Challenges in LTCC

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POLITECHNIKA GDAŃSKA

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Challenges are Two-Fold

- From the Dictionary:
  - …by its nature or character serves as a call to … special effort.
    - I read this as “Opportunities in LTCC”
    - Novel applications
      - “out of the box”
  - Difficulty in…an undertaking that is stimulating…
    - I read this as “Limitations in LTCC”
    - Emphasis: performance, cost, schedule, reliability

Novel Applications-
the Path Includes:

- Shaping (bending, rolling, molding, applique)
- Sacrificial Volume Materials (SVM)
- Multi-purpose (fluidic, electrical, mechanical, chemical, sensors)

"Flat Boards"-
The path includes:

- Shielding
- Thermal issues
- Shrinkage tolerance vs. high-density circuitry
- High Frequency
  - – Location of RF ground planes, features
- Cavities, holes, valleys, ledges
- Assembly

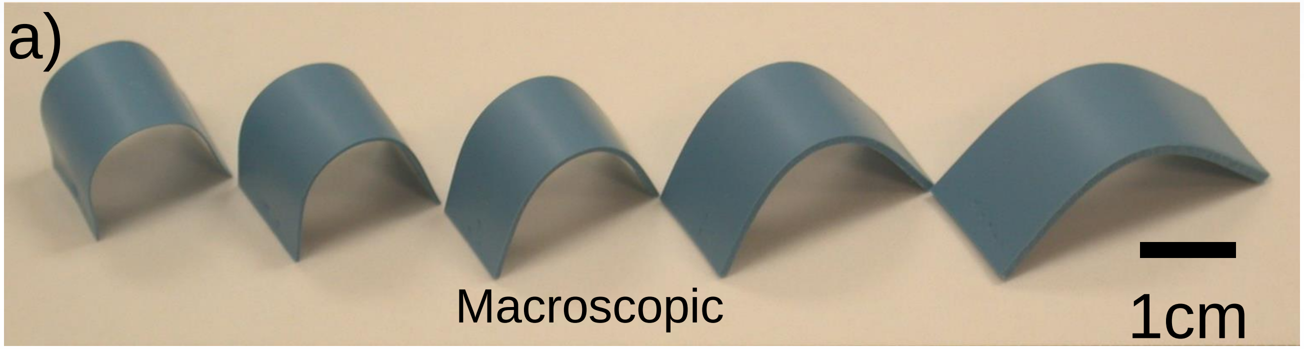
Marketplace

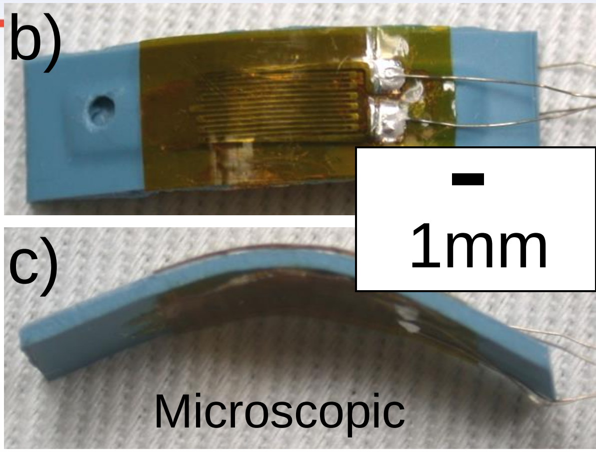
- Drive toward finer features, larger panels, lower cost.
- Maintain high quality, reliability.
- Competing technologies present risk of defection.

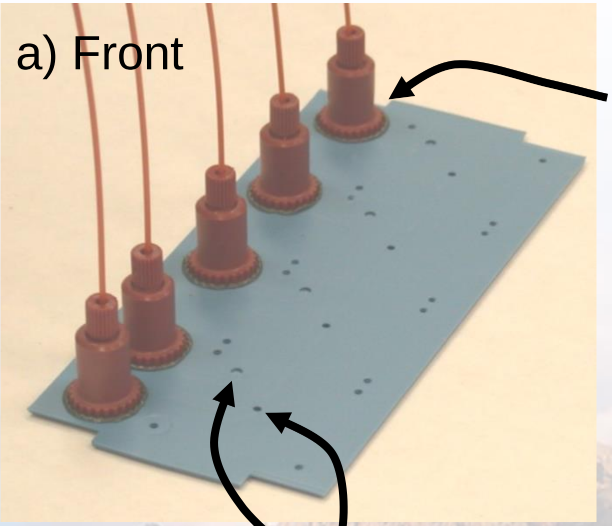
Outline

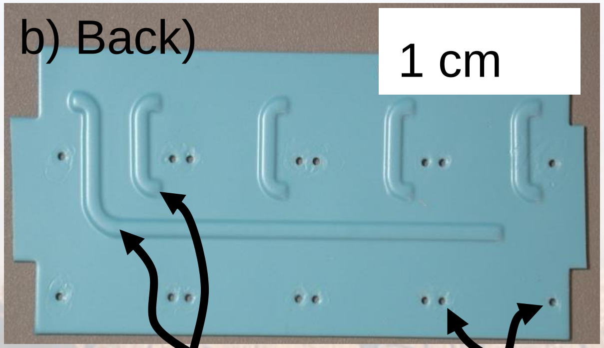
- Review novel processing
  - Shapes
  - Sacrificial materials
  - MEMS applications
- Review MCM structures & processing
- Conclusions

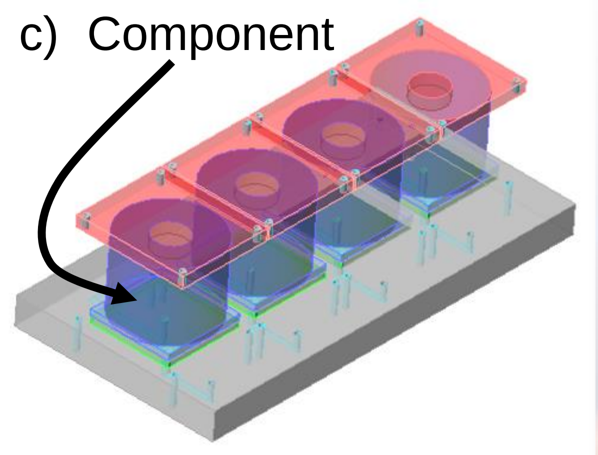
Shaped Structures





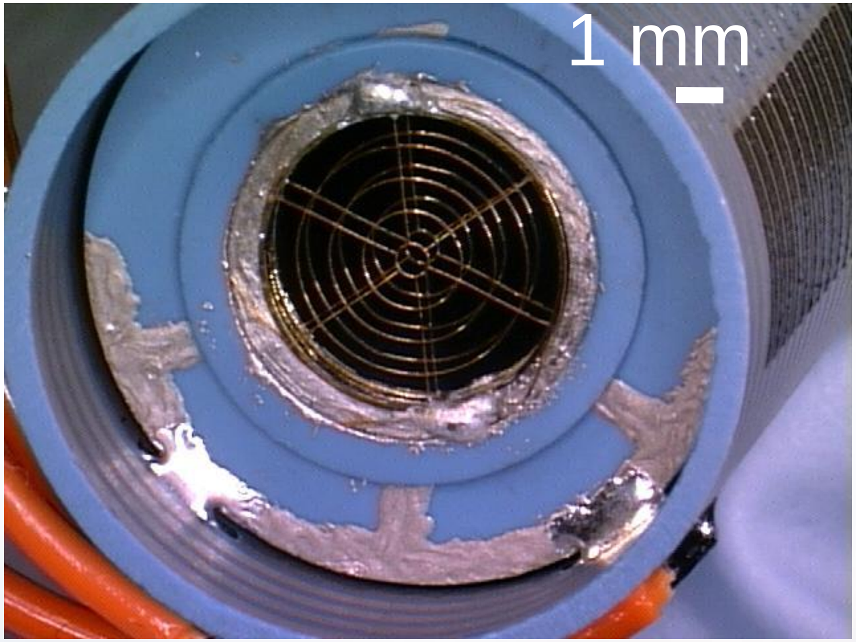


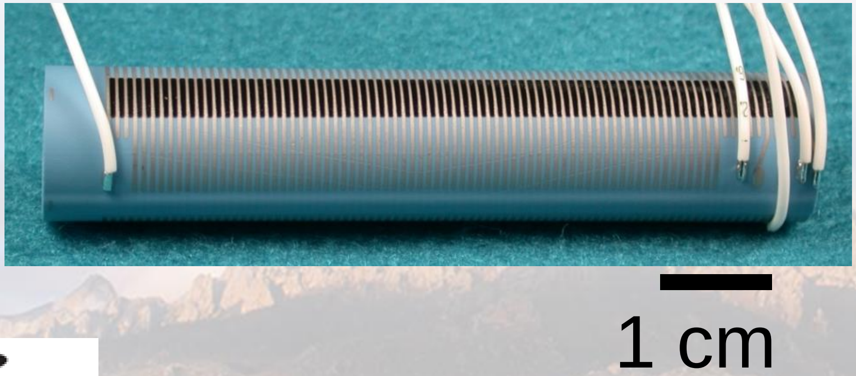


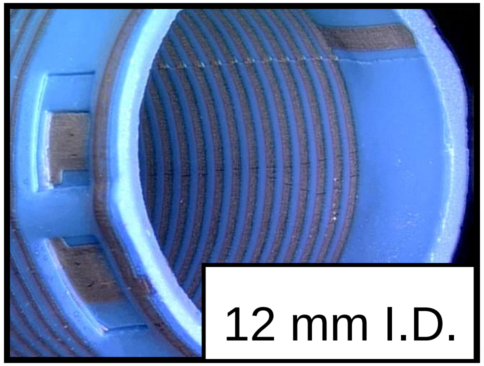


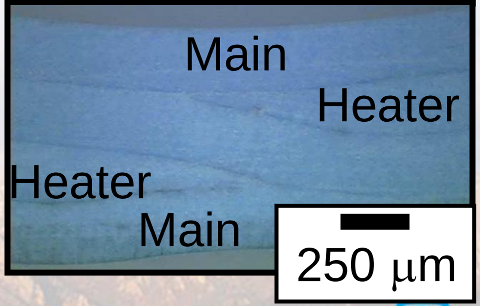
Forming of LTCC to Unconventional Requirements

