Technology Partnerships Canada

Nanocrystalline Co-P for Cr-Replacement

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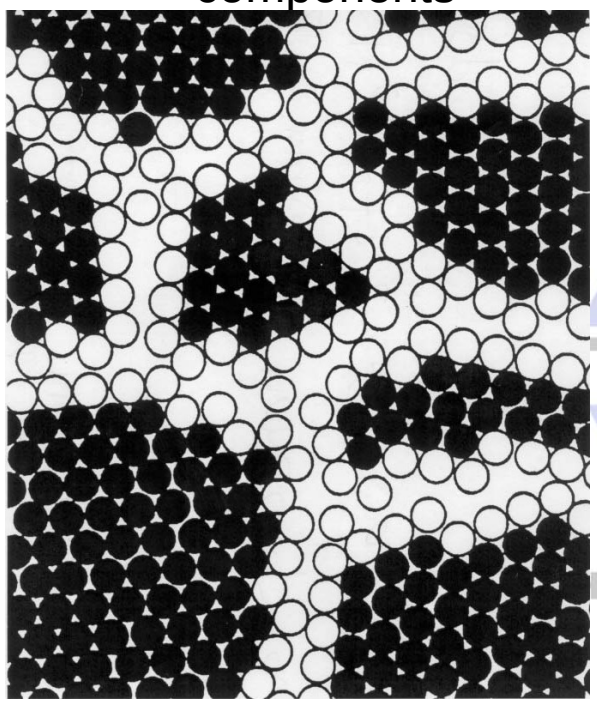
Outline

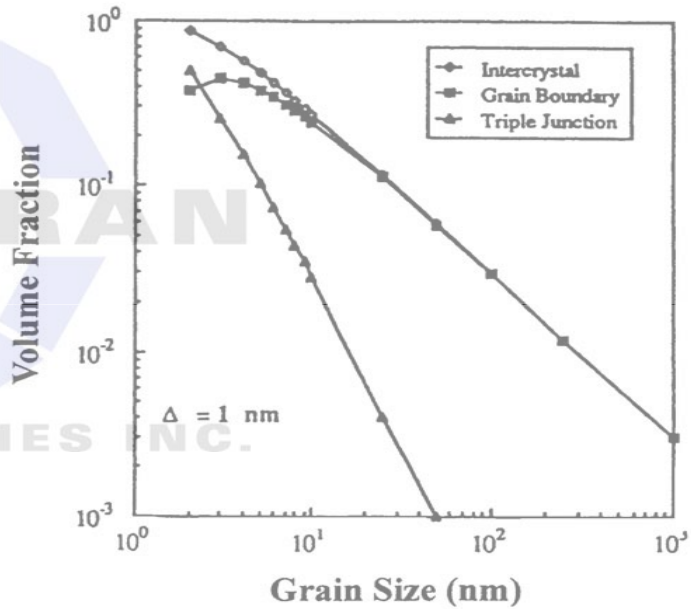
- Nano Co-P Summary
- Background
- Industrial scale-up and move EHC nanoCo-P alternative to depots
- Development of selective plating of nano coatings for repair
- Development of Nano Co-P based as Thin Dense Chrome alternative

Nanocrystalline Materials

- Two Phase Material
  - Crystalline and intercrystalline components



A reduction in grain size **below 100nm, significantly increases the intercrystalline content in the material, leading to many** unique properties**.**



Technical Objectives

- **Develop an environmentally benign nanocrystalline Co-based coating**
  - **Compatible with existing electroplating infrastructure**
  - **Can meet or exceed EHC (hardness, wear, fatigue, corrosion, and thermal stability)**
  - **Costs compatible with life-cycle cost of EHC**
  - **Can be applied to NLOS**
- **Why Co?**
  - **Mechanical properties**
  - **High plating efficiency**
  - **No on EPA or AFMC lists of hazardous materials**
  - **Longer term view**

Nano Co-P Data Summary

	Nanocrystalline Co-P Alloy	Hard Chrome
Bath Chemsitry	Co 2-5wt%P (Chloride Based)	Cr (Chromic Acid)
Efficiency	85-95%	15-35%
Deposition Rate	Up to 8 mil per hour	Up to 1.6 mil per hour
Thickness	Demonstrated up to 0.020”	Typically < .005”
As-Deposited Appearance	Pit / Pore Free	Microcracked
Microstructure	Nanocrystalline (avg. g.s. = 8 -15nm)	-
Emission Analysis	Below OSHA limits	Cr^{6+}

