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Reliability Without Hermeticity: Commercial Vapor Deposited Coatings for High-Frequency RF Micro-Electronics

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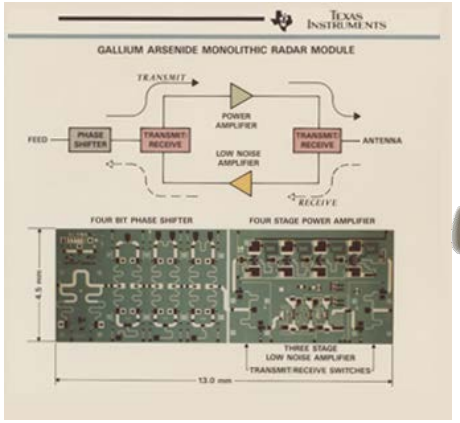
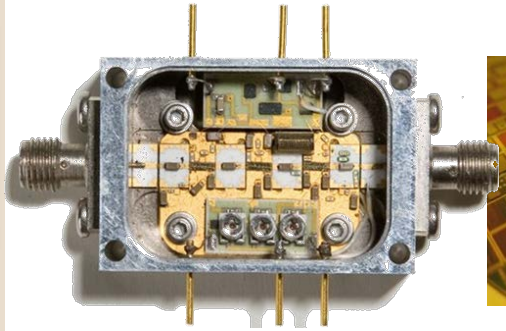
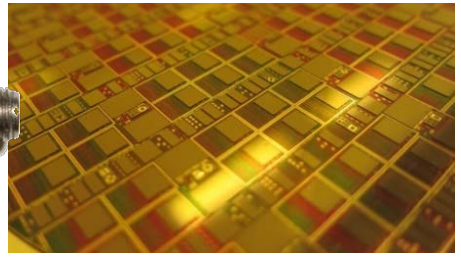
Trends in Electronics

- Higher performance, lighter, smaller footprint, lower cost
- Packaging has a significant impact on size, weight and cost (SWAP-C)



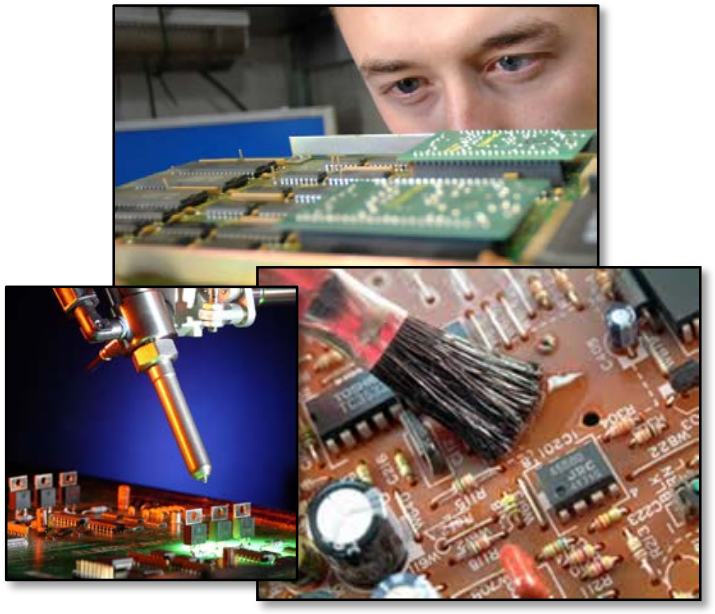


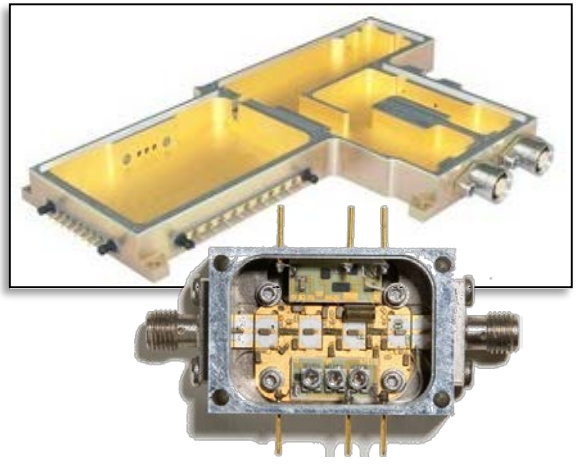


Analog & Digital	COTs & MMICs	RFICs & MMICs	Heterogeneous Integration
‘80s	‘90s	‘00s	‘10s ‘20s

Industry Status Quo for Environmental Protection

- Digital and low RF frequency (<8 GHz)
  - PCB Design
  - Environmental housing (non-hermetic)
  - Conformal Coatings (100's of µm)
    - Wet applied polymers (polyurethanes, silicones)
    - Thicker, vapor applied polymers (parylene)
- RF and Microwave frequency (>8 GHz)
  - Module Design
  - Metal or Ceramic Hermetic Packaging

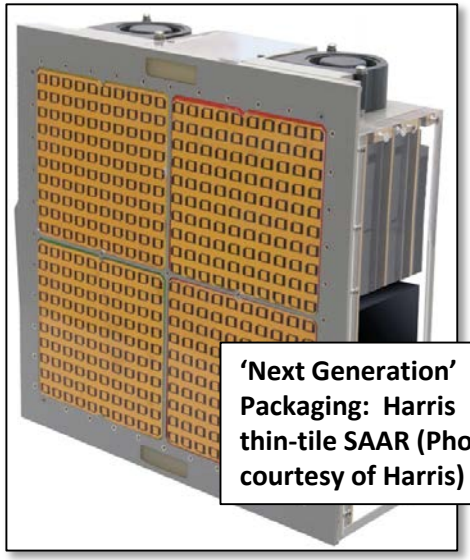




Why is the Status Quo an Issue?