Rolled ion mobility spectrometer (IMS) drift tube

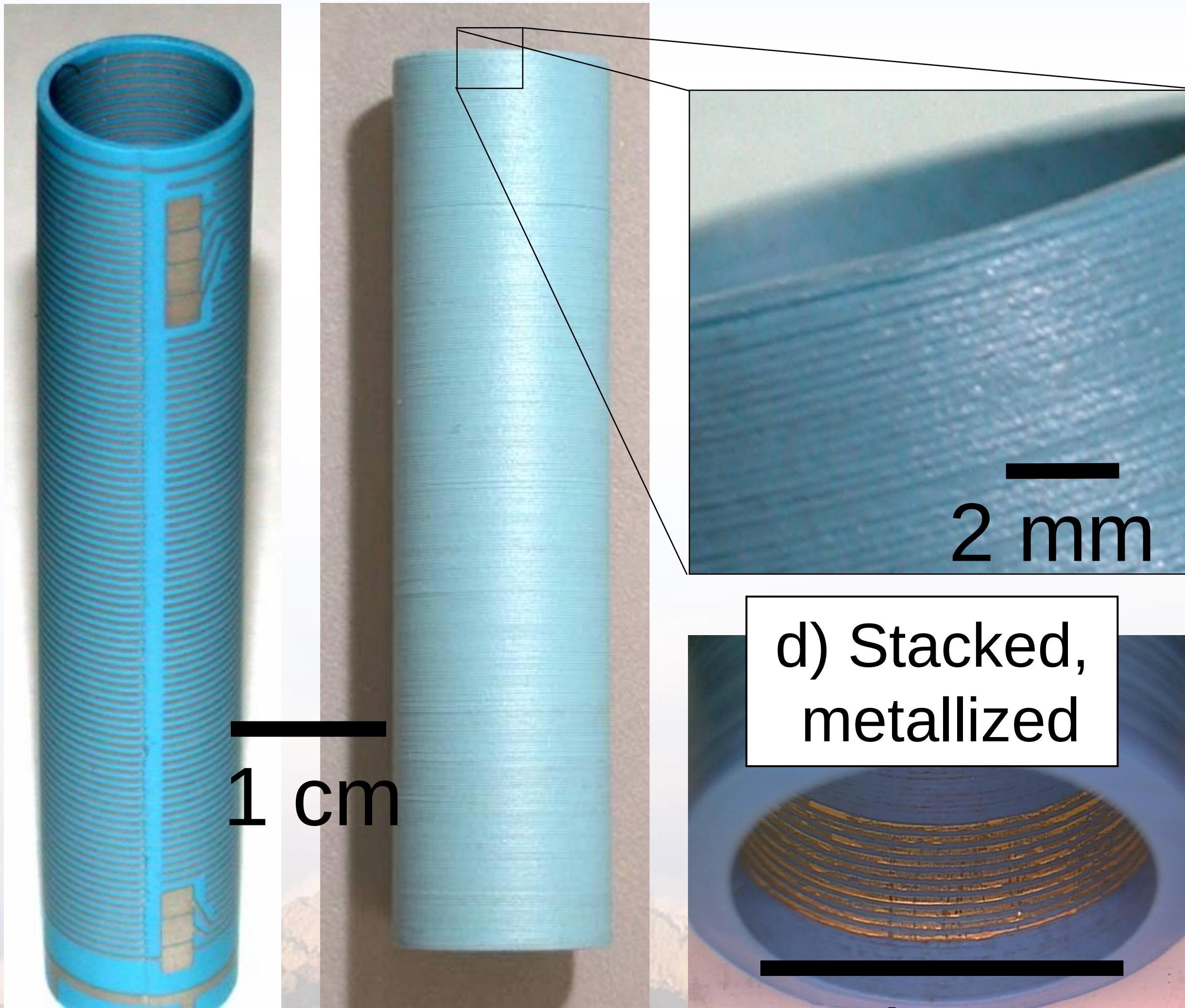








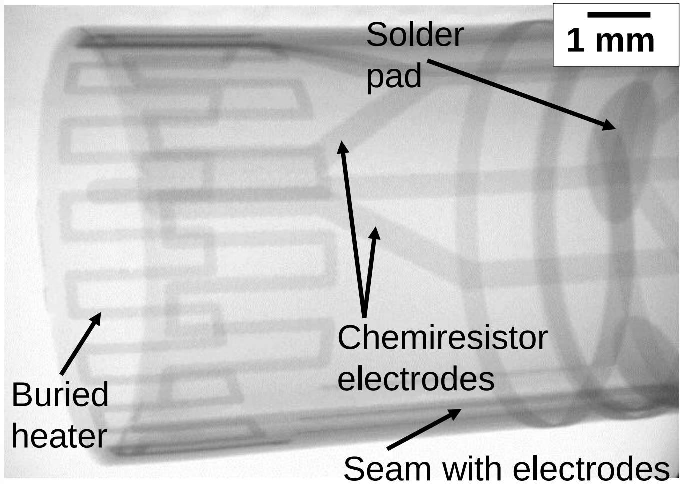
Stacking to 300 layers

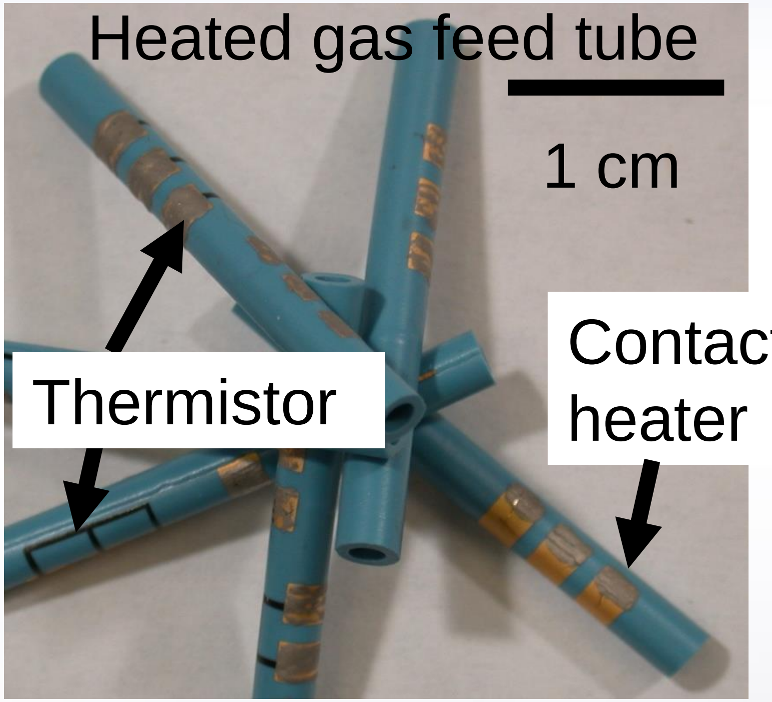


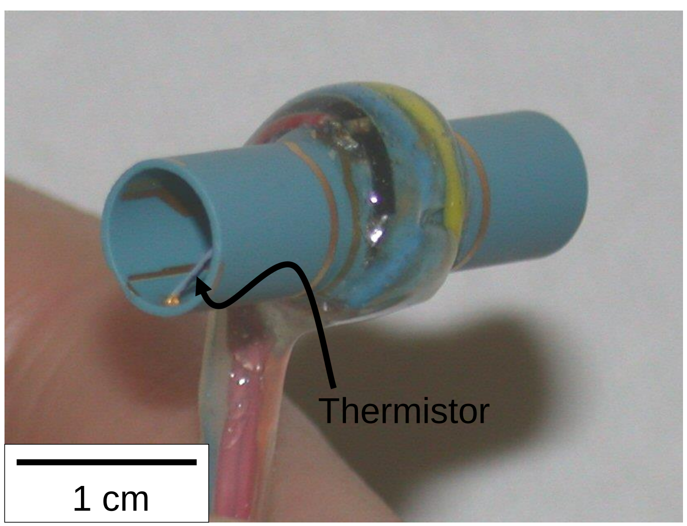
Rolled

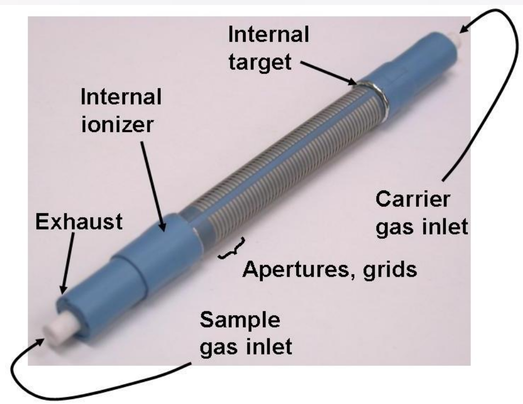
Stacked

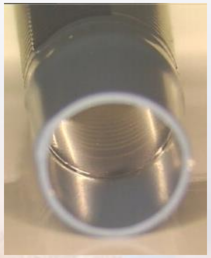
Tubular Devices







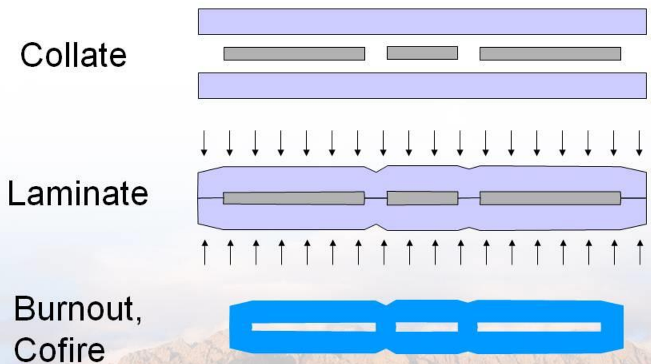




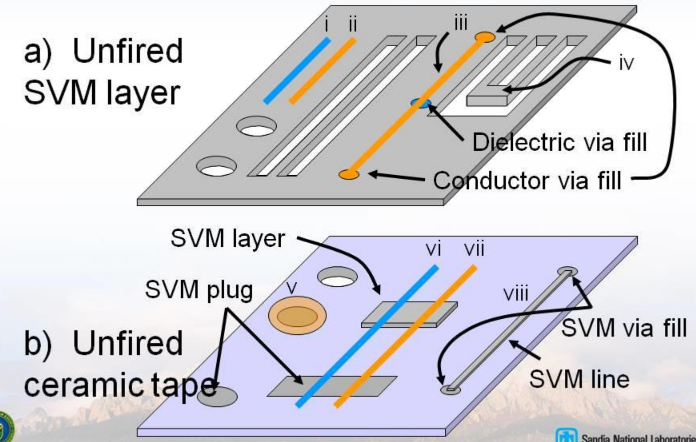
Chemiresistor Smart Channel

Novel Structures 1: SVM

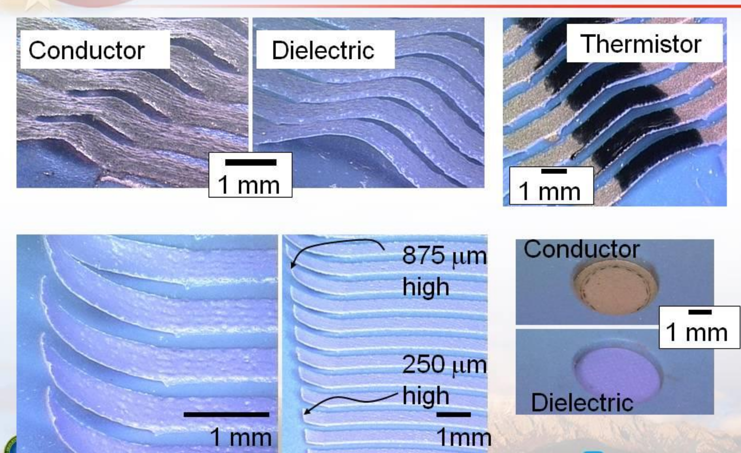
SVM Technique



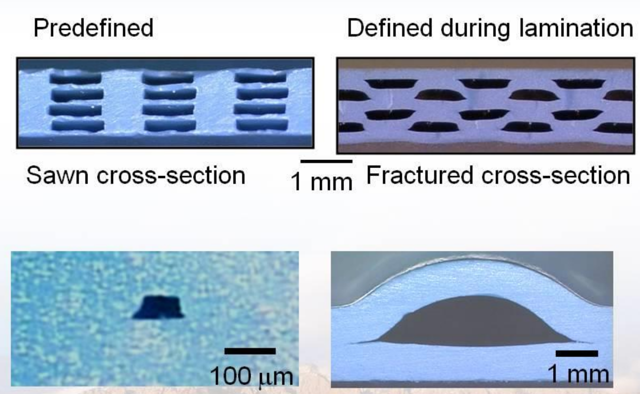
SVM / LTCC Tape / Thick Film Combinations