Nano Co-P Data Summary

		Nanocrystalline Co-P	Hard Chrome
Hardness	*As-Deposited*	600-700 VHN	800-1200 VHN
	HT @ 250°C	700-800 VHN	-
	HT @ 400°C	1000-1200 VHN	-
Ductility		2 – 7 % Elongation	<.1%
Thermal Stability		400°C	-
Wear	*Adhesive (Pin-on-disk)*	5-6 x 10^{-6} mm^3/Nm (Alumina Ball on Nano Co-P Disk)	9-11 x 10^{-6} mm^3/Nm (Alumina Ball on Cr Disk)
	Coefficient of Friction	0.5	0.7
	Abrasive (Taber)	27 mg / 1000 cycles (CS-17) 11 mg / 1000 cycles (CS-10)	3.2 mg / 1000 cycles (CS-17) 1.0 mg / 1000 cycles (CS-10)
Corrosion	Salt Spray	Protection Rating 7 @ 1000 hrs	Protection Rating 2 @ 1000 hrs
Hydrogen Embrittlement		No – No Bake Required	Yes – min bake 14 hrs

Background

- Development originally supported by SERDP PP-1152
- Nano Co-P as EHC alternative was developed
- Dem-Val project supported by ESTCP and TPC
  - Scale up to industrial production & move to depots
  - Develop nano Co-P selective plating as repair
  - Develop nano Co-P based TDC alternative

Industrial Scale up and Technology Transfer to Depots

- Purchase equipment
- Set up equipment at Integran. Qualify
- Move to depot
  - Nano Co-P to JAX
  - Selective plating repair to Ogden
  - Other depots
- Stakeholders kick off meeting in May
- Stakeholders JTP

Industrial Scale up and Technology Transfer to Depots

- **Power supply**
  - **Integran's specifications**
  - **Peak current 1500A**
  - **Average current 500A**
  - **Pulse timing (t_{on} and t_{off}), 0-100ms, Δt=0.1ms**

Industrial Scale up and Technology Transfer to Depots

- Tank
  - Dimensions (3'x5'x3') (~1000L)
  - 1" Polypropylene
  - Separate well to house pump and filter
  - 3/4hp pump
  - 1μm filter
  - 60kw heaters (Ti) digitally controlled`

Selective Plating

- Method to electrodeposit metal without tanks
- Well characterized industrial process
- Moving anode – static cathode
- Can be easily field-implemented
- Can be applied manually, semiautomatic and automatic

Selective Plating

- Properties
  - Excellent adhesion
  - High build-up rates
  - Low (or none) H embrittlement
  - No post-machining (precision build-up)
  - No heat distorsion
  - High deposit density (no porosity)

Selective Plating

- Requirements
  - Specially designed power pack,
  - Assortment of working tools (styluses)
  - Accessories and auxiliary equipment to provide solution flow and stylus or part motion
    .

Selective Plating

- **Initial work results**
  - **Nano Co-P was produced (proof of concept)**
  - **Surface morphology and hardness**
  - **High density (no pits or porosity)**
  - **Good adhesion**

Selective Plating

- **Future work**
  - **Anode wrapping material**
  - **Solution concentration**
  - **pH control**
  - **[wt%P] in the deposit as a function of thickness**
  - **Characterization of the structure of the deposit (surface and cross-section for integrity check)**
  - **Deposit surface roughness vs.thickness**
  - **X-Ray Diffraction (crystal structure and grain size)**
  - **Vicker's Microhardness (VHN) vs composition**
  - **Adhesion and ductility tests**

Properties of TDC

- **Excellent adhesion**
  - No flaking, chipping, spalling or peeling off in ASTM B489-85
- **High hardness**
  - > 850VHN
- **Wear and Friction**
  - Nodular surface – low friction
  - AMS 2438 Spec requires TWI or 2.4 or lower with CS-10 wheels
- **Corrosion**
  - Non-microcracked surface
  - Most specs require 50 hours in ASTM B117
- **Good electroplating precision**
  - Uniform thickness, no excess built-up at edges
  - Low surface roughness

Disadvantages of TDC

- **Same health and environmental issues exist for TDC as for Electrolytic Hard Chrome**
- **Process difficult to maintain**
  - **Reliable suppliers difficult to find**
  - **Difficult meeting specifications**

Nano Co-P for TDC Applications

Nanocrystalline Co-P alloy coatings show promise for TDC Applications:

- **Good adhesion (ASTM B571)**
- **High Hardness**
  - **600-800 VHN As Deposited**
  - **>1000 VHN Heat Treated**
- **Good Tribological Properties**
  - **Low Coefficient of Friction**
  - **Good Sliding Wear (ASTM G99)**
- **Excellent Salt Spray Corrosion (ASTM B117)**
  - **ASTM B537 ranking >7/10 after 1000hrs for 0.002" thickness**

Focus of Development Efforts

- The thickness of the nano Co-P alloy coatings developed in the SERDP program were much thicker (0.002” – 0.010”) than that required for TDC applications (0.00005” – 0.001”)
- Further development of the nano Co-P process is needed to optimize the properties for TDC thickness range.
- Process development efforts will focus on:
  - **Obtaining a uniform, continuous nodular surface that is free from cracks, spalling, chipping, flaking or other imperfections**
  - **Maximizing the throwing power of the solution**
  - **Maximizing hardness**
  - **Maximizing tribological properties**
  - **Optimizing phosphorus concentration**
  - **Providing a highly reliable solution which requires minimal maintenance**

Development Plan

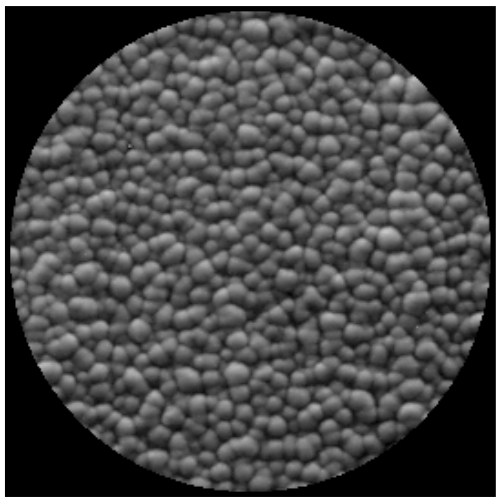
- **Process variables**
  - **Solution composition**
  - **Temperature**
  - **Pulse current parameters**
  - **Current density**
  - **Additives**
  - **Additional particles for increased functionality**

Development Plan

- **Thin nano Co-P within the 2-12% P range**
- **Initial characterization includes**
  - **Surface Morphology (Optical / Scanning Electron Microscopy)**
  - **Thickness uniformity throughout the coating (destructive/metallographic)**
  - **Surface Roughness (Stylus Profilometry)**
  - **Adhesion (ASTM B571 and B489-85)**
  - **Salt Spray Corrosion (ASTM B117)**
  - **Vicker's Microhardness**
  - **Wear**
    - **Pin-on-disk (ASTM G99)**
    - **Taber (CS-10 wheels)**

Surface Morphology and Hardness

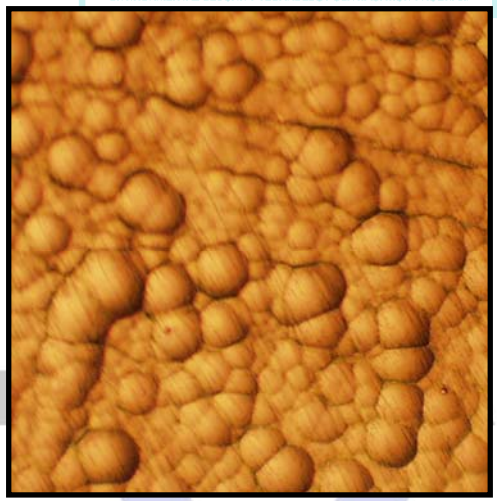
Surface morphology is **nodular** (similar to that of Thin Dense Chrome) and free of pits, pores and/or microcracks. Hardness is close, but needs HT to bring to TDC level.



Thin Dense Chrome

Thickness ~0.0005”

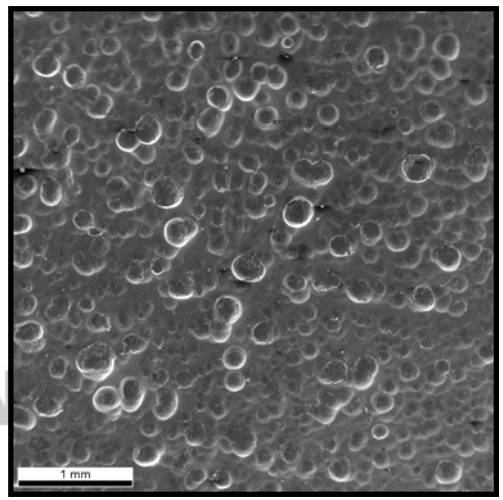
Hardness >900VHN



Co 2-3wt% P

Thickness ~0.002”

Hardness ~600-650VHN



Co 11wt% P

Thickness ~0.002”

Hardness ~700VHN As-Dep

~1000VHN HT 1hr 300°C

Other Testing

- Solution
  - Reliability
  - Reproducibility
  - Qualification
- H_2 embrittlement
- Fatigue