Material Investigation for the Containment of Liquid Tin used in EUV Lithography Devices

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The liquid tin reservoir for droplet generators in EUV systems currently uses tin-compatible and high-strength materials for its high-pressure application. However, with the increased pressure, new material needed to be investigated or a coating that would be compatible with the base and liquid tin. Powder compatibility testing, coated sample corrosion testing and thermal stress test were proposed on different materials. Also with in-depth literature research, recommendations for future experiments were made including base materials that were compatible with liquid tin.

This work is sponsored by ASML
San Diego, CA

Project Background

Motivation:
Liquid tin must be stored for use in EUV Lithography machinery. The machinery hits liquid tin droplets with a high-power CO_2 laser to produce extreme ultraviolet light at a wavelength of 13.5 nm which etches the wafer targets.

Currently the tin reservoir design needs to fulfill some critical requirements:
- Tin-compatible (no corrosion or erosion)
- High temperature rating (above tin melting point)
- High strength for high-pressure application

Liquid tin reservoir is attempting to maintain high volume of storage while increasing pressure in new generations of the machines

Requirement for the new material:
- Compatible with liquid tin
- Equal or higher strength than the baseline material

Previous Work:
- Developing a method to test corrosion in liquid Tin transfer line and investigate the fundamental mechanism behind it

Discussion

Material Selection

Criteria of important factors:
- Least amount of reactivity
- Slow dissolution rate
- pressure vessel approved materials

Materials to avoid:
Plastics / Polymer Materials [13,56]
- Work temperature generally too low.
- High temperature polymers have shorter working life expectancy at elevated temperature than required

Metals and alloys containing Al, Co, Fe, Ni, Ti [4,17, 19]
- Rapidly diffuse and alloy with tin, creating intermetallic(s) that are disallowed in the system
- Nonviable for interaction with liquid tin
- High strength capabilities make them optimal for main reservoir material

Oxide ceramics
- Generally have a very low CTE [21]
- Oxygen leaching into environment is to be avoided at all costs

Materials selected for best use*:
Through research, no single material seems to be capable of the proposed criteria. Research concluded an ASME listed pressure vessel material (like SS304) coated with one of the following could be effective when in contact with tin:
- Tungsten Carbide (WC)
- Titanium Nitride (TiN)
- Silicon Carbide (SiC)
- Chromium Carbide (CrC)
- Molybdenum (Mo)

*The proposed materials will be tested along with the baseline materials to obtain comparative results.

Coating Method Selection

All methods of material coating affect the morphology and structure of the final coating. This will impact the final effectiveness of a coating. Different methods have different effects on the coating:

Sol-Gel: [6,7]
- Production of solution gel of ceramic material in solvent is required
- Final solidification step is required due to the porosity that may form during dissolution of the polymeric solvent

Physical Vapor Deposition (PVD): [47]
- Need equal distance from the sample to the surface at all points
- Final coating result in small grain size and little pinholes

Chemical Vapor Deposition (CVD) : [46]
- Requires chemical reaction between the sample and chemical compound to ensure consistent thickness
- May leave residual pores due to reaction happening at the surface of the coating

Plasma Enhanced Chemical vapor Deposition (PECVD): [46]
- Feature plasma-heating process which amplifies the solidification and sintering of the coating
- Reduces porosity and eliminate pinholes

High Velocity Oxygen Fuel (HVOF): [12, 16, 48]
- Requires powders particles to be injected into a hot gas stream which will be sprayed onto the sample
- Need line of sight to apply coating

Experimental Procedure

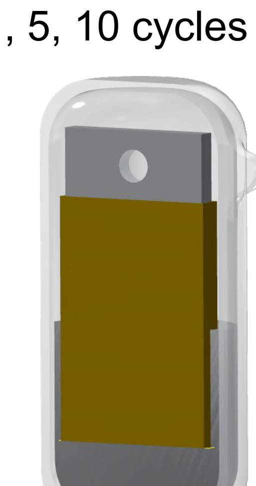
Liquid tin compatibility testing done for powders that were selected along with corrosion testing for coated samples. Thermal stresses can be estimated using Stoney's Equation, with visible cracks

A) Powder Compatibility
1. 5 samples of each tested material powder prepared in ampoules, backfilled with argon, with liquid tin (WC, TiN, SiC, CrC, Mo)
2. Furnace set to 425°C and agitated daily via flipping 180°
3. One powder sample characterized for dissolute material into tin every week