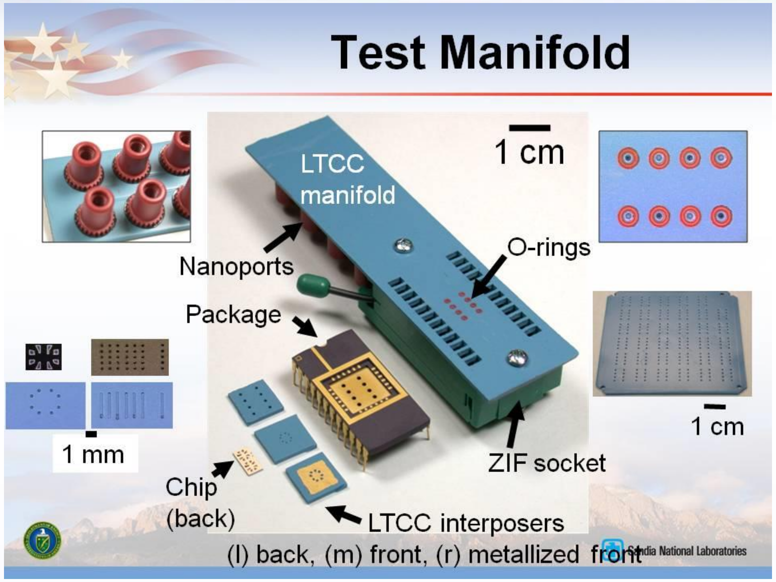
Suspended Thick Film

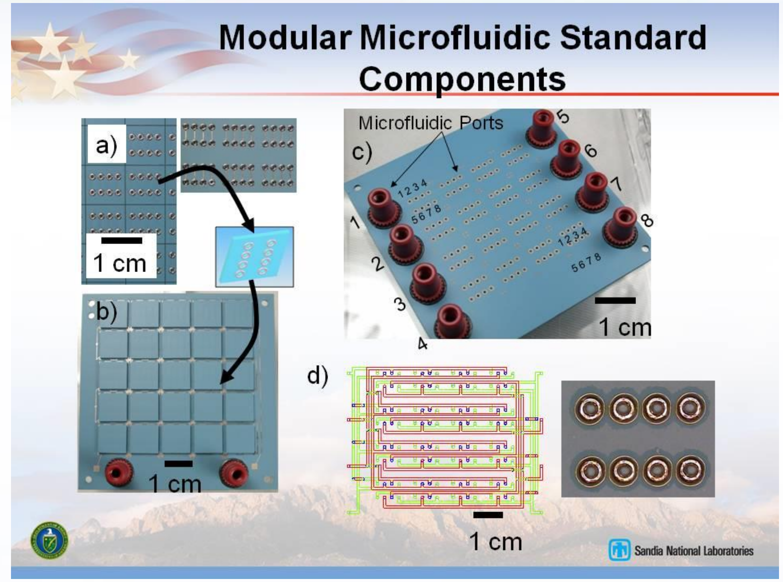


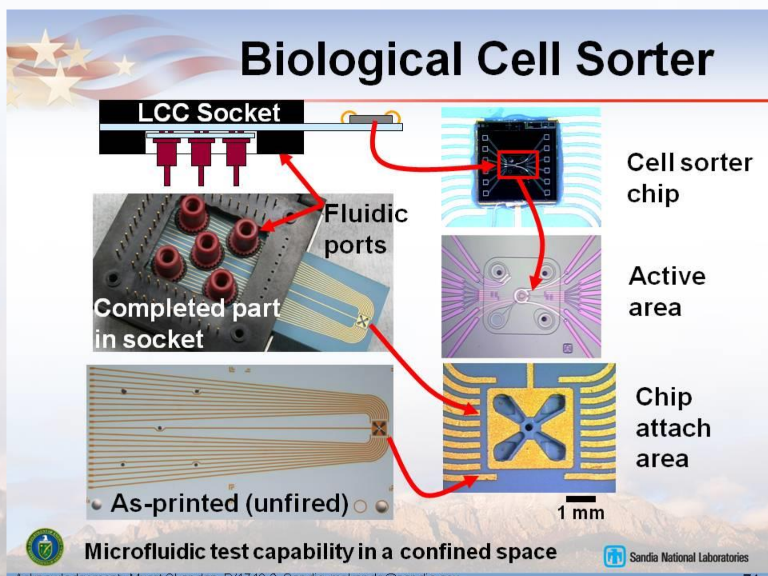
Meso/Micro-Scale Channels

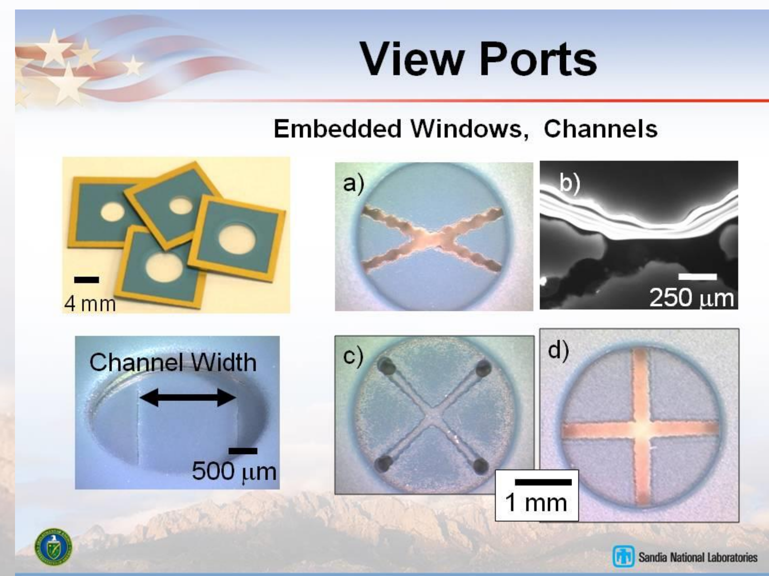


Novel Structures 2: Channels





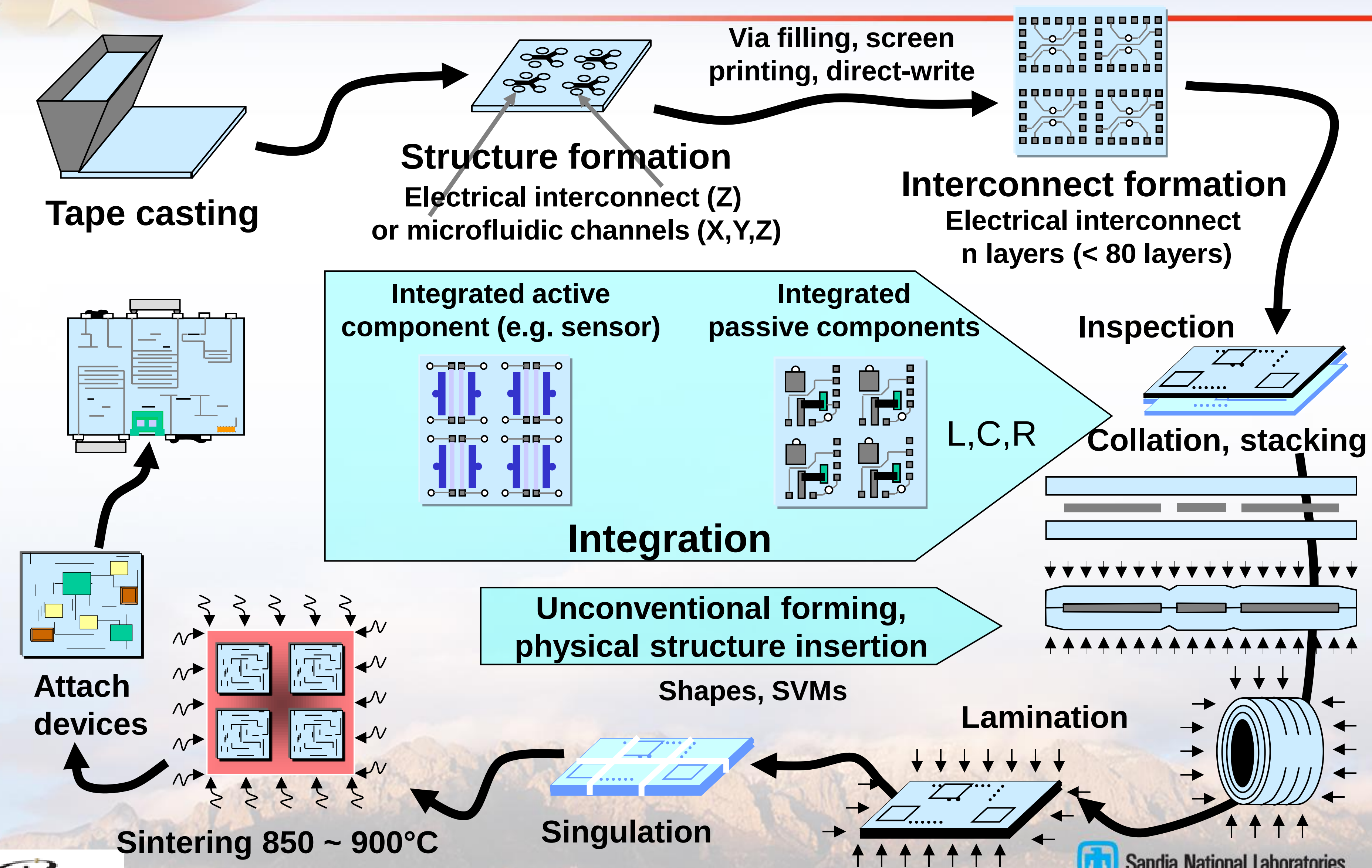




Process Flow for LTCC

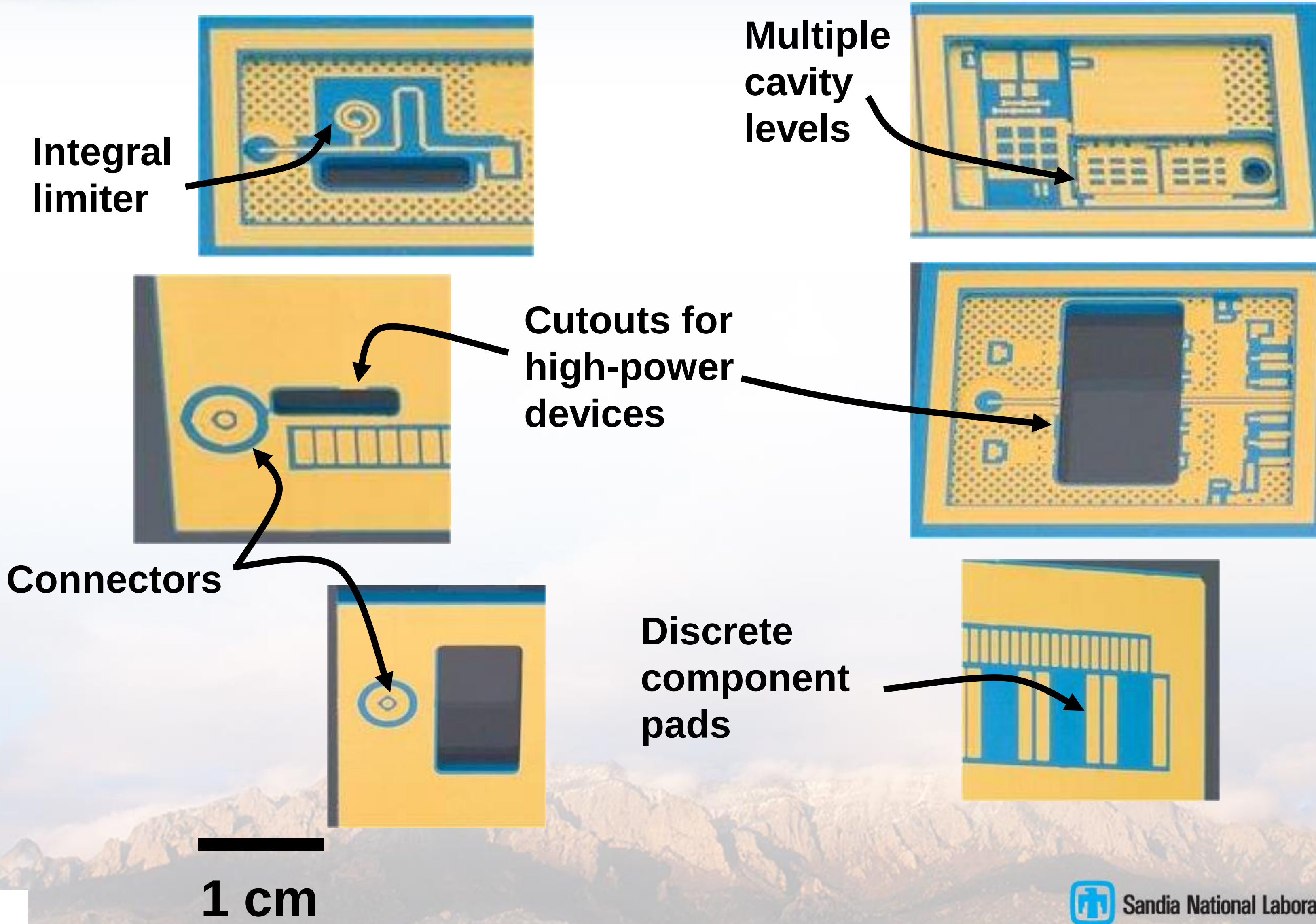
- Storage
- Conditioning
- Preparation
- Z-axis channels (vias)
- X-Y axis features (other axes)
- Collation
- Lamination
- CoFiring
- Post-Processing

LTCC Processing

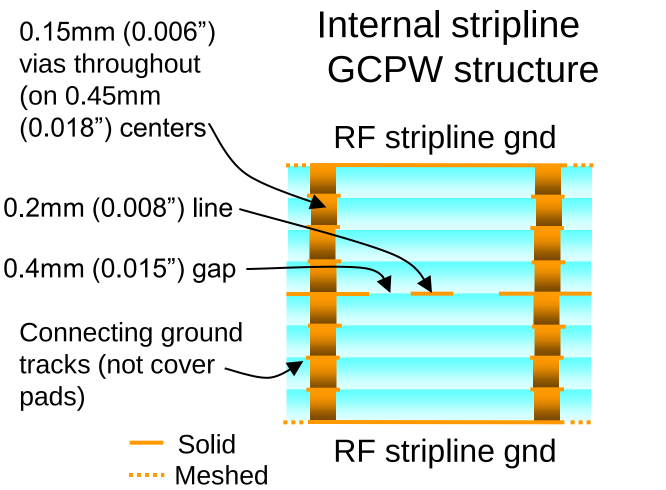


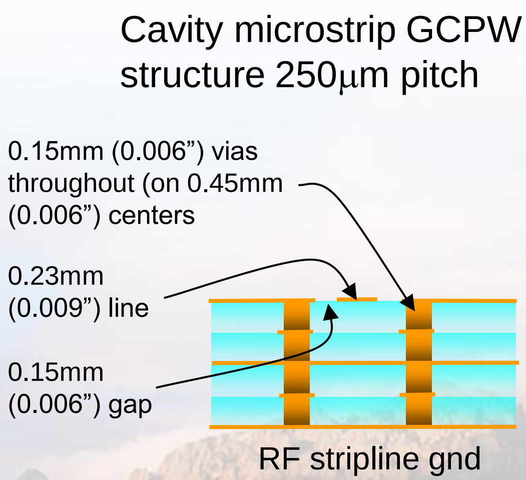
Courtesy: Pin Yang, D/2454, Sandia, pyang@sandia.gov

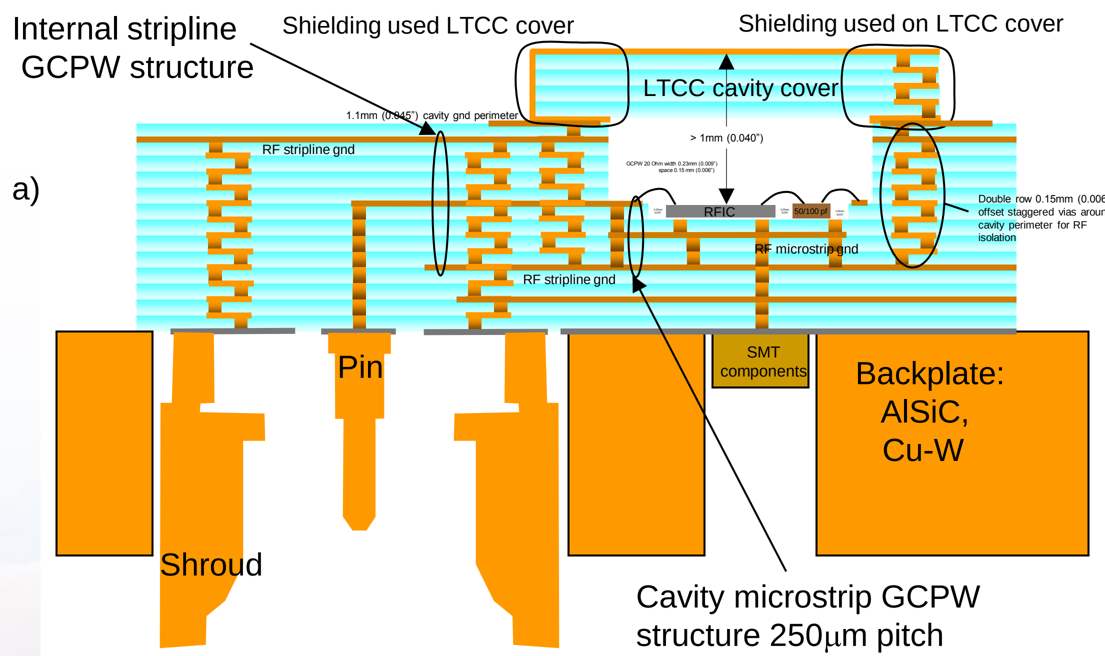
Planar MCM Features



MCM: Sectional View







Well-suited to RF features; stripline, microstrip.