- Hermetic packaging is expensive (custom-made), heavy, requires significant space
- Conventional conformal coating's dielectric constant severely impacts RF circuit performance (can't be applied directly to active components)
- High frequency RF and microwave devices are compatible only with hermetic packaging or no protection at all
- **No viable alternative** as a replacement for hermetic packaging
- **Critical Concerns:**
  - **RF compatibility**
  - **Environmental protection**
  - **Cost-efficiency**
  - **Scalability**

'Traditional' Radar Packaging: SABR Array from F-16, occupies entire nose of aircraft (Photo courtesy Northrop Grumman)

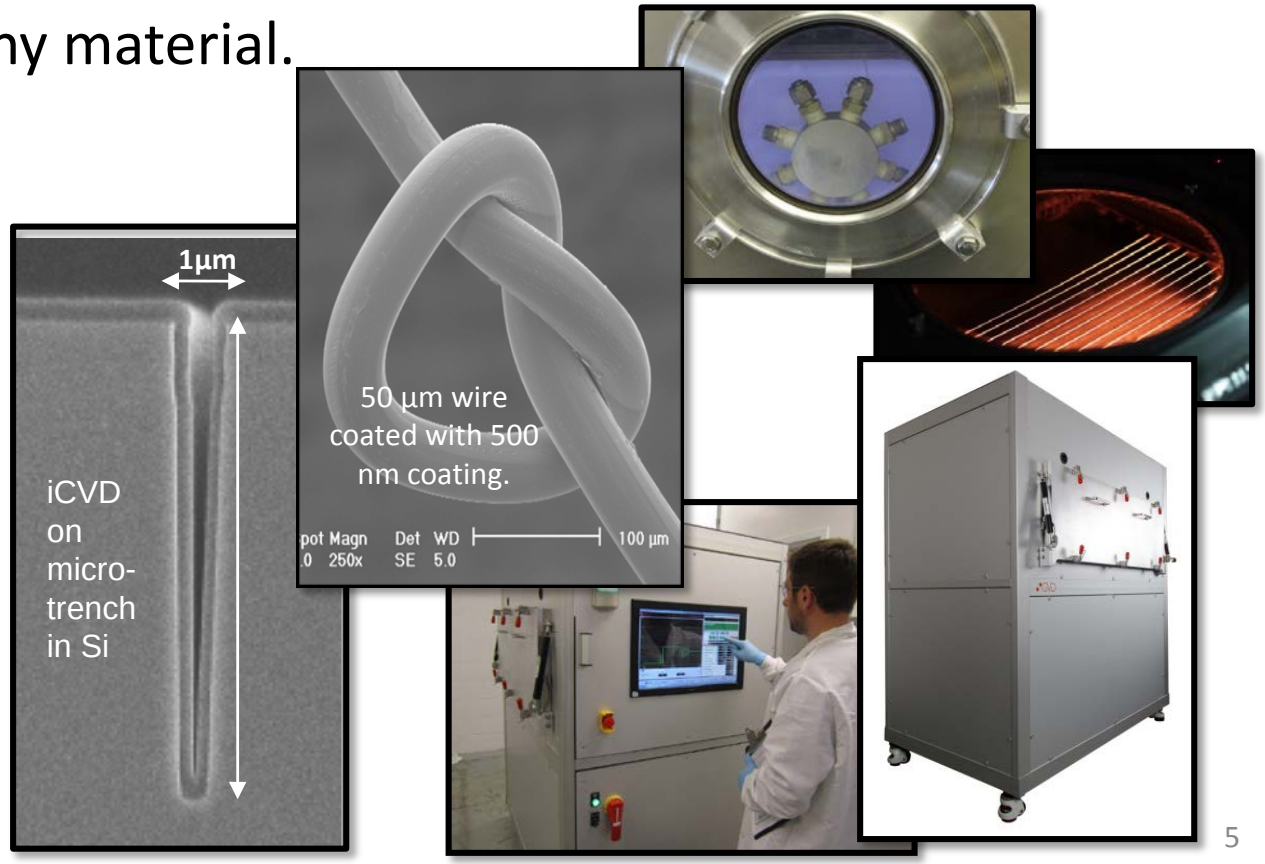


'Next Generation' Packaging: Harris thin-tile SAAR (Photo courtesy of Harris)