B) Coated Sample Corrosion Test
1. Coated samples are prepared in ampoules with liquid tin, also backfilled with argon to prevent oxidation of tin
2. Ampoules are held at temperatures above use temperature (325°C)
3. One sample is removed every week to test amount of material dissolute from the surface

C) Thermal Stress Test
1. Samples of coated stainless steel heated to elevated temperatures
2. Using the reflow oven, allow the samples to go from 300C to room temperature
3. Samples observed optically after 1, 5, 10 cycles

Powder Samples prepared for compatibility testing


Coated sample prepared in ampoule for corrosion test

Recommendations

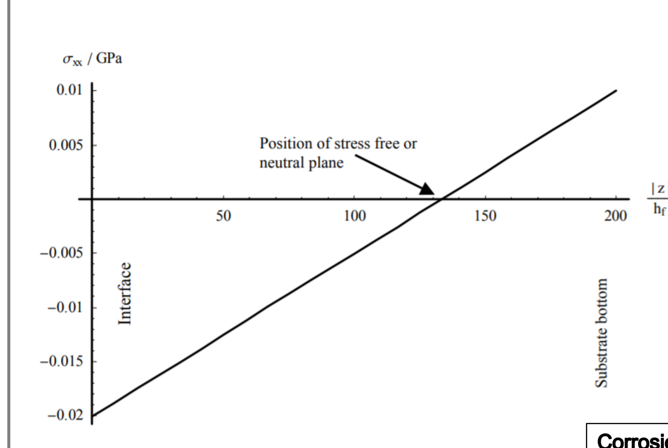
After in-depth literature review, some recommendations with future experiments have been discovered and laid out:

1) Residual Compressive Stress
Ceramics have much greater compressive strength than tensile strength. This implies that at RT, inducing enough residual stress to overcome tensile forces at working temperature will overcome thermal stresses.

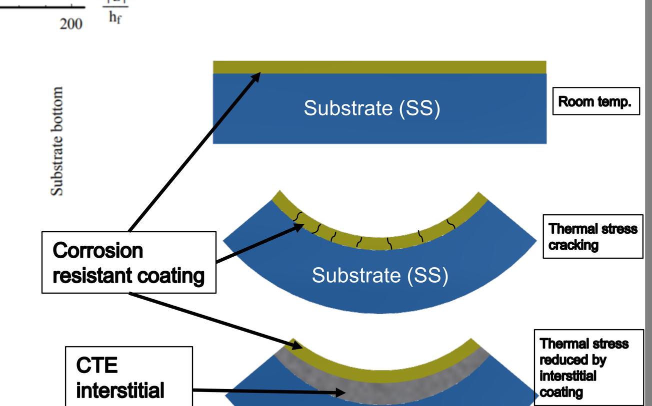
2) Include interstitial bond coatings to reduce the impact of Coefficient of Thermal Expansion (CTE) Mismatch
Forces applied due to thermal stress are applied equally to each interstitial coating, lowering the stress applied to the outermost layer (corrosion layer). This will decrease the likelihood of stress-induced cracks on the ceramic.

3) Morphology of the final coating impacts reaction rate exponentially
Higher surface area increases rate of dissolution and intermetallic formation. Flatter, more solidified coatings are more able to resist the interaction with liquid metal. Along with this, any instance of pinholes in the coating increase the likelihood of interaction between the Tin and the solid metal substrate.

4) Material recommendations
Refractory metal carbides and nitrides prove to be chemically inert with tin. Choosing materials with the CTE closest to that of a chosen pressure vessel material limits the ability for stress cracking to cause cracks which can destroy the structural integrity of the reservoir.



As a factor of bilayer structure, a compressive residual stress within a coating forces tensile residual stress in the sublayer. Due to the coating being made of a material with less tensile strength than compressive strength, this leads to a more durable coating.



Interstitial coatings of gradually changing CTE absorb the thermal stress, reducing crack propagation.

References

Due to the large number of citations required to gather information, a link has been provided to our list of used references. This includes references that were not necessary for production of the poster.

https://tinyurl.com/ASML2019-2020

Conclusions

Ceramics made from refractory metals prove to be an effective coating in resistance of liquid tin corrosion. A coating holding residual stress will prove effective in resistance to thermal stresses on a substrate of stainless steel. These two combined factors solve the problem laid out by ASML.