Whisker-Inpenetrable Metal Cap Process for Electronic Assemblies

Bob Landman, Gordon Davy, Dennis Fritz

LDF Coatings, LLC

LDF COATINGS

www.LDFcoatings.com

Abstract

There are many negatives due to the Pb-free RoHS legislation. There are, still today, no good options available to high-rel OEMs for what are now Pb-free COTS components and assemblies. Component-by-component "mitigation" of tin whisker growth risk is very labor-intensive and, at best, it worked only when the majority of components were not Pb-free.

The *ideal universal process* should be much less expensive and should be applicable to an entire assembly, not just "mitigating" the risk of whisker growth but *preventing* whiskers from growing, with a *permanently impenetrable coating*.

A process is described that deposits a nickel (or other whisker-impenetrable metal) cap *selectively* over all Pb-free tin and high-tin alloys, but will not deposit nickel on any insulating surfaces (component bodies, solder mask, etc..) of an assembly.

LDF COATINGS
www.LDFcoatings.com

What Is The Problem?

- Pb-free tin on electronic assemblies can grow whiskers that can cause circuit failure.
- Because high-reliability assemblies have long design life, whisker problem is of particular concern to designers.
- Regulations and economics have resulted in many otherwise desirable COTS electronic components *and assemblies* being available *only* with
  - Pb-free tin as the termination finish OR
  - Pb-free SAC solder balls under BGAs
- High-rel customers lack clout – don't buy enough.
  - Often impractical to procure desired SnPb termination finish or BGA balls.

What is the Solution?

A paradigm shift is needed

Is mitigation <u>prevention</u> ?

- Component-by-Component mitigation is unreliable and difficult to manage
- LDF Coatings solution protects the entire assembly at once

LDF COATINGS
www.LDFcoatings.com

Tin Whisker Mitigation

- COTS Components
  - 85% have a tin termination finish.
  - If OEM uses SnPb solder, whisker risk is primarily for unsoldered termination areas
- COTS Assemblies
  - BOM cannot be “scrubbed,” hence *no* mitigation.
  - If “dual-use,” has Pb-free (high-Sn) solder.
- “Mitigate” means “reduce” not “prevent.”
- If prevention is possible, why mitigate?

Mitigating Whisker Risk Component-By-Component

If Pb-free Sn is not allowed

OEMS must use:

- No COTS assemblies
- Expert "scrubbing" of OEM-BOM to catch non-conforming components
- 100% receiving inspection to confirm that components match spec

LDF COATINGS
www.LDFcoatings.com

Mitigating Whisker Risk Component-By-Component

Pb-free components must be subjected to a process that modifies termination finish to include Pb.

- Chip components: AEM process
  - Single source
  - High setup costs
  - Logisitics and delays
- Larger components: solder dipping
  - High setup costs
  - Many components can probably withstand manual dipping
  - Risk of undetected damage from heat or handling
  - Logistics and delays

Mitigating Whisker Risk Component-By-Component

If contract allows Sn, OEM must do *more:*

- Have experts "scrub" the OEM-BOM looking for "high-risk" components.
- Pinsky model identifies numerous risk areas
  - Examples: Ni underlayer, reflow, spacing
- Verify that received components match product descriptions.
- Cannot mitigate risk for COTS assemblies.

All agree that risk with Pb-free Sn on component terminations can *at best* only be mitigated.

LDF COATINGS
www.LDFcoatings.com

Mitigating Whisker Risk Component-By-Component

Kim et al, recommend electroplating instead of solder dip.

- Where Pb-free cap layer over Sn termination finish must:
    1. Remain **solderable** during storage
    2. Remain **impenetrable**, even as IMC grows
- Investigated Ni, Au, Pd over 6 µm (240 µin.) Sn

1. **Solderability** During soldering, will thicker Sn under-layer (which expands as it melts), break the cap?
   Example: Oxide on Sn not attacked by Type R flux, but does break up.
   Ni – ***NO*** If cap is continuous, but not for islands
2. **Impenetrability**
   Ni, Au, Pd: ***YES!***
   Pb: ***NO*** (Li, AEM, anecdote, no photos)