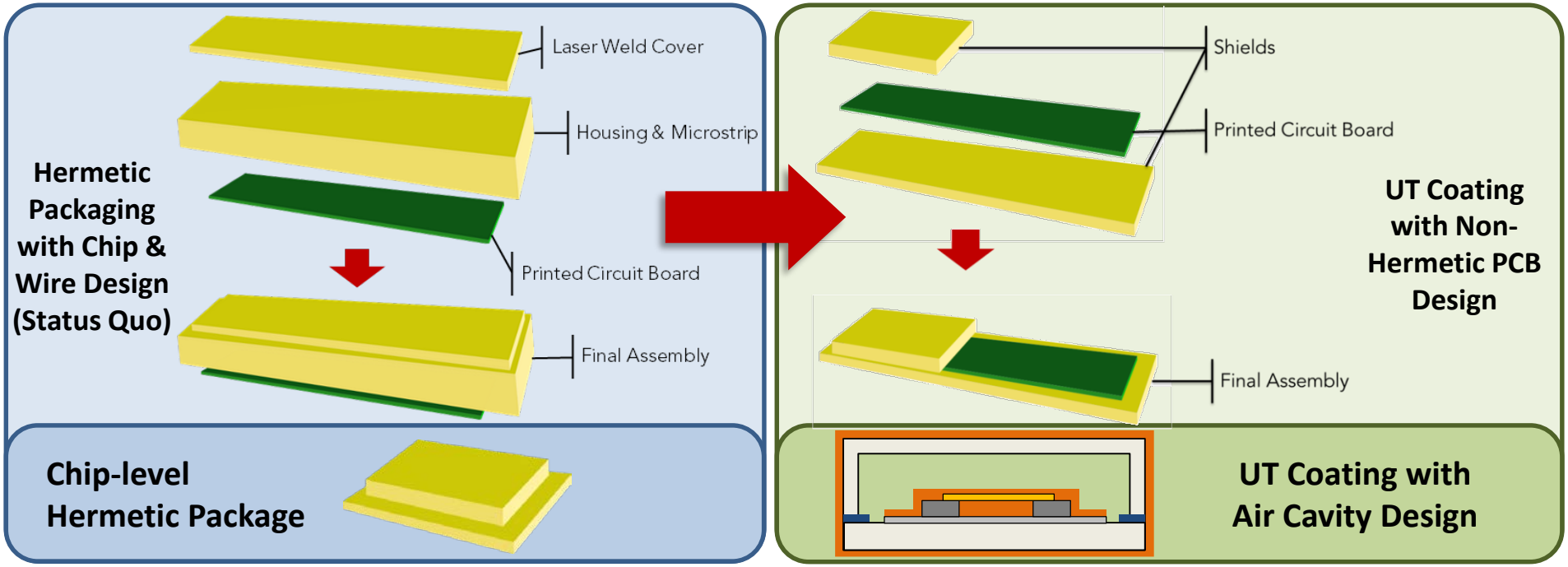
Solution: Ultra-Thin Vapor Deposited Conformal Coatings

A low-temperature coating process which produces thin polymer coatings on almost any material.

- "Gentle" application
- low temperature (20-100°C)
- dry process (no solvents)
- single-step (no drying/annealing)
- nano- to micro- meter thickness control (1-3 µm typical)
- conformal on nano- and micro- structures
- minimal/no RF impact



C. Coating Enables Packaging Design Improvements



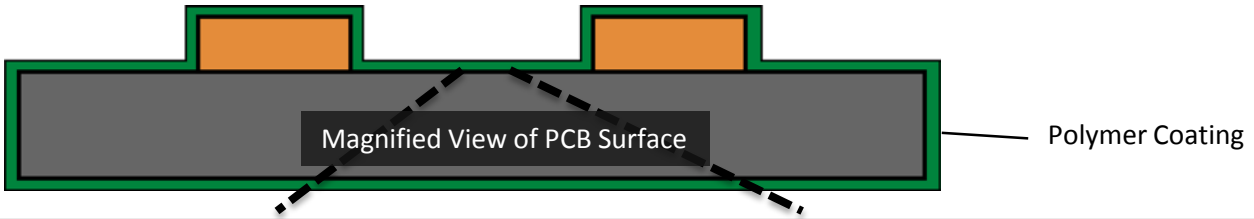
RF-compatible ultra-thin vapor deposited coatings allows RF systems designers to use printed circuit board technology

- **Reduced packaging material cost (>50%)**
- **Reduced design lead time (20%)**
- **Reduced material lead time (>60%)**

Hermetic Protection vs. Conformal Coating

- Hermetic Packaging seals electronics within impermeable housing
  - Validated with leak-rate tests
  - Low-permeability, inorganic materials required
- Conventional (polymer) conformal coatings are not impermeable
  - **No polymer is hermetic** – many coatings act as pseudo-barriers via sheer thickness
- Ultra-thin conformal coatings
  - **Adhesion** is critical to environmental protection, not low permeability

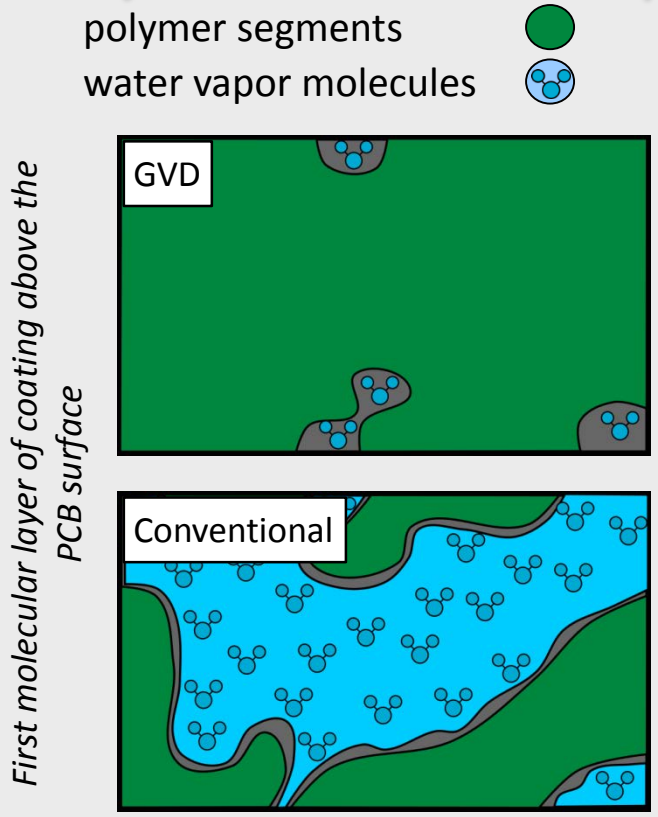
Mechanism of Protection



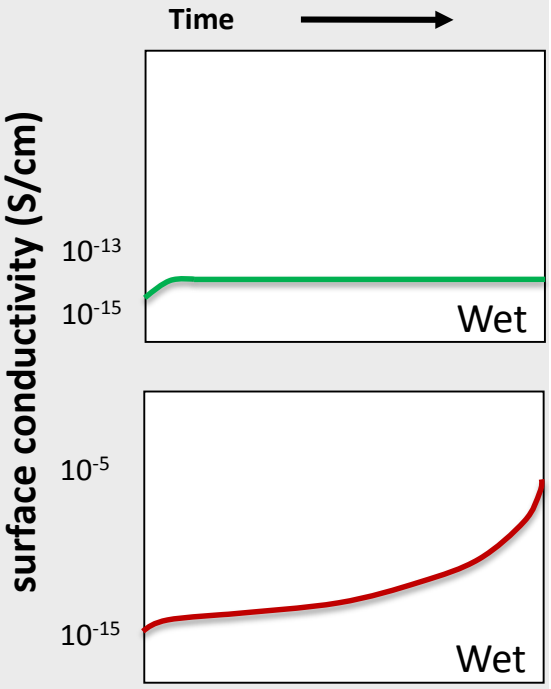
In High Relative Humidity

Well Adhered Polymer
- Molecular-level coverage of surface
- No room for condensation
- Stable in presence of water molecules

Poorly Adhered Polymer
- Regions of poor adhesion
- Readily displaced by water molecules
- Open surface sites allow for condensation, resulting in conductive pathways

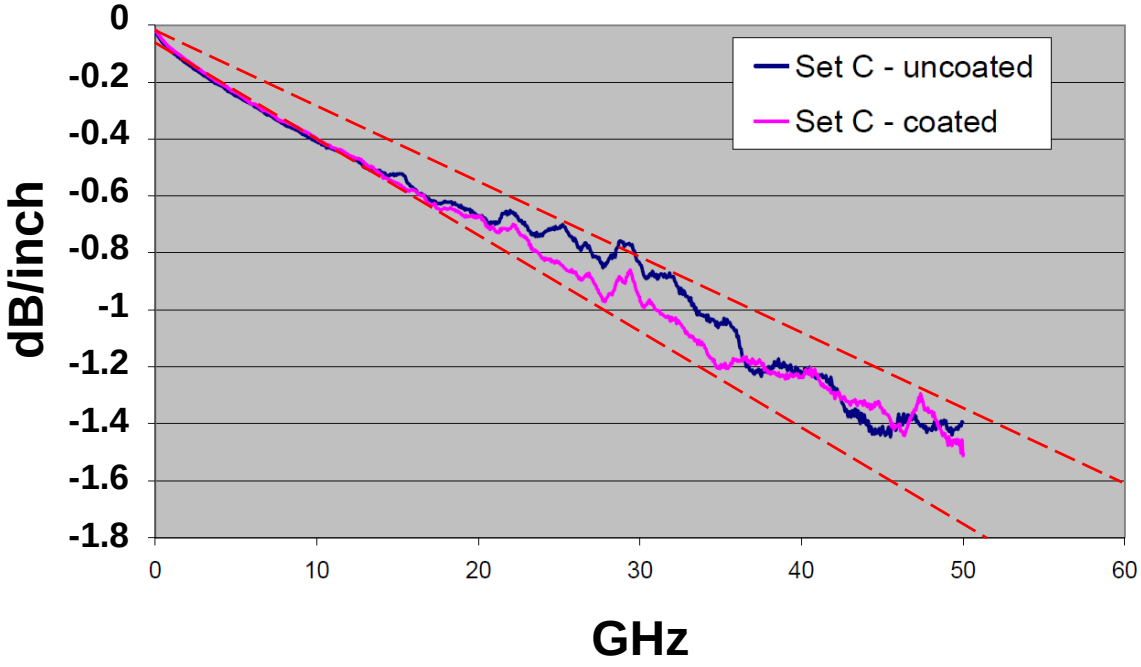


(Troyk P. *IEEE T Compon Hybr Manf Tech* , 1991, *Donaldson P. Int J Adhesion & Adhesives 1996)*



RF Performance Measurements

- Conformal coating causes no measurable increase in insertion loss up to 50GHz on 50ohm transmission lines. (Testing carried out by Rogers Corp.)
- Conformal coatings show negligible impact on S-parameters, gain, isolation, return loss before and after 8 days environmental exposure at 85°C/85%RH. Samples tested to 20GHz. **(Testing carried out by major defense contractor)**



Insertion Loss of 50 Ω Microstrip on 0.0047" Rogers RO4350B Laminate (Red lines show approx. limits of reproducibility in RF measurement)