Structuring

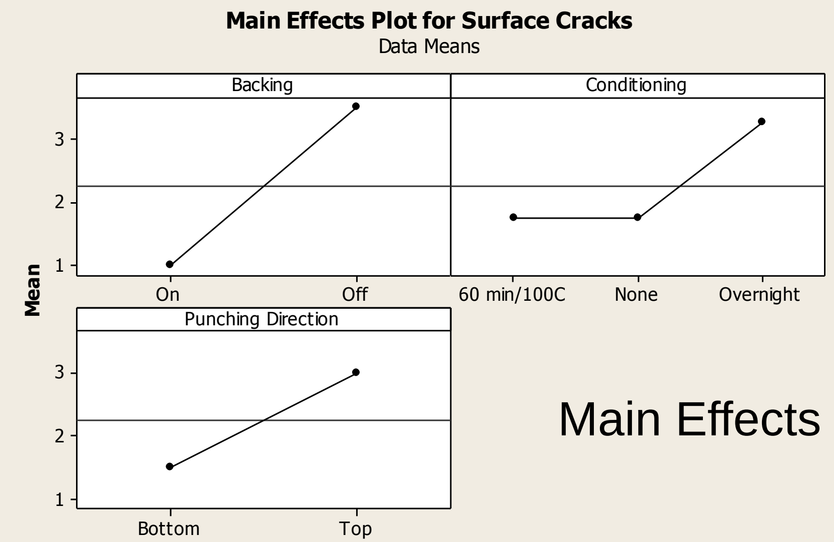
- Punching
- Milling (unfired or fired)
- Laser-ablation (unfired or fired)

Designed Experiment: Punching

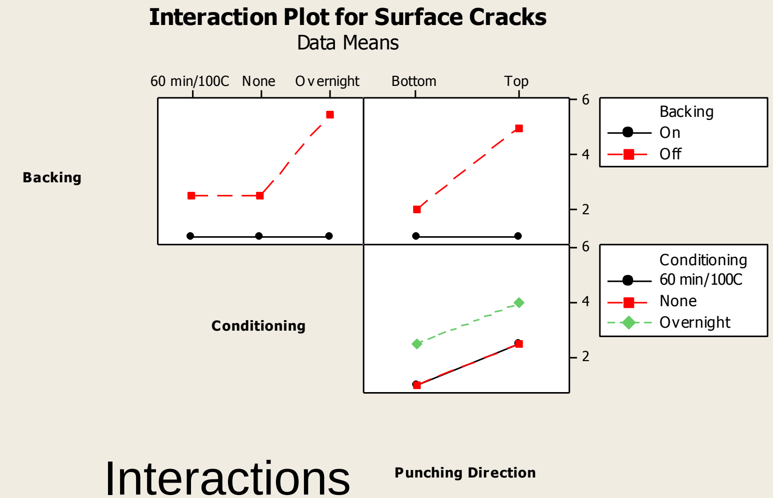
Experimental Matrix

Std Order	Run Order	Backing	Conditioning	Punch Direction	Surface Cracks	Bore Cracks	Perim. Surf. Def.	Ceramic Debris	Entrained Backing	Overall
1	1	On	1h@100°C	Bot	1	1	1	7	4	14
2	10	On	1h@100°C	Top	1	10	7	1	7	26
3	2	On	None	Bot	1	1	4	4	1	11
4	4	On	None	Top	1	1	7	1	1	11
5	6	On	16h@20°C	Bot	1	1	1	4	4	11
6	11	On	16h@20°C	Top	1	7	7	1	1	17
7	9	Off	1h@100°C	Bot	1	4	4	4	1	14
8	3	Off	1h@100°C	Top	4	4	7	4	1	20
9	5	Off	None	Bot	1	4	4	4	4	17
10	8	Off	None	Top	4	10	4	1	1	20
11	7	Off	16h@20°C	Bot	4	7	4	7	1	23
12	12	Off	16h@20°C	Top	7	10	10	1	1	29