LDF COATINGS
www.LDFcoatings.com

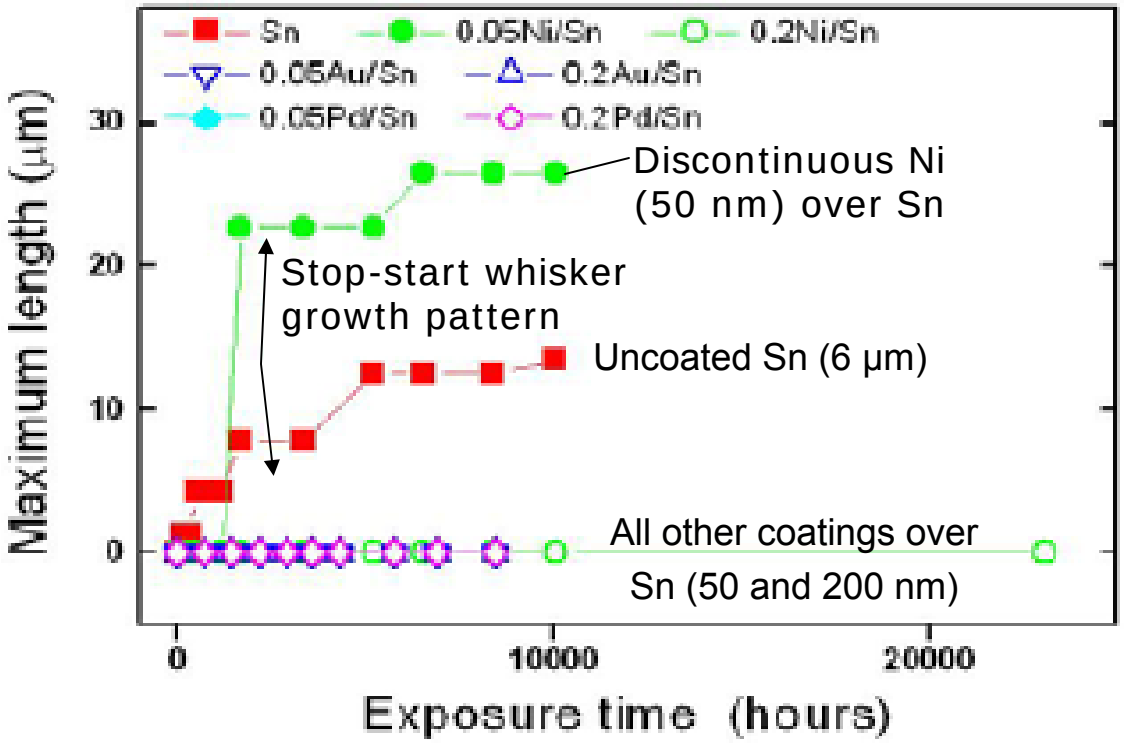
Mitigating Tin Whisker Risk

(Kim, et al)

Cap Type & Attributes	50 nm	200 nm
Ni Electrodeposit continuity? WB solderable (8 hr steam)? Whisker penetration?	 No – Islands Significant decrease Promotes whiskers	 Yes Unsolderable None in 5 years
Au Electrodeposit continuity? WB solderable (8 hr steam)? Whisker penetration?	*Mostly $AuSn_2$ as deposited (1 day)* Yes Yes None in 4 years	*Largely $AuSn_2$ after 2000 hours* Yes Yes None in 4 years
PD Electrodeposit continuity? WB solderable (8 hr steam)? Whisker penetration?	Very little $PdSn_4$ IMC as deposited Yes Yes None in 4 years	PD reaction rate with Sn < Au > Ni Yes Yes None in 4 years

200 nm Ni Cap Impenetrable For Five Years

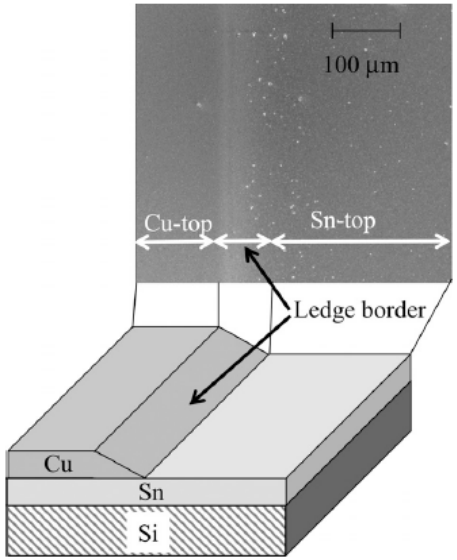
Kim, et al



LDF COATINGS
www.LDFcoatings.com

600 nm Copper Cap Penetrated In 3 Days (Reinbold et al)