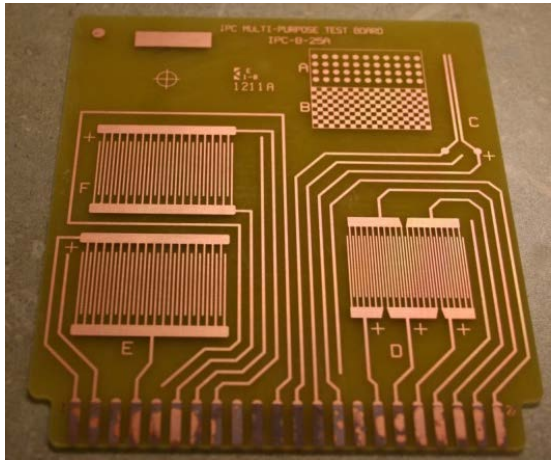
Summary of RF Data

Feature	Test Freq. (GHz)	Performance Degradation	Comments
MMIC SPDT Switch	100	0.7 dB	Minor degradation
MMIC LNA	100	1.3 dB	Minor gain degradation
Balanced Ampl. Config.	35	2.9 dB	Moderate gain degradation
MMIC SPDT Switch	37	0.2 dB	Minor degradation
Coupled line band pass filter	35	0.2 dB	Minor degradation in bandwidth and insertion loss
Coupled line band pass filter	17.6	0.5 dB	Minor degradation in bandwidth and insertion loss
Branchline Couplers back to back	35	0.07 dB	No degradation in bandwidth and insertion loss
2-inch 50 Ω microstrip line	40	0.01 dB	No degradation in bandwidth and insertion loss

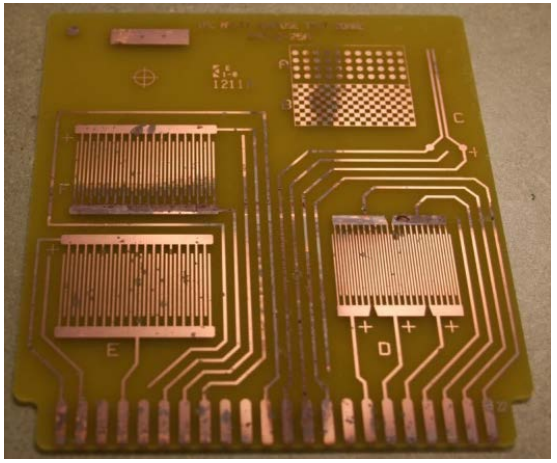
Results of Environmental Exposure

Test	Method	Description	Result
Salt Fog	ASTM B117	500 hours of exposure	PCB covered in salt crystals; PCB operational with no signs of metal corrosion
Humidity	JESD22-A101C (not biased)	1,000 hours of exposure	PCB operational with no signs of metal corrosion
Immersion	N/A	Electrode soaked for 7 years in salt water under sweeping +/- 5V bias	No drop in resistance across the coating, indicating no degradation

With Conformal Coating

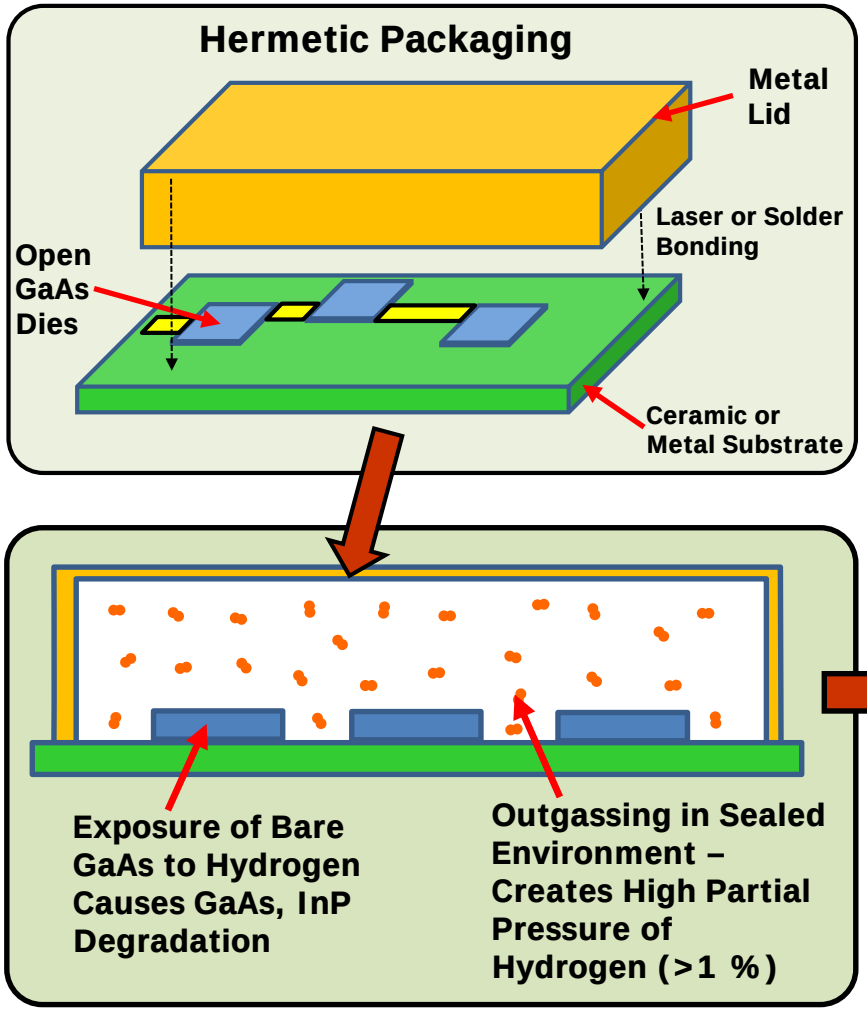


With No Coating

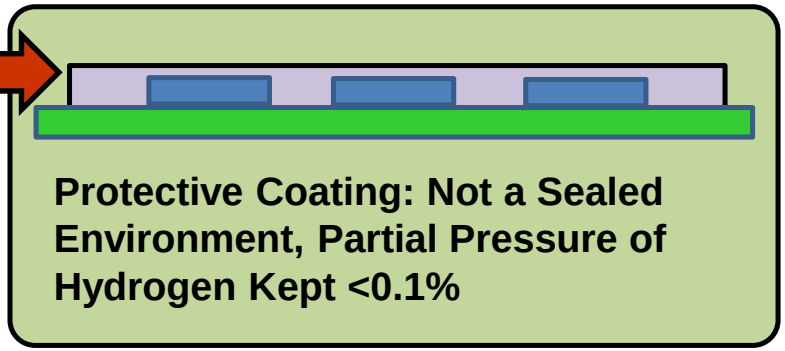


Images of coated board (1 µm thick coating) with lower contacts masked and an uncoated board after Salt Fog testing per MIL-STD-810G Method 509.5

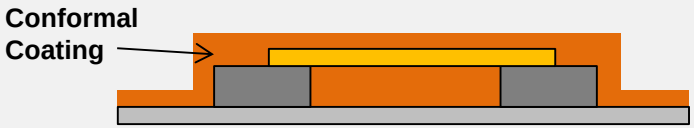
Coating Advantages – Avoiding Hydrogen Poisoning



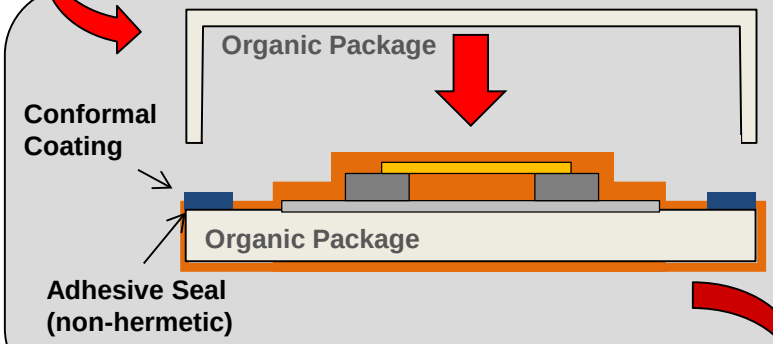
- **Hermetic Packaging**
  - Metal components used in manufacture can outgas hydrogen
  - Sealed environment results in hydrogen build-up
  - Results in 'poisoning' of GaAs and InP devices
- **Conformal Coating**
  - Open (non-sealed) environment over coating does not allow hydrogen build-up



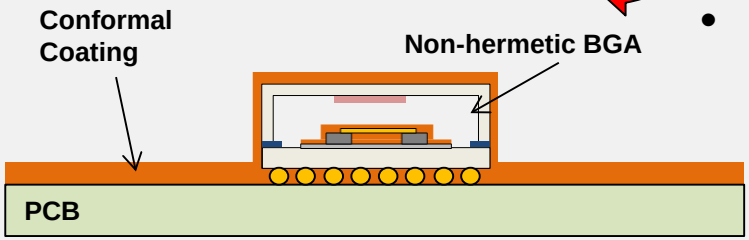
Multiple Levels of Protection



- **Level 1: Chip-Level Protection**
  - Protects bare die from Foreign Object Debris
  - Provides Structural Support for air bridges without significant RF impact
  - Last Line of Defense of reliability w/o hermeticity



- **Level 2: Package-Level Protection**
  - Non-Hermetic seals and materials reduce weight/cost of packaging
  - Exilis Protective Layer to provide extra reliability w/o hermeticity
  - Can coat Individual or Board-Mounted Packages
  - Hydrophobic Layer to reduce impact of condensed moisture



- **Level 3: Board-Level Protection**
  - Exilis Protective Layer for environmental protection of board traces (RF and otherwise)
  - Improved Rework compared to hermetic packaging, Parylene, and other coatings

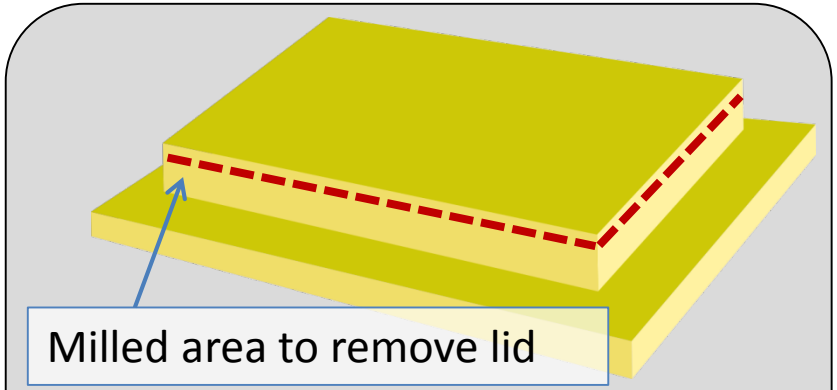
Other Conformal Coating Requirements:

Area of Need:	Ideal Coating Behavior
Connector Masking	**Easy to Mask** and does not require painstaking coverage to prevent coating of connecting pins/surfaces
Demasking	Easy demasking with **no coating peelback** or delamination
Handle-ability	Coating **withstands normal handling**
Rework	Coating **easily removed** using standard processes (microparticle abrasion, reactive ion etch)
Touch-Up	Coating **easily redeposits** to both coated and uncoated regions with good adhesion
Coating Time	**<2-4 hrs for 1 to 3 µm thick coating**. Shorter deposition time = lower chamber maintenance costs.
Thermal stability	Able to withstand contact with **high temperature devices** during operation.

Reworkability: Other Protective Solutions

Hermetic Packaging

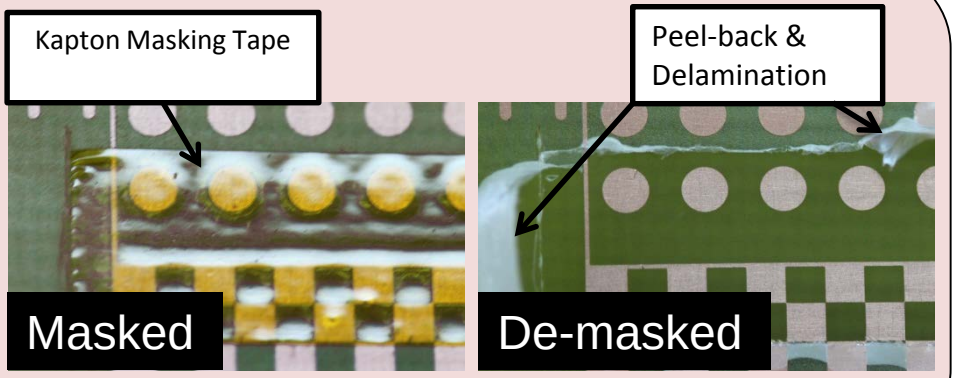
- Defective small packages rarely repaired
- Requires the welded lid of larger units to be milled away
  - Time-consuming and expensive
- Rework introduces conductive foreign debris to sensitive electronics



Hermetic Package

Parylene and other conventional coatings

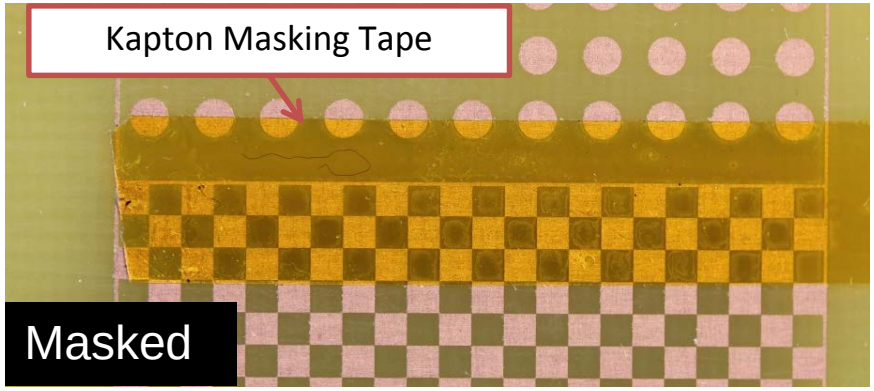
- Major bottleneck due to labor-intensive processing
- Reduced system reliability due to:
  - Poor adhesion increases risk of moisture ingress
  - Challenging masking/demask increases risk of localized failure

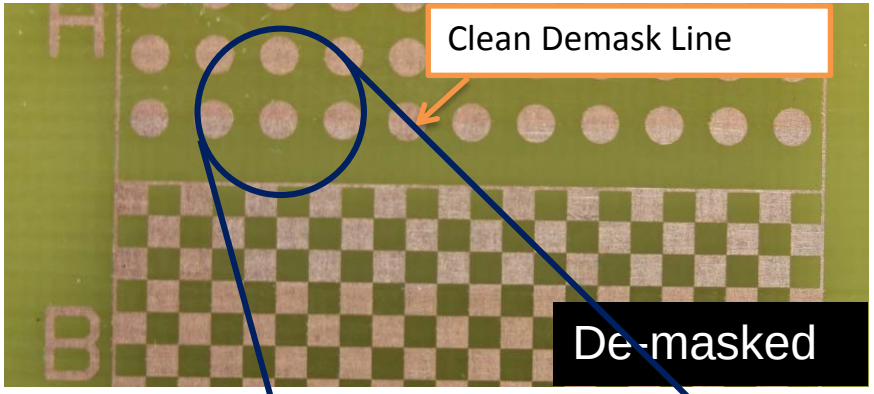


Parylene-C (20 µm or 0.8 mils)

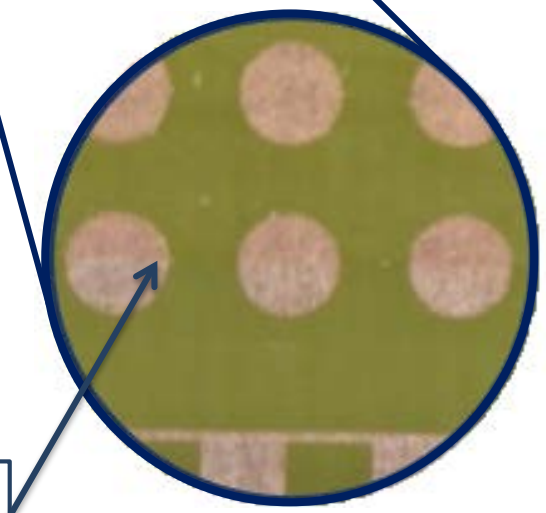
Reworkability: Optimally Designed Conformal Coating

Conformal Coating (<2 µm) applied to B-25A IPC Test Board



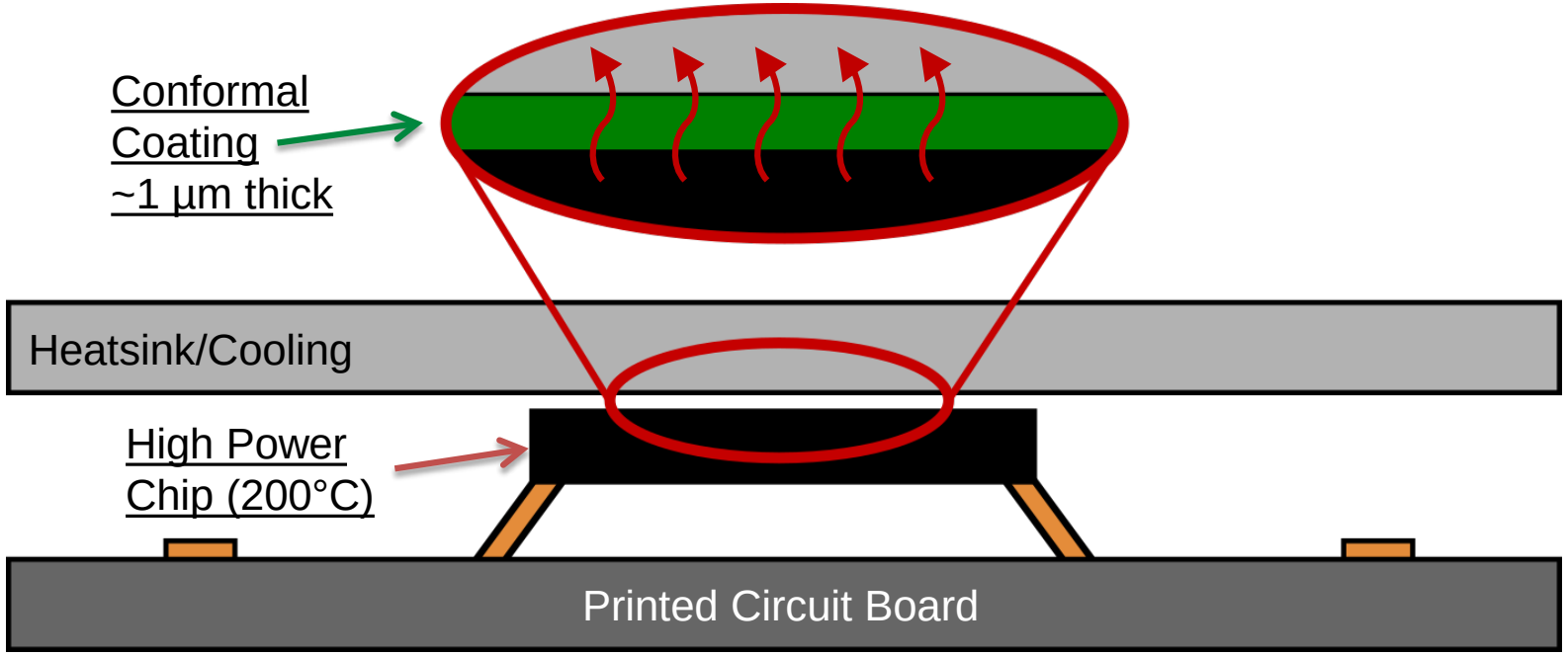


- **Processing:** Masking and demasking are easy processes, do not require scoring, result in a clean de-masking line.
- **Rework of a faulty component:** Remove the component as if the coating were not present. Replaced components demonstrated to pass solder joint life testing.
- **Coating reapplication:** Can be reapplied to the entire PCB or selectively applied via masking methods.



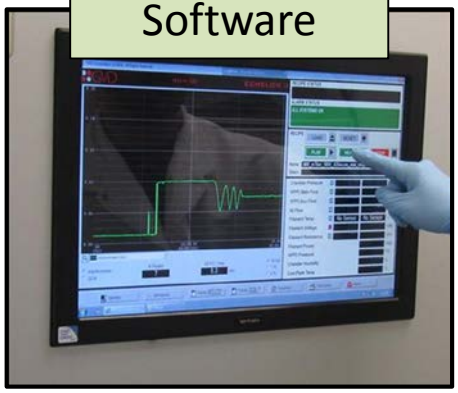
Compatible with Board Cooling Techniques

- Thin (≤ 1 µm) coatings do not impede cooling
- No need to mask high-power, hot-running chips reduces masking preparation prior to coating
- Thermally stable to 200˚C, can be treated to be stable up to 250˚C

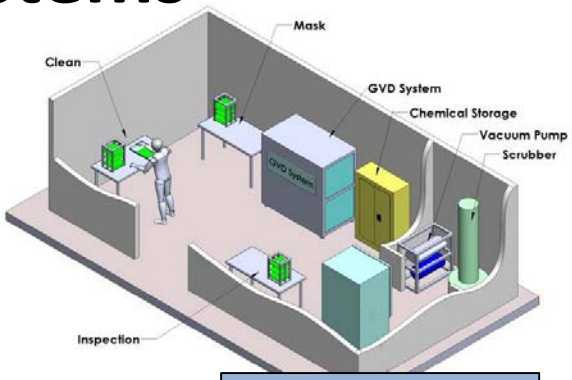


Commercial Coating Systems

- Small facility footprint
  - 14’ x 28’
- Vapor Coating System:
  - Dimensions:
    - Length: 40”
    - Width: 20”
    - Height: 12”
  - Recipe-driven controls
  - Automated for repeatability and ease for production



Recipe-Driven Software



Facility Layout

Prototype Production-Scale Coating Systems

Summary

- Ultra-Thin, Conformal Polymer coatings are a viable method for achieving Reliability Without Hermeticity
- Compatible with RF microelectronics
- Can be applied on multiple levels (wafer, package, and board)
- No impact on thermal control
- Enables new types of combined RF-Digital boards