop/etch and strip” plant that leaves the antenna with the tracking pattern established.

The electro-chemical plating processes will be applied to the ceramic parts as mounted in an array on a small stainless-steel jig which mounts (and where necessary connects electrical currents to) at least 10 individual parts using conical terminated spring connections which plug the axial hole in the ceramic cores. The jig mounting scheme is loosely defined in figure 1.2.

Figure 1.2: Array of 10 33mm by φ=14mm ceramic substrates in a prototype jig. The jig spring-points are securely attached to the ceramic parts by the action of two cone-ended spring points which are sprung in opposition to secure each ceramic part onto the metal jig (whose overall features are not shown). The hole through the centre of the ceramic is φ=3mm.

The parts will pass through wet-bench 1 and 2 using the linear-array metal jig scheme that is loosely defined in figure 1.3. The design of what is used in the: “develop-etch and strip bench” (wet-bench 3) shall be different and is defined in figure 4.1.

# Electro-less and Electrolytic Plating

The prototype ceramic plating plant shall comprise of a linearly orientated system of chemical treatment and electroplating tanks for the envelope plating of electro-ceramic 3D blanks. The tanks should be small: large enough to accommodate a small array of jigged parts as defined in figure 1.2 but small enough for chemicals to be dispensed and removed using normal small-scale laboratory practices. The 3D blanks shall be mounted onto fish-bone spine springs on a jig-frame that connects to the flight-bar attachment points above the treatment tanks. The 3D blanks shall then be passed manually through a series of process tanks as detailed in this section.

The design of a plating jig is loosely defined in figure 1.2 and shall have a window area that is suitable for plating an array of at least 10 parts of dimension 33mm length and 14mm diameter. 5 plating jigs should be supplied together with a suitable drying/storage rack.

The overall processing structure of the electro-less and electrolytic plating wet-bench is shown in figure 2.1:

Conditioner 3323

Surface pre-treatment

De-ionised Spray Water Rinse

De-ionised Water Rinse

Pre-dip 3340

Surface pre-treatment

Catalyst 3344

Electro-less Copper

Drag-out Rinse

Immersion Rinse

Sulphuric Pre-dip

Electrolytic Copper (4 cells)

Hot De-ionised Water Rinse

De-ionised Water Rinse

Anti-Tarnish Coating

Figure 2.1: Functions of the cells in the electro-less and electrolytic wet-bench.

## Conditioner Pre-Treatment

These tanks shall be provided for the use of a surface cleaning and conditioner agent (Circuposit Conditioner 3323A) to enhance the adhesion of the metal to ceramic. The surface-treating tank shall be equipped with a heater and temperature sense-controller that is designed to pre-set to a specific operating temperature (43 degrees centigrade). The tanks shall be equipped with a drain valve to permit draining into storage containers.

## De-ionised Water Spray-Rinse

Thorough rinsing of the antennas, to remove all remnants of cleaning solution on the surfaces, is conducted by immersion into a spray rinse tank which is activated when a jig is inserted to spray de-ionised clean water (or clean town-water) through an array of nozzles at the antenna parts. The design of the spray system must be carefully conducted to avoid over-spray or excess atomisation of the liquid which could cause contamination of subsequent reagents.

## Second De-ionised Water Rinse

Further rinsing of the antennas is conducted by immersion into a rinse tank containing de-ionised water (or clean town-water). This tank is equipped with a valved air sparger system.

## Surface Catalysis Pre-dip Treatment

This tank shall be used for the pre-dip surface catalysis treatment of the ceramic blanks which is a necessary precursor to the electro-less copper plating process. The chemical agent in this tank is a solution of the Circuposit pre-Dip 3340 powder. The tank shall be heated to a temperature of 25°C with a vertically mounted PTFE heater controlled by a digital temperature controller unit which uses a steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The tank shall be topped with a lip fume extraction plenum box to meet COSHH rules and safety best practice procedures. The solution quality shall be maintained by a pump filter unit with the capacity to do a duty of at least 3 solution turnovers per hour. In addition the tank shall be equipped with a drain valve to permit draining into storage containers.