With respect to Surface Cracking



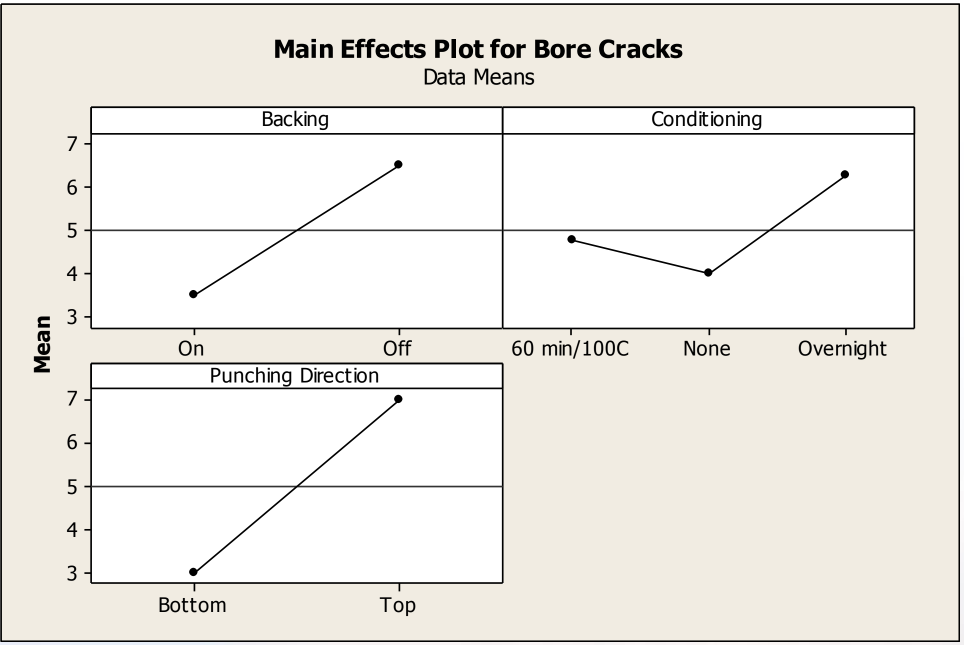
Main Effects

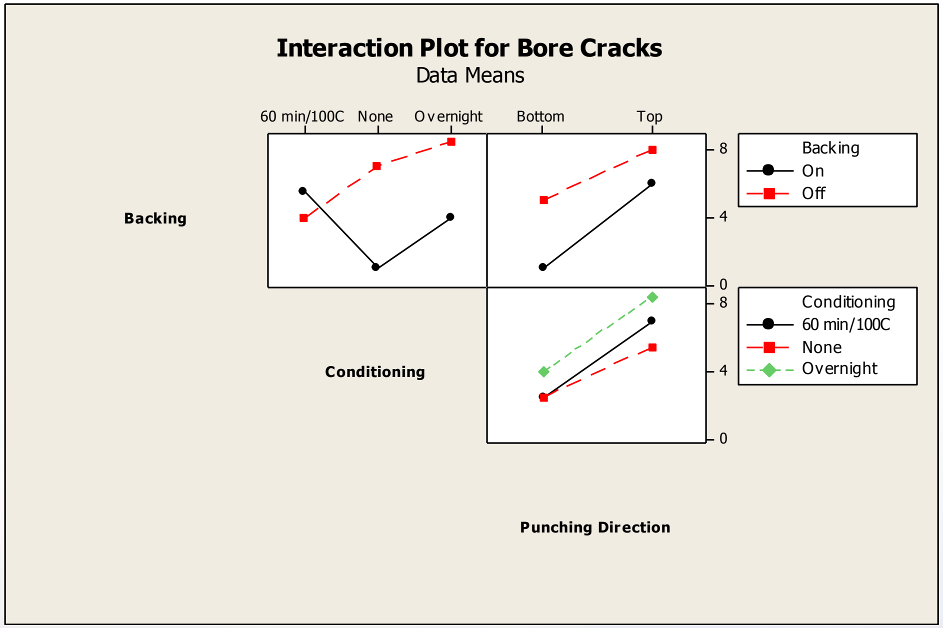


Interactions

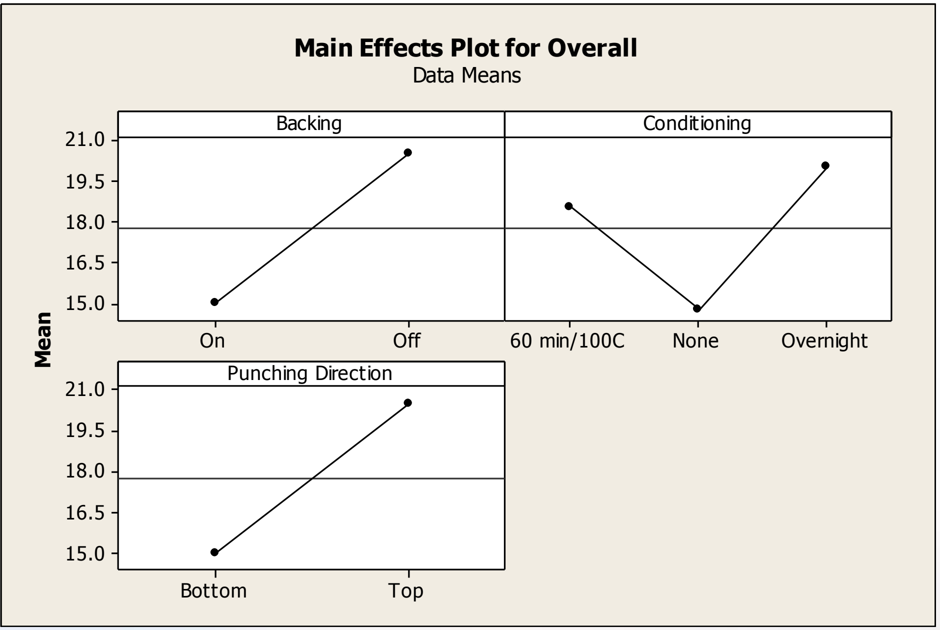
Designed Experiment: Punching

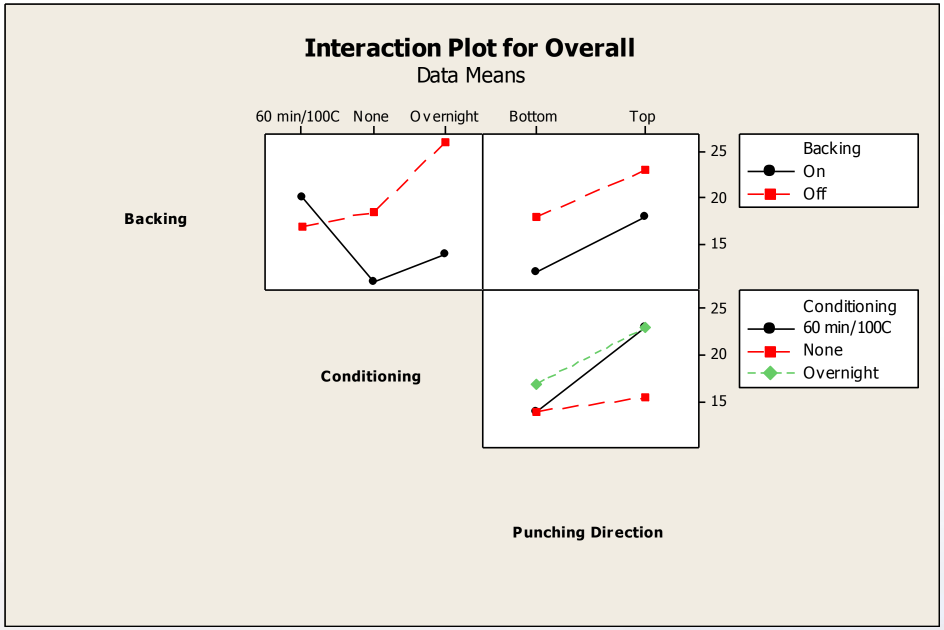
With respect to Bore Cracking





Overall Punching

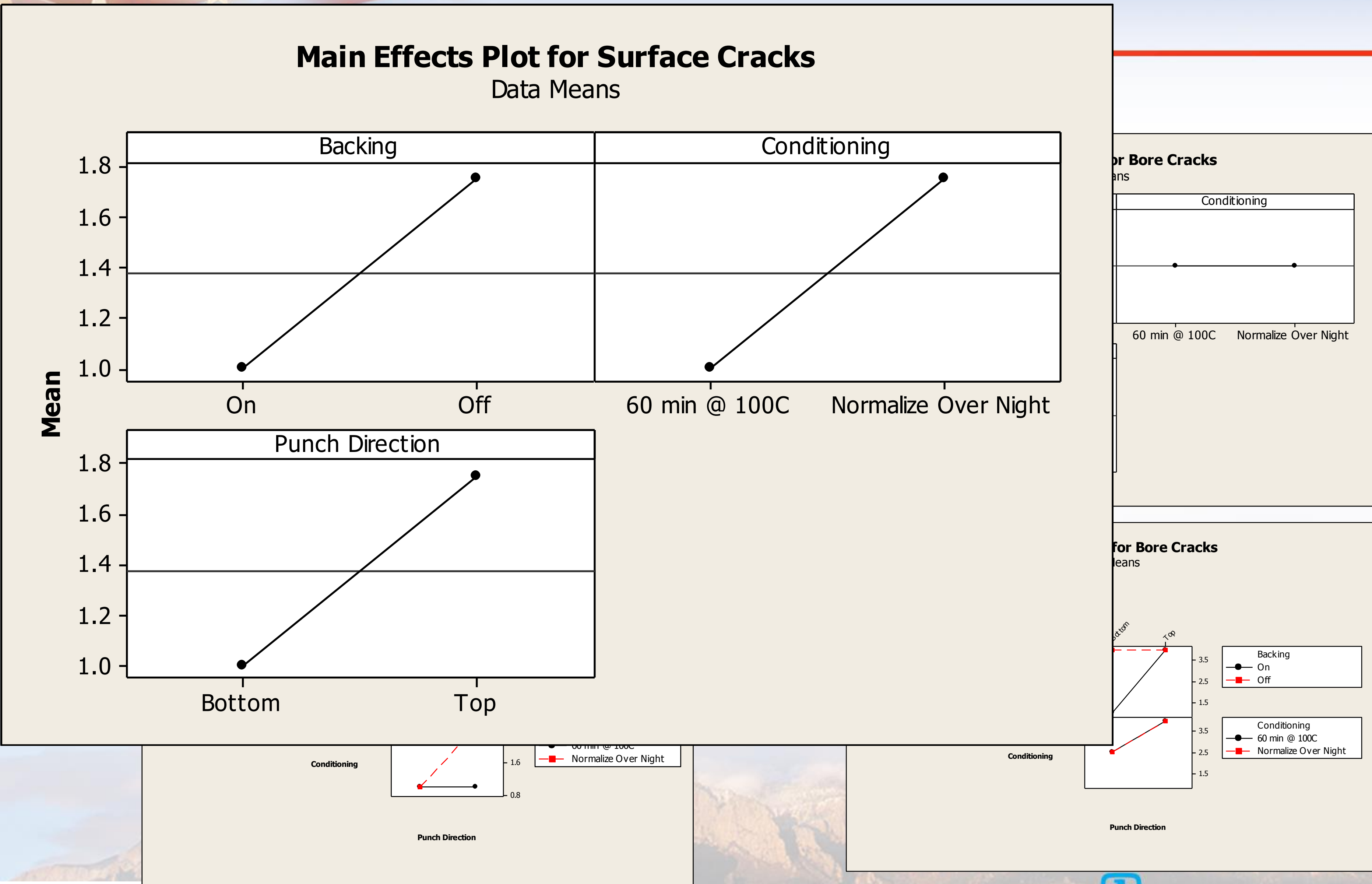




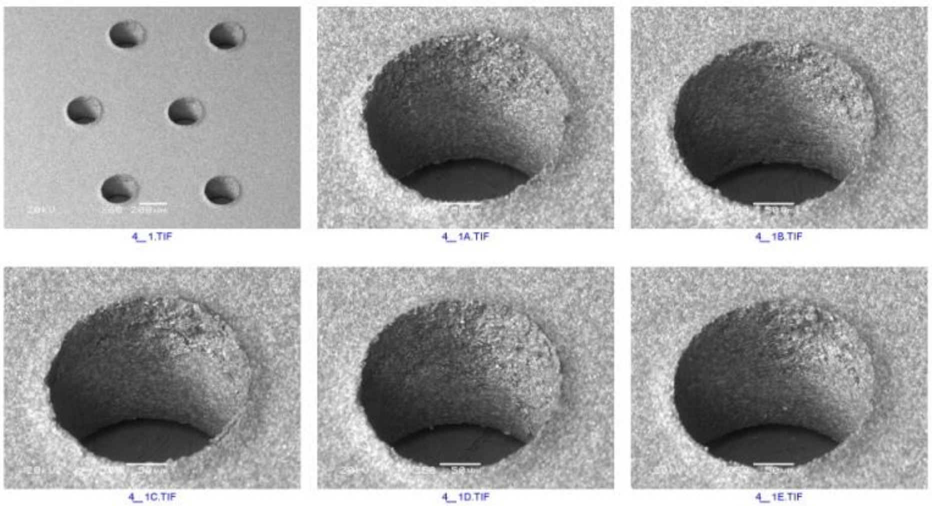
Designed Experiment: Punch #2

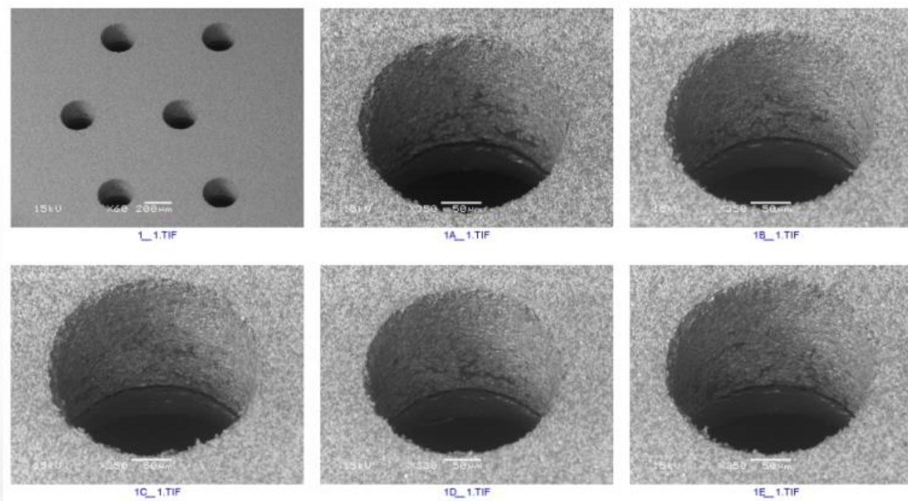
	Order	Back.	Cond.	Dir.	Surf.	Bore	Def	Debris
5	1	on	1h@100C	top	1	4	4	1
1	2	on	1h@100C	bottom	1	1	4	4
4	3	off	16h@20C	bottom	1	4	1	4
6	4	off	1h@100C	top	1	4	1	4
7	5	on	16h@20C	top	1	4	4	1
3	6	on	16h@20C	bottom	1	1	1	4
8	7	off	16h@20C	top	4	4	1	4
2	8	off	1h@100C	bottom	1	4	1	1

Main Effects and Interactions



Examples





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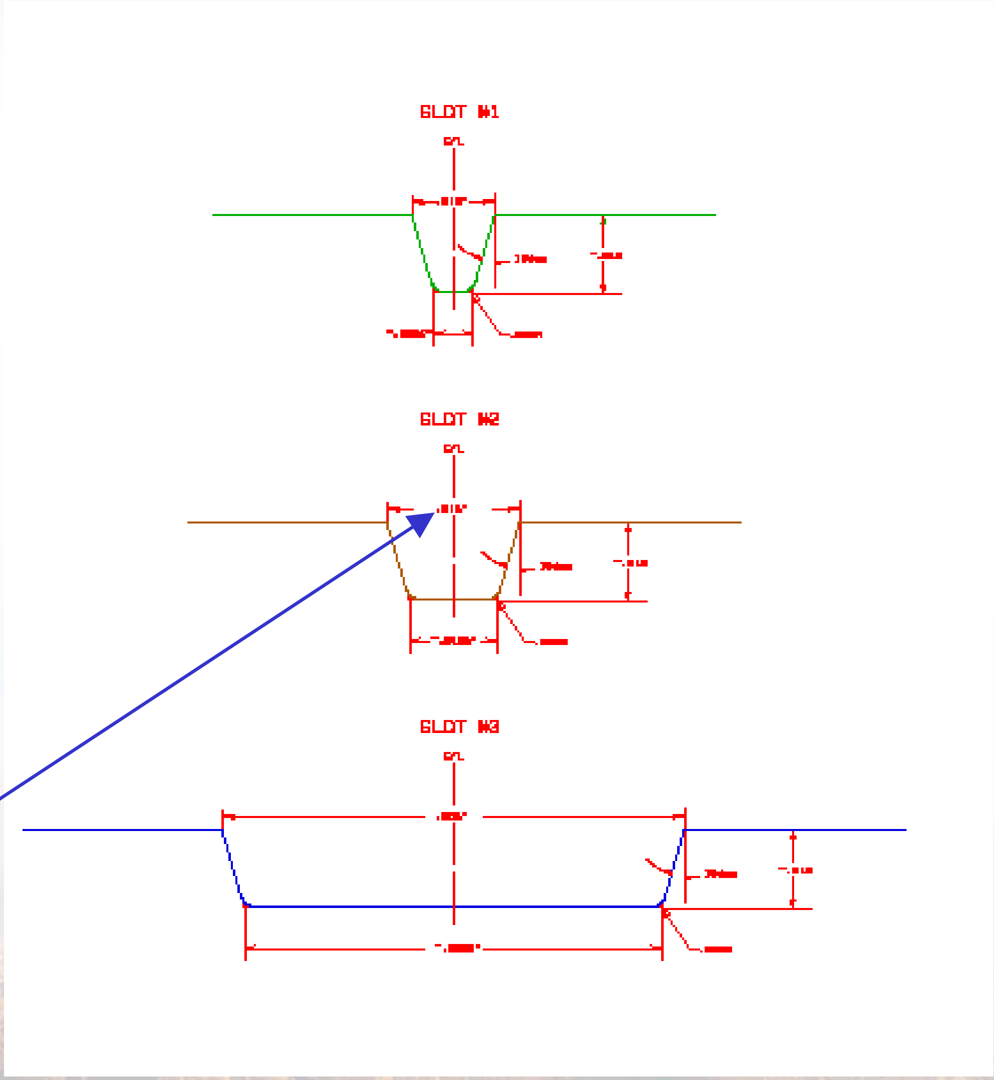
Milling

- Why Mill Unfired Tape?
  - The best mold insert possible!
    - Superior to
      - Metal, elastomer,
- Metallized cavity floors/walls
  - Sense-mode machining
- Drawbacks to Milling
  - Machining rates/material behavior
  - Dulling of tools from a ceramic/glass loaded polymer
  - Not much different than sandpaper

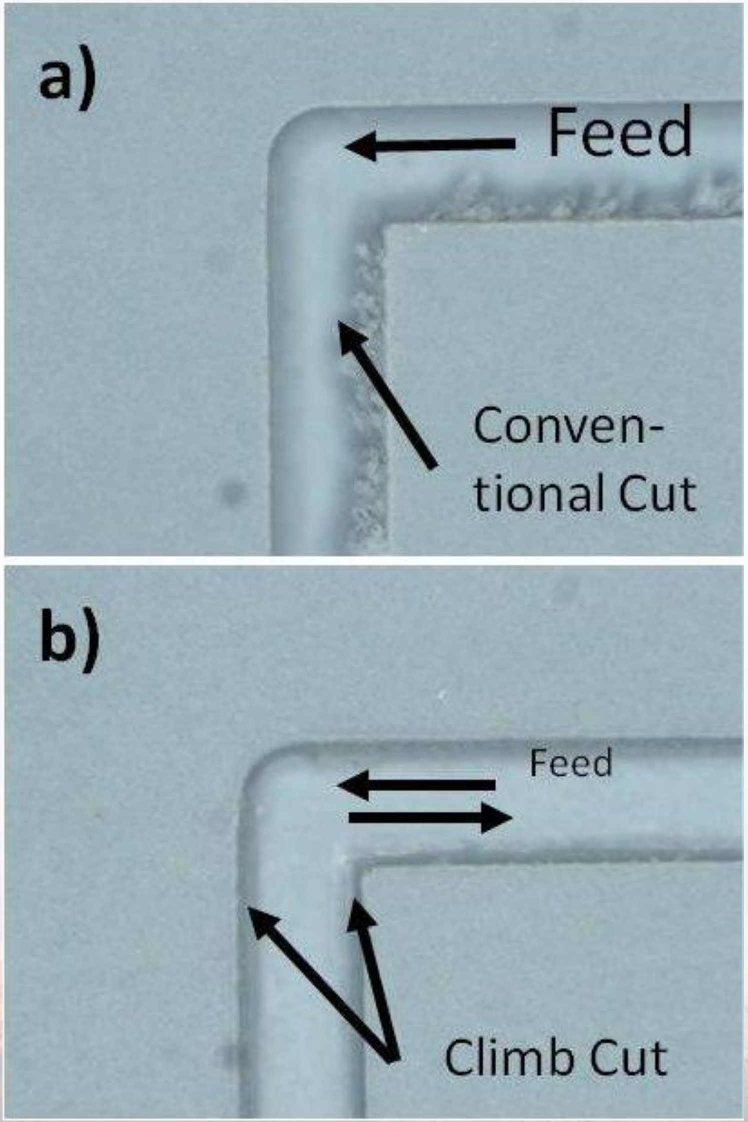
Schmoll Tooling

.010” Ø Single Flute End Mill

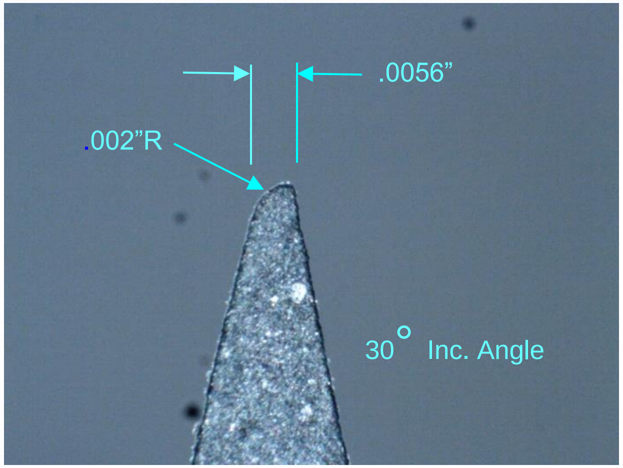
Pantograph Style Tool



Green Machining

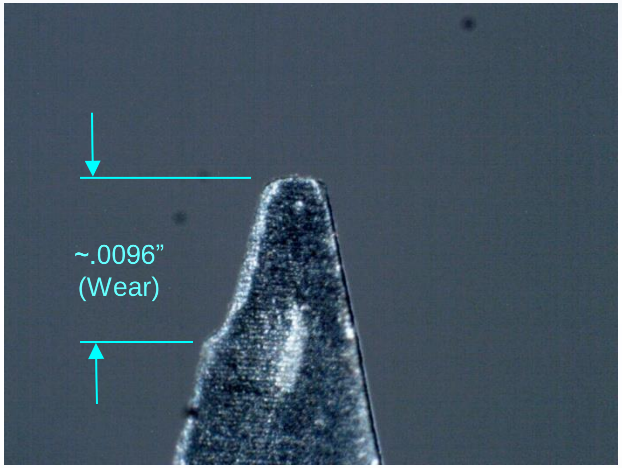


Tool Wear – Engraving Cutters

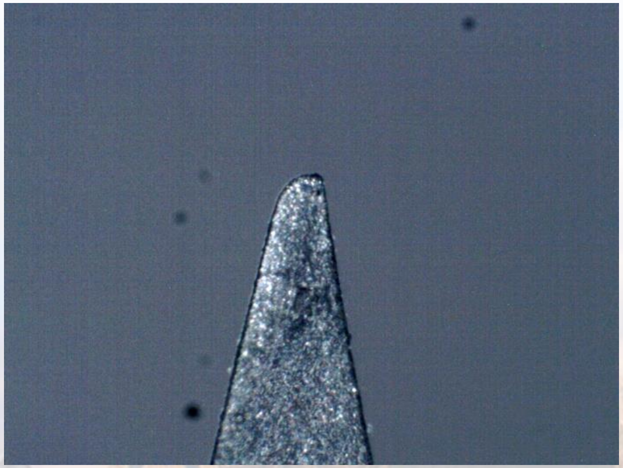


Unused CVD .010” Ø Pantograph Tool

(115x)



Worn non-Coated .010” Pantograph Tool after Milling ~400 linear inches



Used CVD COated Pantograph Tool after Milling ~2400 linear inches

- CVD Diamond Coating 8-10 micron thick Grown” . Directly on Micro-Grain Carbide Tool
- Hardness (88-98 GPa) & COF (.05 - .3) = Diamond
- Provides 50x Cutter Life
- Non-Conductive - Does Not Support Conductive . (Sensing) Depth Control
- Investigate: Boron Ion Doping of Diamond Coating Cryogenic Treatment (Tempering)

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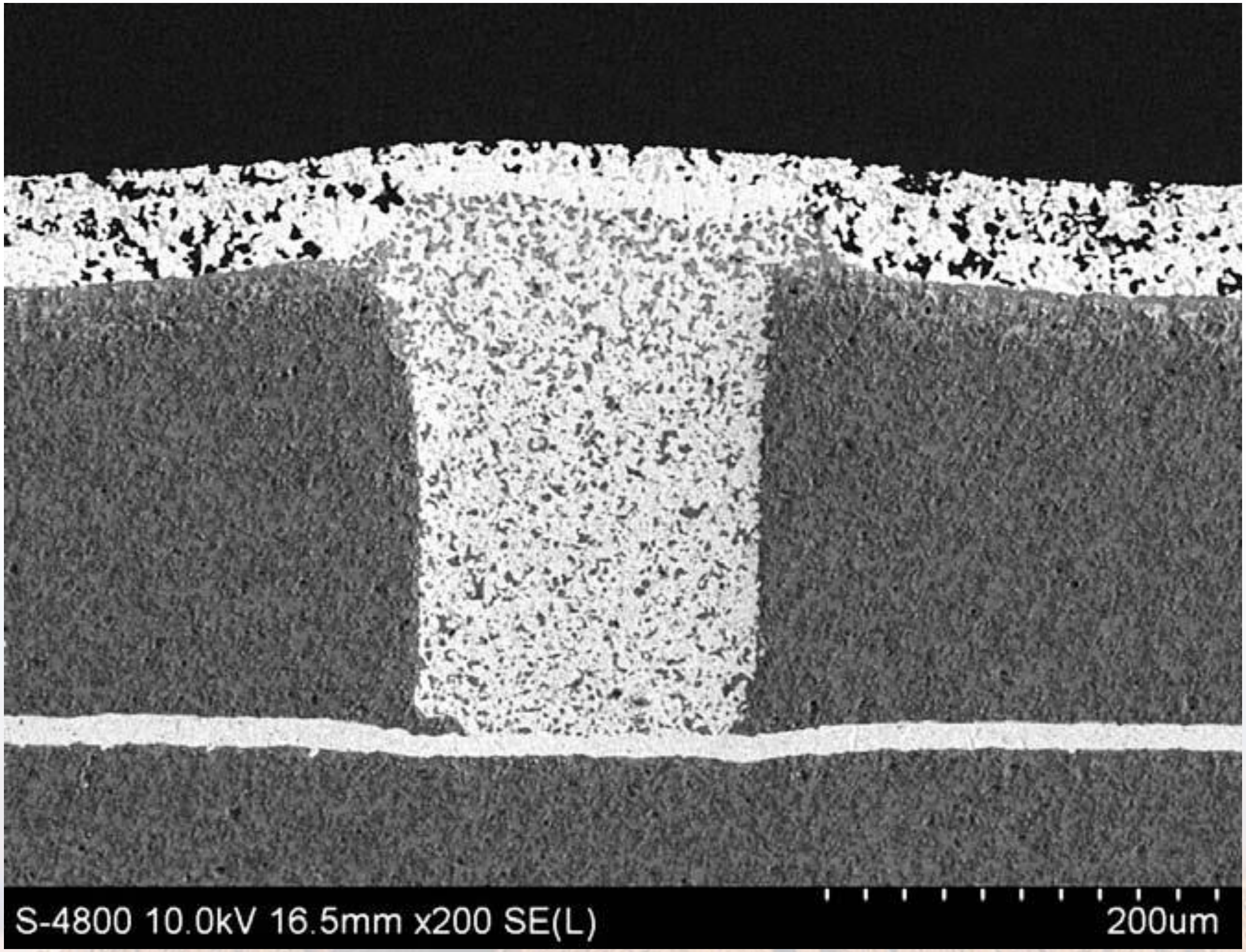
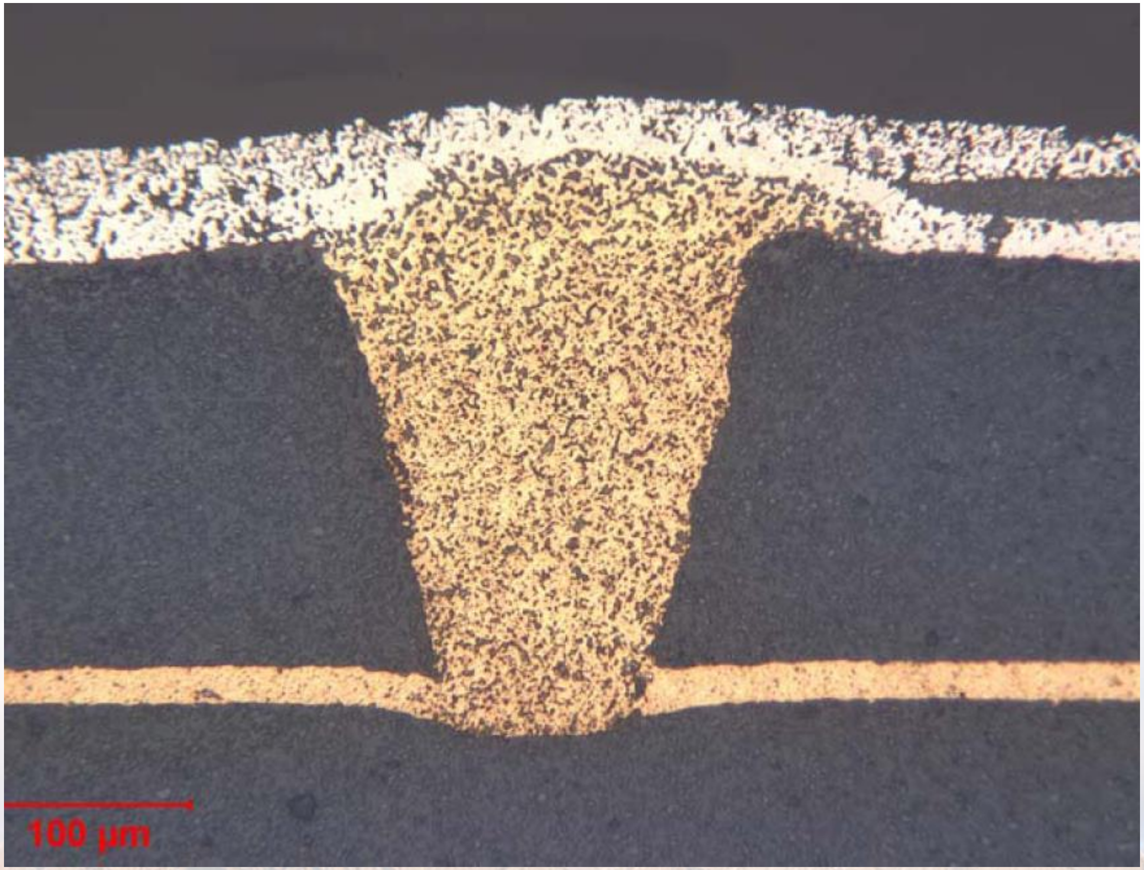
Cross Section: Mill to GP



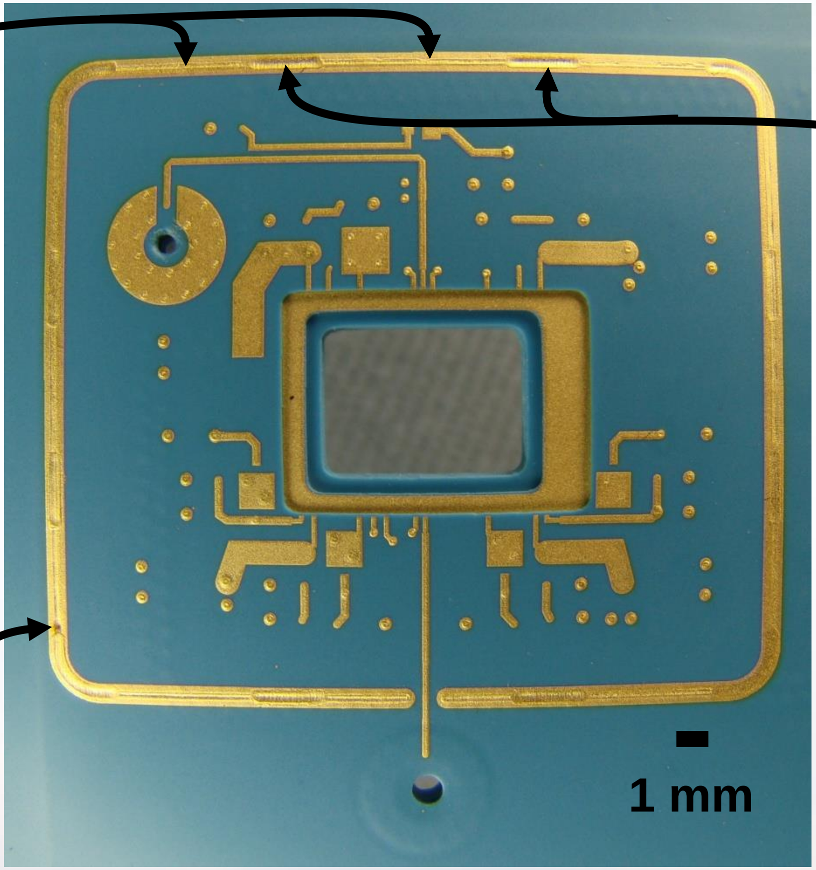
Cross Section: Angled Walls



Milling Tool

Fired Solid Wall
(eight layer test fixture)

Primary punching of top layer



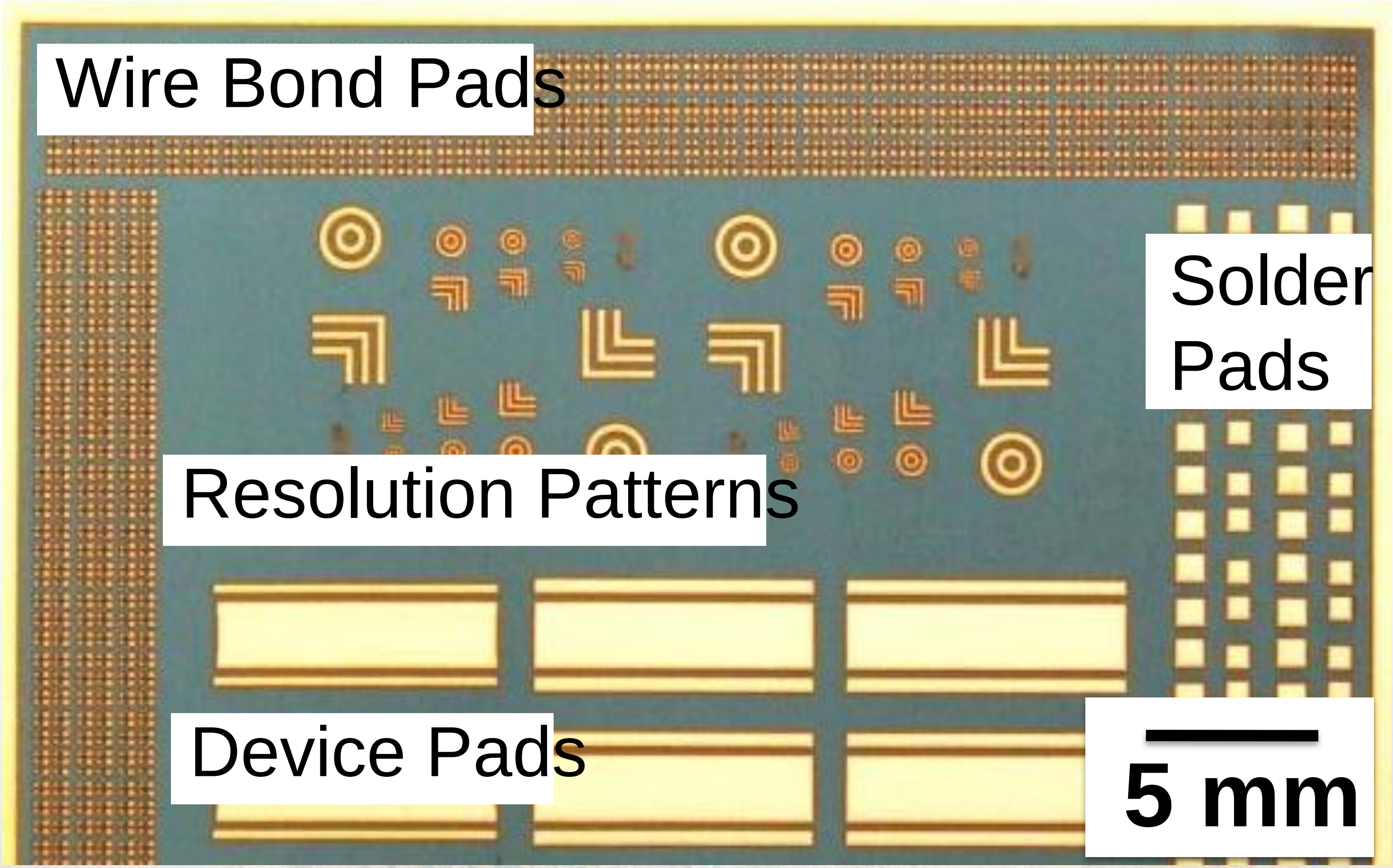
Secondary punching of top two layers

Defect: missing via-fill material

Solid wall covered by cofired barrier layer; No cracks.

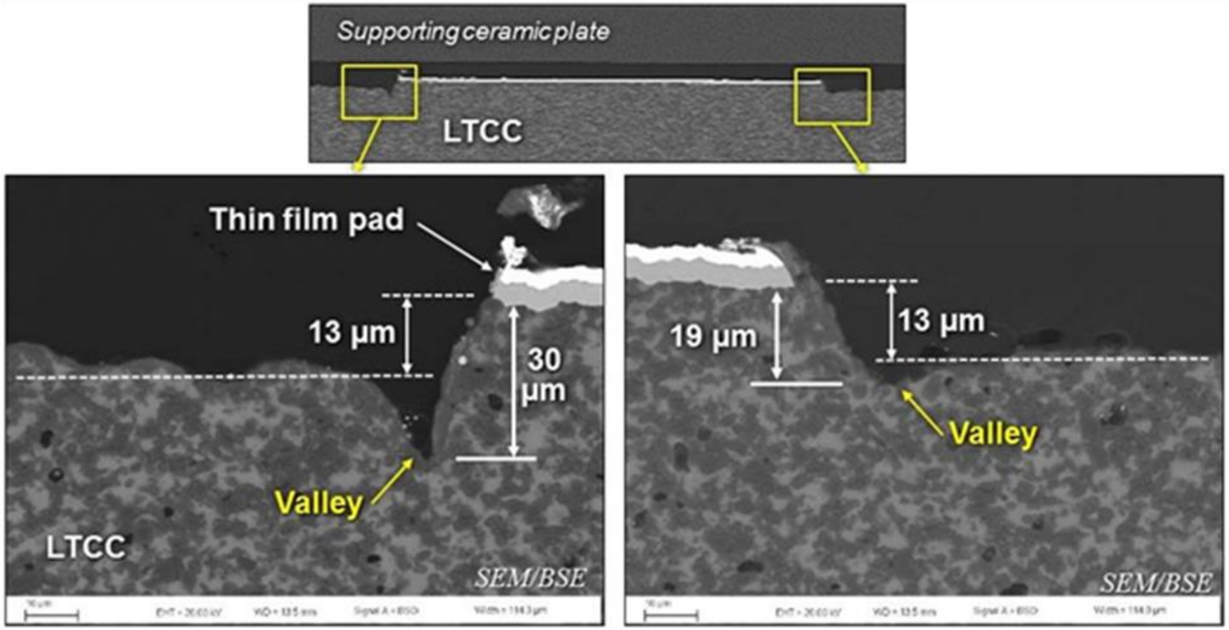
Applications of Laser Etching

- Definition of conventional circuitry
- Minimal etching approach
- Definition of unfired circuitry
- Depth engraving to a buried ground plane



- LPKF U1 UV Laser
- SEM/SE and BSE images follow

Phase Three



U3 process parameters:

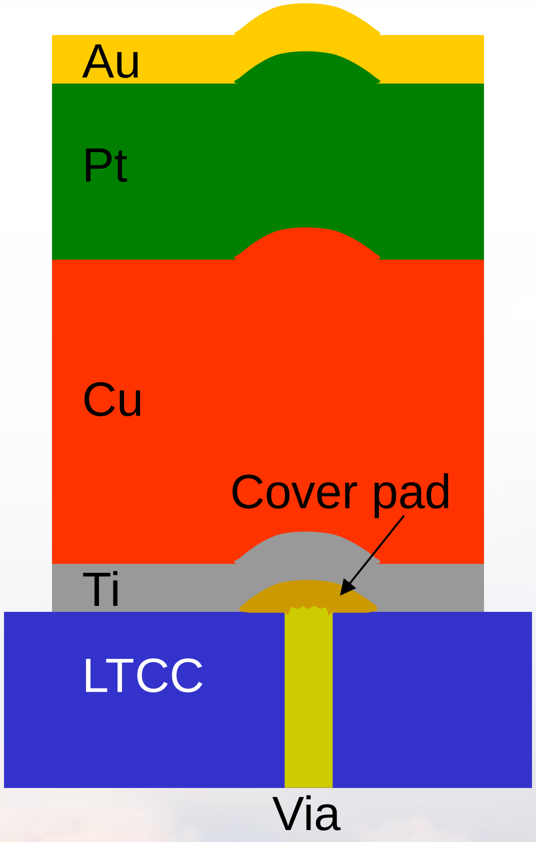
- 6.67 watts laser power
- 15um beam spot size
- 12um beam pulse width
- 250 mm/s travel speed
- One hatch/contour pattern

The Bane of LTCC

- Shrinkage – not so bad
- Shrinkage tolerance is the problem!
- Design rules
- Fabrication practices
- Production quantities

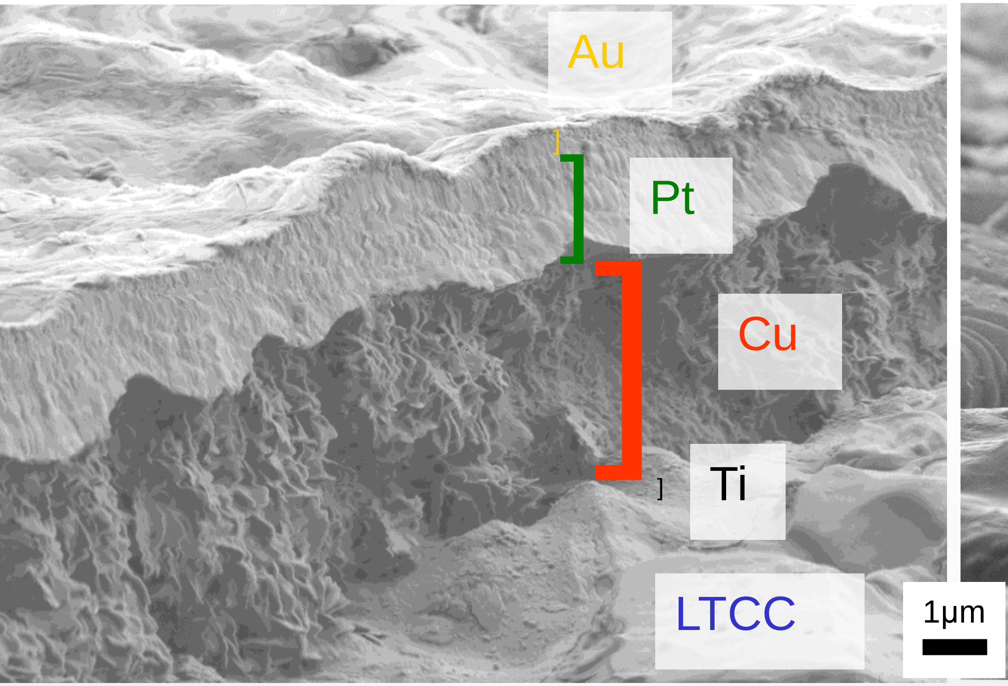
Thin Film Multilayer

- Goal: single thin film material that satisfies all requirements:
  - Solder connectivity;
  - Wire bond connectivity;
  - RF conductivity;
  - