Polyurethane spray coating of aluminum wire bonds to prevent corrosion and suppress resonant oscillations

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Introduction and Goals

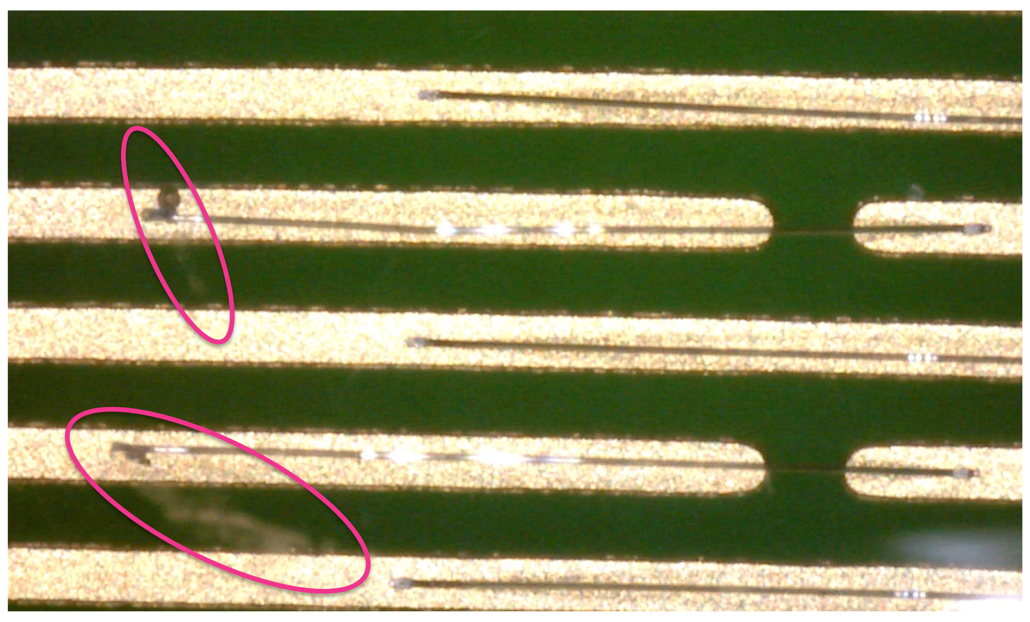
Unencapsulated aluminum-wedge wire bonds are common in pixel and strip detectors.
Bulk bond encapsulation traditionally eschewed due to thermal expansion and radiation concerns.
Wire bond problems are a persistent failure mode:

Condensation-induced corrosion, particularly when Cl^- present.

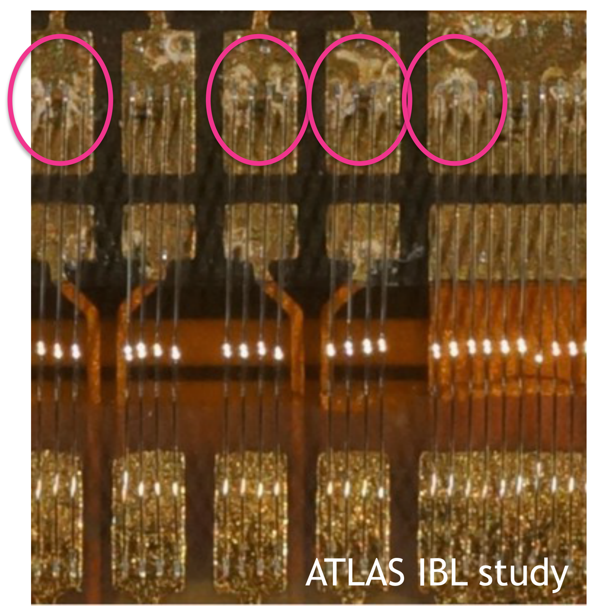
Periodic Lorenz forces at wire bond resonance frequency can break bonds.

Goals: Perfect PU spray-coating techniques. Evaluate PU coating corrosion resistance and the protection PU affords against resonant driving forces. Qualify PU for use with the ATLAS ITK Pixel detector, first at room temperature, and then at -20 C

Halide-Catylized Corrosion: $Al + 3H_2O \rightarrow Al(OH)_3 + 3H_2 \uparrow$



Aluminum wire bonds in deionized (DI) water. Hydrogen plumes and bubbles visible



White corrosion residue visible with low-angle lighting. Traces of chlorine detected on ENIG surface

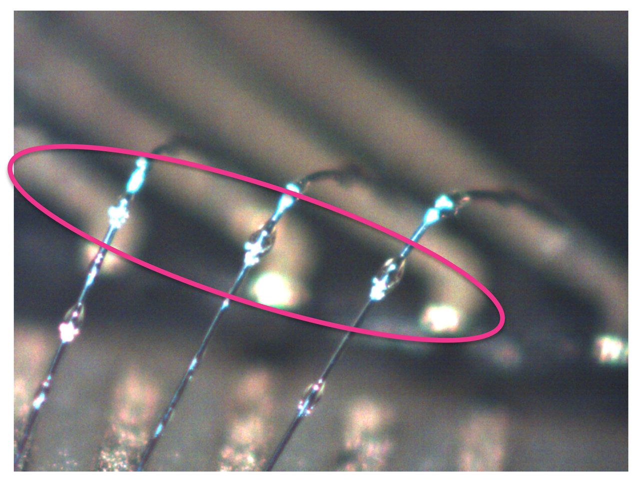
- QARTlab test: DI water test provokes corrosion in 6 of 8 PC boards sampled from CERN experiments and labs [1]
- Condensation/corrosion prior to and during quality assurance testing, particular for tests requiring cooling [2]
- Corrosion risk appears to be a common concert.

Application of Polyurethane Coatings

Polyurethane: Cellpack D 9201 Urethane
Spray can and bulk liquid
Formulated for electrical insulation and corrosion resistance

Spray can results unusable
Uneven blobs on bond wires in every attempt

No control of droplet size and flow rate



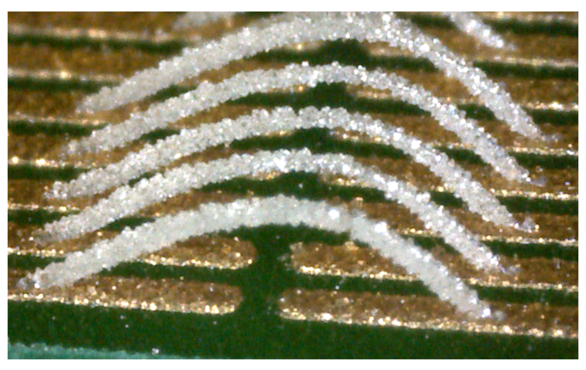
PU coating from a spray can

Paasche Talon Dual Action Airbrush TG2L

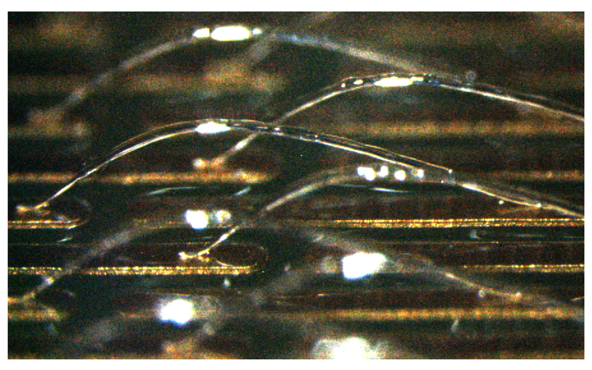
Art-Supply Air Brush

- Better control of pressure, flow, nozzle size
  - Smaller droplet size in atomized spray
  - Some control over droplet size
  - Coating build-up in several passes
- Nozzle + needle can be cleaned
- Smaller painted region
  - Further collimation of spray possible with a mask
- Use liquid Cellpack D 9201 PU, 0.65mm nozzle

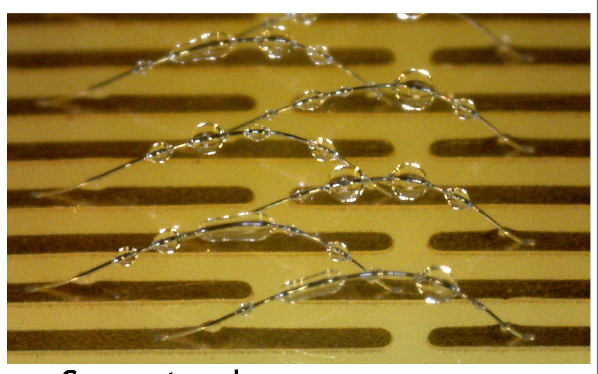
Polyurethane-coated 25 μ Al wire bonds



Spray too fine: droplets partly dry before reaching wire.