## Surface Catalyst

This tank shall apply a palladium-tin surface acting catalyst to the surface of the ceramic which is a necessary precursor to the electro-less copper plating process. This tank is filled with exactly the same Circuposit pre-Dip 3340 based solution as was present in the previous tank but with quantities of Circuposit Catalyst 3344 and Cataposit 449 added. The tank shall be heated to a temperature of 40°C with a vertically mounted PTFE heater controlled by a digital temperature controller unit which uses a steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The tank shall be topped with a lip fume extraction plenum box to meet COSHH rules and safety best practice procedures. The solution quality shall be maintained by a pump filter unit with the capacity to do a duty of at least 3 solution turnovers per hour. In addition the tank shall be equipped with a drain valve to permit draining into storage containers.

## Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into two rinse tanks containing agitated clean de-ionised water (or clean town water). Both tanks are equipped with valved air sparger systems.

## Second Immersion Rinse Tank

Thorough rinsing of the antennas is conducted by immersion into the second of two rinse tanks containing agitated clean de-ionised water (or clean town water). Both tanks are equipped with valved air sparger systems.

## Electro-less-Copper Deposition Tanks

There shall be two electro-less copper plating cells each containing two positions for plating jigs using the Shipley HiBuild ™ process. Each plating cell comprises of two stations in a manner that shall be described in the foregoing.

The electro-less copper deposition shall take approximately 30 minutes and therefore it is necessary to configure an on-duty/standby cycle of operation to occur. This is necessary as the electro-less copper cell must be operated on a cycle of plating use followed by de-plating regeneration which uses a separate nitric acid stripping agent. The chemical solution shall be agitated using pumped air (this is provided locally and not from a compressed air source) and is introduced into the solution using an air sparger system. The electro-less copper plate cells shall contain formaldehyde which requires that an appropriate COSHH approved flue cover is provided. This shall be implemented in the form of a lip fume extract plenum box. According to Dow Chemicals an alternative reagent: EP1300 Acid Copper which does not contain formaldehyde is due to replace the current reagent.

The operating temperature of these tank shall be maintained at 26°C. Each tank shall be equipped with two suitable PTFE coated heaters which are vertically mounted. The heater units shall be controlled by a digital temperature controller unit which uses a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The tanks shall be managed to maintain a good quality of solution cleanliness using a pump filter with the capacity to undertake at least 4 solution turnovers per hour.

Both tanks shall perform process tasks in rotation. The electro-less plate cell shall be plating 3D part blanks and the tank containing stripping chemicals shall be used to remove copper from the plating jigs so that these can be recycled clean to the start of the process.

An off-line tank located behind the line shall be used as a reservoir to permit cross-transfer between tanks.

## Drag-out Tank

This tank shall provide a facility for washing using rinse dipping into a static solution of de-ionised water (or clean town-water). The de-ionised water shall be agitated using a valved air sparger system and the water quality shall be maintained by periodic replenishment.

## Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into two rinse tanks containing agitated de-ionised water (or clean town-water). Both tanks are equipped with valved air sparger systems.

## Second Immersion Rinse Tank

Thorough rinsing of the 3D parts is conducted by immersion into the second of two rinse tanks containing agitated clean de-ionised water (or clean town water). Both tanks are equipped with valved air sparger systems.

## Pre-dip Tank

This tank shall provide a facility for mild sulphuric acid cleaning of the parts prior to electrolytic plating. The chemical composition of the solution in the tank shall be dilute sulphuric acid. In compliance with COSHH regulation the tank shall be equipped with a lip fume extract plenum box. The quality of the solution shall be maintained by periodic recharging and there shall be a facility to evacuate the old solution to storage containers. The plating solution shall be maintained at 46°C by suitable PTFE heaters which are vertically mounted in the tank and controlled by a digital temperature controller unit which uses a stainless steel temperature probe.