White spots are whiskers seen at 49 days; first whisker on Cu-top seen at 3 days



600 nm thick layer of Cu vapor deposited with shadow mask over 1200 nm Sn (w/10 nm Cr adhesion layer)

Virtually no growth of whiskers far from ledge. Cu diffused away from ledge; whiskers were found growing ahead of where Cu could be detected ⇒ IMC precipitation plastically deforms nearby Sn; whisker nucleates when stress exceeds a critical value.

Cu and Ni diffusion rate difference in Sn cannot explain huge whisker penetration difference.

∴ For Ni,

1) Sn whisker is not an irresistible force, or
2) IMC precipitation does not deform Sn above critical nucleation value

LDF COATINGS
www.LDFcoatings.com

The Prevention Challenge

Develop a practical process that can be applied to an assembly to protect it from whisker-induced shorts.

- Coat all tin with a material that permanently prevents whiskers from penetrating from below.
- Prospects for a non-material added process are gloomy.
- No more mitigation!

LDF COATINGS
www.LDFcoatings.com

The Ideal Prevention Process For Assemblies

- Permanently suppresses whisker growth (with supporting data)
- Eliminates BOM scrubbing
- Eliminates testing for Pb-free Sn at receiving
- Eliminates all mitigation efforts
- Solves whisker problem with COTS assemblies
- Applies to all electronic assemblies
- Covers all tin – no shadowing
- Negligible risk of damage to assembly function, reliability, and legibility
- Negligible fixed and maintenance costs for equipment

LDF COATINGS
www.LDFcoatings.com

The Ideal Prevention Process For Assemblies

- Small equipment footprint
- Inherently safe – doesn't use exotic chemicals (i.e., not already in use in electronics industry)
- Simple training of work force
- Quick: handling time req't ≯5 minutes/assembly, so no bottleneck
- Can be performed immediately after cleaning and before conformal coating; no additional cost for masking

What would it be worth per square foot?

LDF COATINGS
www.LDFcoatings.com

Whisker Prevention Coating Processes For Assemblies

(Not Mitigation!)

Three Game Changing Options:

1. "ALD-Cap" conformal ceramic
   - Sundew Technologies
2. "Whisker-Tough" conformal polymer
   - Smith & Co.
3. Selective metal cap
   - LDF Coatings, LLC

LDF COATINGS
www.LDFcoatings.com

Sundew ALD-Cap

- Thin layer (~ 200 nm) of ceramic applied after proper surface prep.
- Takes only minutes to apply
- Batch process
- Coating properties unlikely to change with temp, humidity, or time
- Substitutes for polymer conformal coating
- Rework not a problem
- Process inherently coats under BGAs

LDF COATINGS
www.LDFcoatings.com

Smith & Company
“Whisker Tough”

- Penetration and adhesion of flexible films was studied *extensively* to determine formulation requirements
  - Unique concept: tent and redirect a whisker’s growth rather than prevent its growth – no penetration.
  - Coating material formulated per findings to give at least 0.1 mil coverage along sharp edges of terminations (thixotropy).
- Replaces conventional conformal coating
  - ∴ marginal costs involve only extra cost of material, if any
- FOD virtually eliminated with specially designed dip tank
  - A reasonable amount of operator training required
  - Pot life ≮ 3 hrs (extendable indefinitely by replacing dragout)
  - Overnight bake w/ temperature ramp, incl. 2 hrs at 85°C for full cure
  - Compliance verification
    - Completely transparent
    - Any area of non-coverage findable by non-fluorescence under UV illumination
    - Proper composition and cure easily verified by measuring coating modulus
  - Rework comparable to conventional urethane CC’s

LDF COATINGS
www.LDFcoatings.com

LDF Coatings
Selective Metal Cap

Available whisker-preventing cap processes:

- Ceramic – "ALD-Cap"
- Polymer – "Whisker-Tough"
- Metal Apply to a functioning assembly

1. Must apply to surfaces *selectively*:
   - Must coat all exposed tin
   - OK to coat other metals (mask contact areas)
   - Must not coat any insulating surface
2. Must be proven whisker-impenetrable

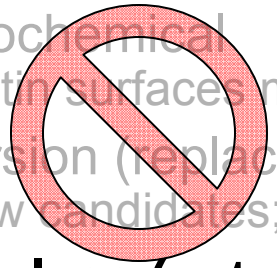
Solderability, ductility not requirements!