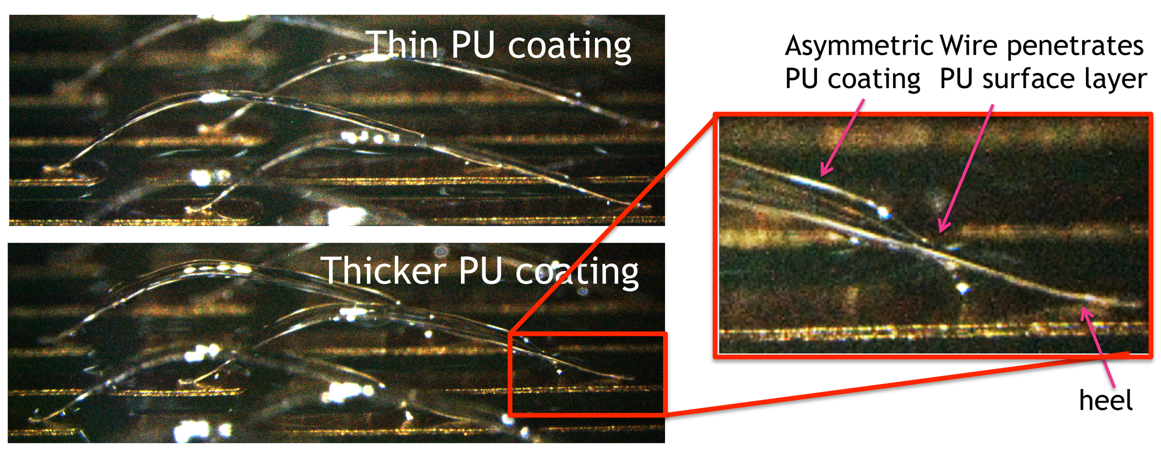


Goldilocks spraying
Smooth, hermetic coatings
~35μ to ~100μ outer diameter



Spray too heavy.
Droplets

Tens of spray passes build up desired PU thickness

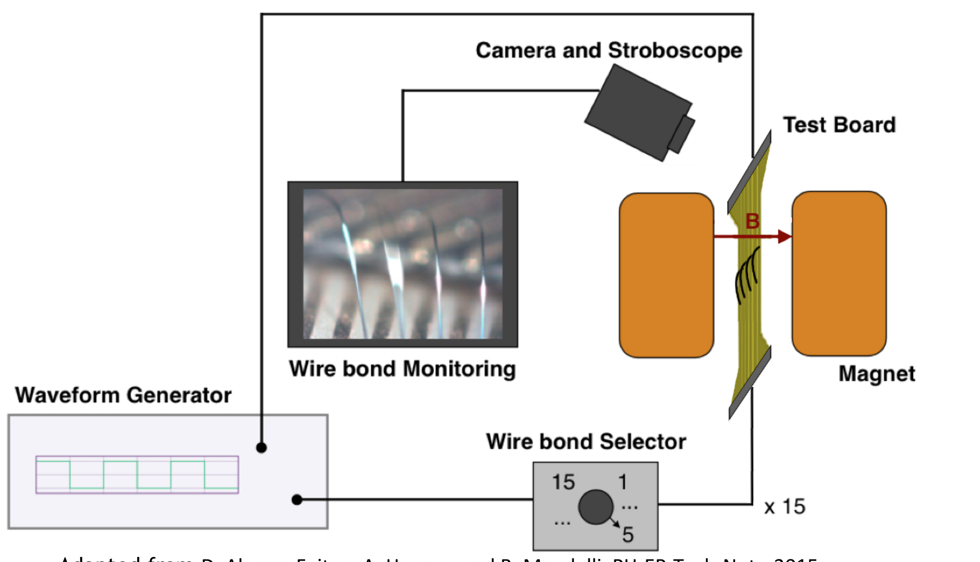


Fresh PU coatings put through 350 thermal cycles in 4 days , -30 C to +50 C.
No thermal expansion breakage
All PU thicknesses pass DI water challenge >20mins: No Bubbling, no corrosion residue.

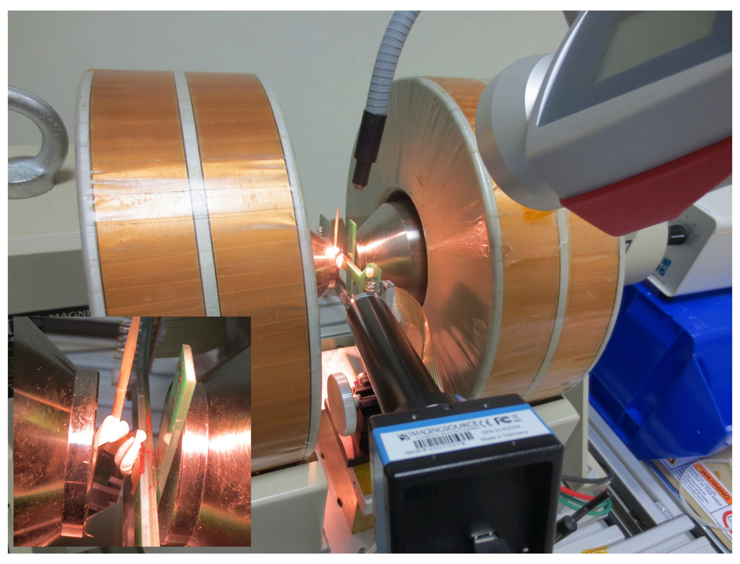
Periodic Lorenz Force: Intermittant Current in a B Field

- Resonant oscillations broke wire bonds on CDF silicon tracker [3]
- ATLAS Pixel protects disk LV power wire regulator wire bond heels by potted with Dymax
- ATLAS SCT and IBL: software prevents readout in resonance frequency range

- Goal: survive 100 mA p-p, B = 2T, at wire bond resonant freq.



Adapted from D. Alvarez Feitoa, A. Honma, and B. Mandelli, PH-EP-Tech-Note-2015-



B=1.5-1.7 T   50% duty square wave   0 – 180 mA p-p
Worst-case (end cap/disk) geometry   Test 25μ, 2.8 mm long bond wires at f_{res}

Sample	f_{res} [kHz] mean, range	Q mean, range	$I_{p\text{-}p}$ [mA] to break
2.8 mm uncoated PCB C3, N_{wires}=17	11.78 (11.68 -11.97)	92 (69 – 117)	4 one wire
2.8 mm potted PCB D2, N_{wires}= 8	14.95 (13.80 – 16.17)	68 (60 – 77)	12 – 15 one wire
2.8 mm PU light PCB C10, N_{wires} = 15	9.28 (8.88 – 9.76)	36 (26 – 46)	32 – 40 one wire
2.8 mm PU heavy PCB C9, N_{wires}= 8	(8.1 – 14.1)	(7 – 14)	f_{res} = 10.4 kHz: breaks @ 180 mA p-p f_{res} = 13.3 kHz: 38.5 hours @ 180 mA p-p 1.7 T

As PU coating thickens,
- f_{res} decreases to ~8 kHz due to increasing mass
- Then f_{res} increases due to mechanical stiffness of PU
- Energy absorption from flexing PU decreases Q-factor
- Best protection when f_{res} > 12 kHz

4 "bullet-proof" 2.8mm wires survive B=1.7 T, disk geometry, $I_{p\text{-}p} \geqq 180$ mA, > 1 h
- f_{res} = 12.1, 13.5, 11.3, 13.3 kHz

Mechanical energy absorption by PU flexing reduces Q-factor and oscillation amplitude

First irradiated sample 27 MeV protons: 0.94×10^{16} 1 MeV n_{eq}/cm^2 = 10.3 MGy)
Maximum Expected ITK Pixel Dose: Inner Barrel 7.7 MGy   1st Disk – 0.9 MGy [4]

Sample B3 ~100μ OD	Before Irradiation		After Irradiation		
Wire Number	f_{res} (Khz) ±0.1	Q_{before} ±7%	f_{res} (Khz) ±0.1	Q_{after} ±7%	Q_{before}/Q_{after} ±10%
2	9.8	15.0	11.3	35.9	2.4
3	9.8	12.5	11.6	32.1	2.6
4	9.9	15.1	11.9	33.0	2.2
10	12.8	12.2	16.2	32.5	2.7
12	13.5	14.7	17.1	31.7	2.2
13	13.5	12.1	16.9	34.9	2.9
15	12.5	13.6	16.7	40.3	3.0
16	11.4	14.5	13.7	30.3	2.1

- Increase in f_{res} and Q consistent with radiation curing of PU and some loss of flexibility

Status and Conclusions

- Acceptable PU coatings achieved
- Corrosion and resonance protection at room temperature demonstrated
- PU a co-polymer of polyisocyanate and a polyol such as polyether or polyester.
  - Chain length affects flexibility
  - Explore formulations developed for flexibility
- Study thermal expansion damage as a function of thickness.
  - ITK Pixel Endcap/disk wire bonds may prefer a thicker PU coat that ITK Pixel Barrel

References

[1] A. Honma, F. Manolescu, I. McGill, *https://indico.cern.ch/event/283860/contribution/1/attachments/523709/722352/status_report_honma_18nov2013.pdf*, p.6.
[2] Atlas Collaboration, Atlas Pixel IBL: Stave Quality Assurance, 2014, CERN, ATL-INDET-PUB-2014-006, https://cds.cern.ch/record/1754509/files/ATL-INDET-PUB-2014-006.pdf
[3] G. Bolla et al., Nucl. Instr. and Methods A518, 277 (2004)
[4] ATLAS Letter of Intent – Phase II Upgrade, https://cds.cern.ch/record/1502664/files/LHCC-I-023.pdf

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