## Electrolytic-Copper Plating Cells

There shall be 4 electrolytic copper plating cells each equipped with two rectifiers connected to cathodes at opposing sides of the cell so that it is possible to vary the plating density according to the differential surface area that is present on either side of the active anode rail. The supplier shall set up this rectifier arrangement to optimise the plating of the 3D components using the specified plating jig. The optimum use of brightener and leveller additives in the tank shall be manually controlled using standard laboratory practices. It shall be possible to operate the cells as discrete independent plating cells using polypropylene stray current baffles to separate the cells.

The plating solution shall be maintained at 25°C by suitable PTFE heaters which are vertically mounted in the tank and controlled by a digital temperature controller unit which uses a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. In addition the effects of gassing are mitigated using a valved air sparger unit which agitates the solution around the parts thereby dislodging gas bubbles. The gas shall be collected from the cell using a lip-fume extract plenum box connecting to a flue system. The quality of the plating solution shall be maintained using a pumped filter unit with the capacity to do a duty of at least 3 solution turnovers per hour.

The tank shall be equipped with 8 brass anode rails complete with DC connections to the rectifier units. In line with the proposed methodology which provides a distributed supply of plating current there shall be a battery of 8 rectifier units rated at 8V at a current of up to 10 Amps.

## Drag-out Tank

This tank shall provide a facility for washing using rinse dipping into a static solution of de-ionised water (or clean town water). The water shall be agitated using a valved air sparger system and the water quality shall be maintained by periodic replenishment using a valved water inlet and a drain valve.

## Anti-Tarnish Coating

A thorough cleaning and coating with an anti-tarnish agent is applied using a solution of dilute sulphuric acid with added Cuprotec 3.

## Hot De-ionised Water Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into a rinse tank containing agitated de-ionised water. This must be de-ionised water it cannot be town-water. This tank is equipped with a valved air sparger system. The tank shall be heated to a temperature of 50°C with a vertically mounted PTFE heater controlled by a digital temperature controller unit which uses a steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit.

# EP Resist Deposit

This section describes the plant and chemical operation of the EP-resist deposition plant. A “positive EP-resist” process (coppering shall be present at locations which were exposed) shall be employed. The plant shall pre-treat the plated ceramic blanks, coat them with the EP-resist agent and then harden them to ensure that they are not damaged by handling. The parts can then have the pattern accurately printed onto the surface using a laser imaging machine which to be constructed by a laser imaging machine manufacturer. Because the EP-resist agent is sensitive and of course activated by light it is important that this equipment must be operated within a yellow-light area.

The process path through the EP-resist application system shall proceed as follows. The parts remain mounted on the plating jig that is loosely defined in defined in figure 1.2.

The overall processing structure of the electro-less and electrolytic plating wet-bench is shown in figure 3.1. Note that the electro-phoretic coating process is particularly sensitive to contamination arising from the pre-dip process and the rinsing system is necessarily very thorough before photo-etch coating is applied.

Acid Pre-dip Cleaning

De-ionised Water Rinse

De-ionised Spray Water Rinse

De-ionised Water Rinse

Static De-ionised Water Rinse

De-ionised Spray Water Rinse

Electro-phoretic Photo-etch Resist Coating

Permeate Dipping

Eagle Top-coat

Coating

De-ionised Water Rinse

Hot Air Drying

Micro-etch Dip

Figure 3.1: Functions of the cells in the electro-phoretic etch resist deposition wet-bench.

## Pre-dip Cleaning Tank

This tank shall provide a facility for cleaning of the parts using an acidic solution that is made up with Shipley Spray Cleaner 742. In compliance with COSHH regulation the tank shall be equipped with a lip fume extract plenum box.

The cleaning solution shall be maintained at 42°C by suitable PTFE low watt density immersion heaters which are vertically mounted in the tank and controlled by a digital temperature controller unit which uses a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The quality of the plating solution shall be maintained using a pumped filter unit with the capacity to do a duty of at least 3 solution turnovers per hour. The chemical action shall be sustained by periodic recharging and there shall be a facility to evacuate the old solution to storage containers for professional disposal.

## Rinse Tank

Rinsing of the 3D parts is conducted by immersion into a rinse tank containing agitated clean de-ionised water. This tank is equipped with a valved air sparger system.