1. Reduced to practice; patent applied for
2. Whisker penetration data:
   - Kim: No penetration of *200* nm Ni in 5 years
   - Chason: Penetration of 600 nm Cu in 3 days
   - Li: Penetration of Pb

LDF COATINGS
www.LDFcoatings.com

Selective Metal Cap Layer Process For Coating Tin

- Must be a chemical process
- Theoretically, three options
  - Electrochemical
    - All tin surfaces must be electrically connected
  - Immersion (replacement)
    - Few candidates; too thin
  - **Electroless (autocatalytic)**
    - Except with special procedures, does not deposit on insulators
    - Numerous metals known to electrolessly deposit on tin
    - Ni and Pd are known to be impenetrable



What metal would *you* try first?

What experiment would *you* try first?

LDF COATINGS
www.LDFcoatings.com

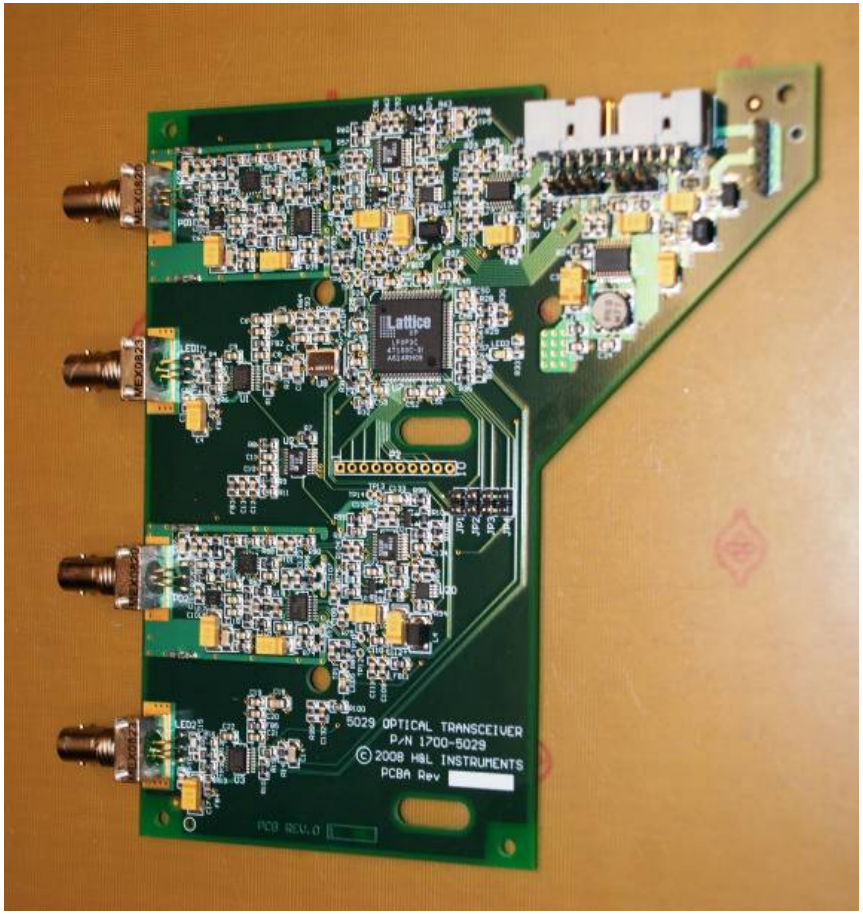
LDF Coatings, LLC is Formed

- Landman, Davy, Fritz
- Provisional patent applied for
  - ↳ June 26, 2010 reduced to practice on an H&L Instruments fiberoptic pcb
  - – Masked with tape and removable mask coating
  - – Uses conventional cleaning
  - – Total immersion 1 hr. ⇒ ~25 μm (1 mil) Ni *deposited*
- Actual estimated deposit thickness *needed* ~ 1-2 μm < 5 min.
- **Kim et al. found no penetration of 200 nm (0.2 μm) Ni in 5 yrs.**
  - – Ni reacts with air to form a protective oxide layer
  - – Ni reacts with tin very slowly to form IMC; reaction rate drops as $t^{1/2}$

Plenty of metallic Ni cap layer will remain in 30 years

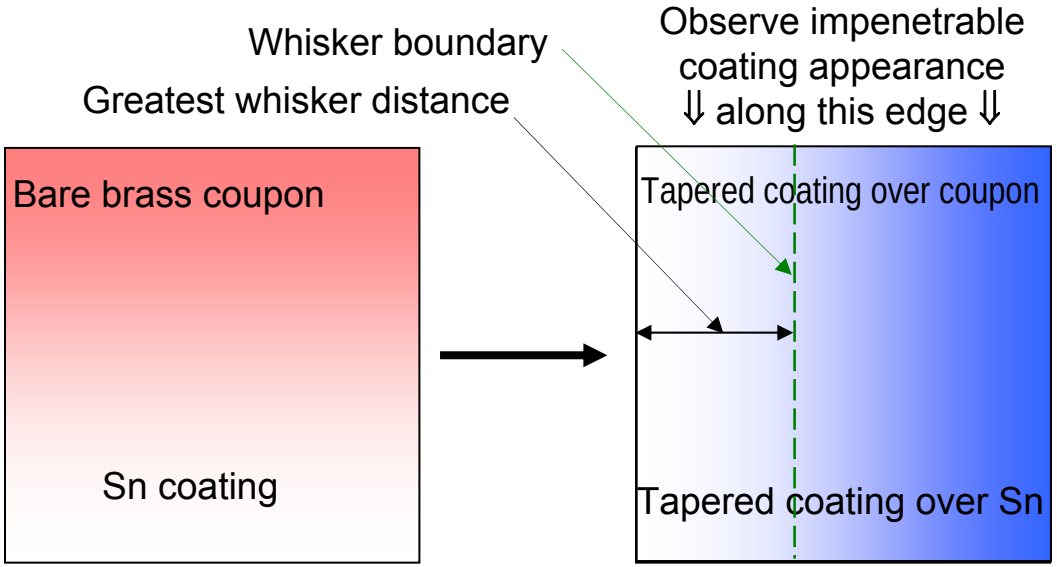
LDF COATINGS
www.LDFcoatings.com

Process Applied To This Commercial Product



LDF COATINGS
www.LDFcoatings.com

Concept: Testing For Permanent Impenetrability



L – Coupon with coating of tapered thickness of Sn
R – Coupon with coatings of perpendicular tapered thicknesses of Sn and impenetrable coating.

Greatest whisker distance is distance from edge to farthest whisker in a single observation.

Whisker boundary is greatest whisker distance remaining unchanged for three successive monthly observations.

LDF COATINGS
www.LDFcoatings.com

How LDF Coatings Process Compares to Ideal

- Eliminates BOM scrubbing and testing components for Pb-free Sn at receiving
- Solves termination finish whisker problem with COTS assemblies
- *Permanently* suppresses whisker growth (Kim *et al.* > 5 yrs for 200 nm Ni)
- Applicable to all electronic assemblies (mask, and add components later if necessary)
- All tin is covered – no shadowing – hot aqueous immersion
- Risk of damage to assembly function, reliability, and legibility is negligible
- Fixed and maintenance costs negligible
- Small equipment footprint
- Process is inherently safe – does not use exotic chemicals (i.e., not already in use in electronics industry)
  - Long history, wide use of electroless Ni

LDF COATINGS
www.LDFcoatings.com

How LDF Coatings Process Compares to Ideal

- Training of work force is simple – expect a broad process window
- Quick, so no bottlenecks: time requirement ⊁ 5 minutes per assembly
- Process can be performed immediately after cleaning and before conf. coating;
  no additional cost for masking
- Easy cleanup of assembly for next process step – water and steam then dry
- Built-in practical compliance verification – bubbles, coated Cu looks different (+XRF)
- No interference w/ rework - masking allows components to be added later

LDF COATINGS
www.LDFcoatings.com

LDF Coatings Next Steps

- Provisional patent applied for
- Continue research and publish, while seeking select companies for participation in trials
- Seek a corporate licensing partner
  - For more R&D and to commercialize
    - Verify min. thickness for permanent suppression
    - Does IMC prevent penetration?
    - Explore process window for robustness
    - Effects of porosity, P content, etc.
    - Pd over Ni, Ni-Pd alloy for extra corrosion resistance?
  - To assume marketing, production, installation, distribution, customer service (including recycling)

LDF COATINGS
www.LDFcoatings.com

Problem and Solution Review

- High-rel assemblies risk tin whiskers from COTS components and sub-assemblies.
- Preventing whisker risk with an ideal process on an assembly beats “mitigating” risk component-by-component.
- Prepared and presented requirements list for an ideal process for assemblies.
- Analyzed three processes for assemblies: ceramic, polymer, and selective metal coating.