## Micro-Etch Dip Tank

The surface adhesion to the 3D parts shall be improved by immersion into a mildly acidic micro-etch solution (Rohm & Haas Circuposit Etch 3330). This tank is equipped with a valved air sparger system. The tank shall be heated to a temperature of 27°C with a vertically mounted PTFE heater controlled by a digital temperature controller unit which uses a steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit.

## Immersion Rinse Tank

Rinsing of the 3D parts, to remove the cleaner agent, is conducted by immersion into a series of four rinse tanks containing de-ionised water. The first of these provides a dip into agitated water as the tank is equipped with a valved air sparger system.

## De-ionised Water Spray-Rinse

Thorough rinsing of the 3D parts, to remove all remnants of cleaning solution on the surfaces, is conducted by immersion into a spray rinse tank which is activated when a jig is inserted to spray de-ionised clean water through an array of nozzles at the 3D parts. The design of the spray system must be carefully conducted to avoid over-spray or excess atomisation or the liquid which could cause contamination of subsequent reagents.

## Second Immersion Rinse Tank

Thorough rinsing of the antennas is conducted by immersion into the second of two rinse tanks containing static clean de-ionised water.

## De-ionised Water Spray-Rinse

Thorough rinsing of the 3D parts, to remove all remnants of cleaning solution on the surfaces, is conducted by immersion into a spray rinse tank which is activated when a jig is inserted to spray de-ionised clean water through an array of nozzles at the antenna parts. The design of the spray system must be carefully conducted to avoid over-spray or excess atomisation of the liquid which could cause contamination of subsequent reagents.

##  Deposition, Permeate and Sump (Positive Resist)

This part of the process comprises of three active parts. In the deposition stage actual deposition of photo-resist occurs using cataphoretic electrophoresis (the coating is deposited onto the cathode). The electrophoretic resist reagent is Shipley’s ED2100 photoresist. In the next active phase a permeate or conservation rinse is employed to reclaim the excess resist emulsion. The sump functions as common compartments so that all three stations are linked as a “closed loop” system via a diaphragm pump, pre-filter and 5 micron ultrafiltration module.

The EP coating solution shall be maintained at 30°C by a suitable PTFE low watt density immersion heaters which are vertically mounted in the tank and controlled by a digital temperature controller unit which uses a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit.

The process for coating of the EP resist requires vibration of the parts for the duration of the time that they are immersed. The supplier should propose a vibrating mechanism that is activated by docking the plating jig flight-bar.

The EP coating is applied with 120 volts applied between the anode plate and the plating jig (acting as the cathode). This is provided by a suitable rectifier capable of supplying 4 Amps at this voltage. This bath operates at a hazardous voltage and therefore must be protected using reliable guard-interlocks to prevent electrocution.

The permeate solution shall be maintained at 30°C by a suitable PTFE low watt density immersion heaters which are vertically mounted in the tank and controlled by a digital temperature controller unit which uses a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit.

## Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into a rinse tank containing agitated clean de-ionised water. The tank is equipped with a valved air sparger system.

## Eagle Top-Coat Solution

This tank shall a contain an Eagle 2002 cellulose top-coat solution which shall fix the EP resist coating into a hard enough coating to be fit for the subsequent handling. The process is carried out at a temperature of 19°C which is maintained by a temperature control system comprising of a suitable low watt-density heater that is vertically mounted and controlled by a digital temperature controller unit using a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The solution shall be agitated using a valved air sparger system. The fumes shall be collected from the cell using a lip fume extract plenum box connecting to a flue system.

The solution quality shall be maintained using a pump filter unit with the capacity to do a duty of at least 10 solution turnovers per hour. The filtered solution shall be reintroduced into the bath using eductors to aid the re-mixing in of the filtered solution. Should it be necessary to drain the tank it is also equipped with a drain valve to permit run-off to storage containers for professional disposal.

## Hot Air Drying

A high-temperature “hair dryer” heater, set to a temperature of 80°C, shall be used to dry and harden the electrophoretic etch-resist coating on the 3D parts. Once the parts have thoroughly dried and cooled they shall be removed from the jigs ready for feeding into the laser imaging machine that will be constructed by a laser-imaging machine contractor.

# Develop, Etch and Strip Processing.

The patterning that is required on the antenna is applied by laser exposure of the required image using the laser imaging machine which is to be constructed by a laser imaging machine contractor. This final stage of the plant uses chemical etching to establish the required coppered artwork pattern on the antennas. The antennas are returned from the laser imaging machine and are mounted onto loosely fitting pegs (so designed as to allow free movement of fluids from the axial hole of the antennas) of circular plastic carousel etching-jig carriers which can be assembled into multiple layers. The dimensioning of the carousel jigs to enable at least 10 parts per carousel layer to be mounted shall be proposed by the supplier. The supplier should provide at least 5 jig-sets and also a suitable drying rack.

Figure 4.1: Array of 10 33mm by φ=14mm ceramic substrates in a plastic develop, etch and strip prototype jig. The antennas are placed on loose-fitting plastic pegs which are designed so as to permit very free passage of fluids into and out of the axial hole through the centre of the antenna elements. The hole through the centre of the ceramic is φ=3mm.

The overall processing structure of the “develop, etch and strip” wet-bench is shown in figure 4.2.

Developer

De-ionised Water Rinse

De-ionised Water Rinse

Ferric-Chloride Copper Etch

Drag-out De-ionised Water Rinse

De-ionised Water Rinse

De-ionised Water Rinse

Stripper

De-ionised Water Rinse

De-ionised Water Rinse

Anti-Tarnish Coating

Hot de-ionised Water Rinse

Figure 4.2: Functions of the cells in the “develop, etch and strip” wet-bench.

## Developer Tank (Positive Resist)

This tank shall contain a solution of Eagle 2005 developer which shall develop the image onto the EP-resist by dissolving off the unexposed etch-resist layer. The bath shall be operated at a temperature of 40°C. This temperature shall be maintained by a system comprising of a suitable heater that is vertically mounted and controlled by a digital temperature controller unit using a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The solution shall be agitated using a valved air sparger system. The fumes shall be collected from the cell using a lip fume extract plenum box connecting to a flue system.

The solution quality shall be maintained using a pump filter unit with the capacity to do a duty of at least 3 solution turnovers per hour. The filtered solution shall be reintroduced into the bath using eductors to aid the re-mixing in of the filtered solution. Should it be necessary to drain the tank entirely the tank is also equipped with a drain valve.

## Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into two rinse tanks containing agitated de-ionised water. The bath shall be operated at a temperature of 27°C. This temperature shall be maintained by a system comprising of a suitable heater that is vertically mounted and controlled by a digital temperature controller unit using a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. Both tanks are equipped with valved air sparger systems.

## Second Immersion Rinse Tank

Thorough rinsing of the 3D parts is conducted by immersion into the second of two rinse tanks containing agitated clean de-ionised water. This bath shall also be operated at a temperature of 27°C. This temperature shall be maintained by a system comprising of a suitable heater that is vertically mounted and controlled by a digital temperature controller unit using a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. Both tanks are equipped with valved air sparger systems.

##  Etching Tank

This tank shall contain a ferric chloride solution which shall develop the image into the copper by etching the areas which are not protected by etch-resist coating. The process is carried out at a temperature of 40°C which is maintained by a temperature control system comprising of a suitable heater that is vertically mounted and controlled by a digital temperature controller unit using a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The solution shall be agitated using a valved air sparger system. The fumes shall be collected from the cell using a lip fume extract plenum box connecting to a flue system.

The solution quality shall be maintained using a pump filter unit with the capacity to do a duty of at least 3 solution turnovers per hour. The filtered solution shall be reintroduced into the bath using eductors to aid the re-mixing in of the filtered solution. Should it be necessary to drain the tank entirely the tank is also equipped with a drain valve to permit run-off to storage containers for professional disposal.

## Drag-out Tank

This tank shall provide a facility for washing using rinse dipping into a static solution of de-ionised water. The de-ionised water shall be agitated using a valved air sparger system and the water quality shall be maintained by periodic replenishment.

## Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into two rinse tanks containing agitated de-ionised water. Both tanks are equipped with valved air sparger systems.

## Second Immersion Rinse Tank

Thorough rinsing of the antennas is conducted by immersion into the second of two rinse tanks containing agitated clean deionised water. Both tanks are equipped with valved air sparger systems.

##  Etch-resist Stripper Tank

This tank shall a stripper pre-mix solution (based in acetic acid) which shall remove the remaining EP-resist. The process is carried out at a temperature of 40°C which is maintained by a temperature control system comprising of a suitable PTFE coated heater that is vertically mounted and controlled by a digital temperature controller unit using a stainless steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit. The fumes shall be collected from the cell using a lip-fume extract plenum box connecting to a flue system.

The solution quality shall be maintained using a pump filter unit with the capacity to do a duty of at least 3 solution turnovers per hour. Should it be necessary to drain the tank entirely the tank is also equipped with a drain valve.

## Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into two rinse tanks containing agitated deionised water. Both tanks are equipped with valved air sparger systems.

## Second Immersion Rinse Tank

Thorough rinsing of the 3D parts is conducted by immersion into the second of two rinse tanks containing agitated clean deionised water. Both tanks are equipped with valved air sparger systems.

## Anti-Tarnish Coating

A thorough cleaning and coating with an anti-tarnish agent is applied using a solution of dilute sulphuric acid with added Cuprotec 3.

##  Hot De-ionised Water Immersion Rinse Tank

Rinsing of the 3D parts is conducted by immersion into a rinse tanks containing agitated de-ionised water. This tank is equipped with a valved air sparger system. The tank shall be heated to a temperature of 50°C with a vertically mounted PTFE heater controlled by a digital temperature controller unit which uses a steel temperature probe. As a safety feature the heating system shall have a cut-out switch that is activated if the solution level drops below a safety limit.

## Hot Air Drying

A high-temperature “hair dryer” heater, set to a temperature of 70°C, shall be used to dry off the completed 3D parts.

# Machine Safety

The plant shall be operated according to safe chemical operating procedures. Noxious odours and fumes shall be safely extracted using forced extraction. In positions where particularly hazardous fumes could exist the safety of operators is protected by equipping the particular tank with lip fume extraction plenum box to meet COSHH rules and safety best practice procedures.

The EP-resist is applied using electrophoresis using a DC voltage of up to 120 Volts. This is of course very dangerous and effective measures must be taken to avoid operator contact with any structures carrying such high voltages. A system of insulating barriers equipped with interlock switches shall ensure operator safety by isolating the voltage source until all insulating safety barriers have been correctly deployed. The voltage hazard shall be marked using the appropriate standard hazard marking signs.

Should any accident or mishap still occur despite all the above measures there shall be provided a clearly marked emergency stop button. For this plant configured as long arrays of tanks the stop switches should be implemented as safety cords mounted along the operator face of the plant so that from any operator position in the entire process chain the plant can be immediately switched off.

# Factory Acceptance Requirements

This section explains the requirements to be tested to determine that the purpose and functionality of the machine has been met. This shall be invoked at two stages of the contract:

* Final machine acceptance at Satellite Applications Catapult, Harwell.
* The machine shall be tested as must be found to comply with the following agreed parameters:
	+ Process effectiveness: can high quality copper patterned ceramic 3D parts be made reproducibly.
	+ Correct and accurate translation of required 3D patterning image to puck image.
	+ Validation of jig/fixturing arrangements.
	+ Validation of flue/ventilation system.
	+ Validation of electrophoretic resist coating cell operator safety features.
* Full set of drawings and sub-system manuals:
	+ Electrical wiring diagrams.
	+ Drawings of wearing parts.
	+ Drawings of spare parts.
* Machine must operate for a continuous half-day.

The Satellite Applications Catapult must be satisfied with the following items of information relating to ongoing machine concept verification:

* Electrical wiring arrangements.
* Adequacy of operating manual
* Drawings of wearing parts
* Spare parts.
* Service / support arrangements.

Finally the Satellite Applications Catapult must be satisfied that the machine is compliant with EU safety regulations and perhaps any superseding UK safety regulations.