LDF COATINGS
www.LDFcoatings.com

Problem and Solution Review

- Process for selective deposition of a thin cap layer of whisker-impenetrable metal, coating all tin but not insulating surfaces
  - Process described
  - Reduced to practice
  - Compares favorably to the ideal
  - Assemblies are likely to remain permanently impenetrable
- LDF Coatings, LLC was formed to
  - Publicize the process
  - Seek assemblies from OEMs for further testing and to ensure that the process does not impair function
  - Seek a corporate licensing partner
  - Promote the implementation.

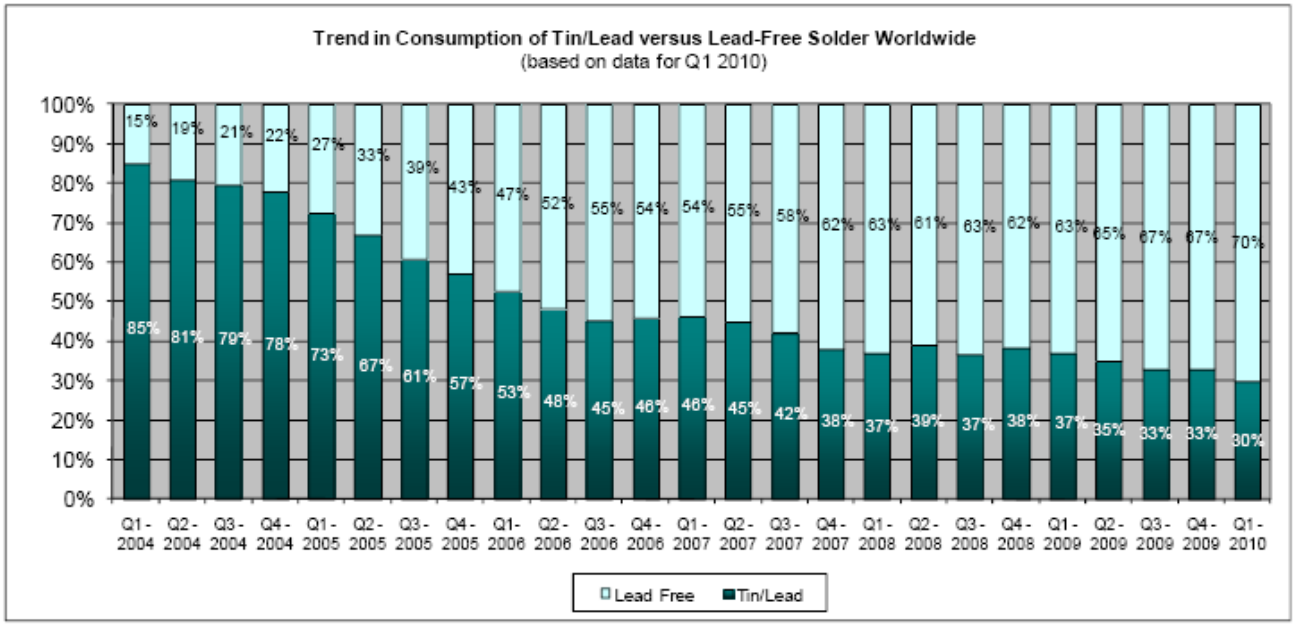
LDF COATINGS
www.LDFcoatings.com

Footnote

Who says we won't be able to buy SnPb solder?

Lead-Free Solder Market has Stabilized

The growing proportion of lead-free solder in the marketplace has slowed and now stands at around 70 percent of worldwide solder consumption in Q1 2010.



Source: IPC Global Quarterly Solder Statistical Program, *Electronics Industries Market Data Update*, Spring 2010. Free to members at http://www.ipc.org/Update.

LDF COATINGS
www.LDFcoatings.com

LDF
COATINGS
www.LDFcoatings.com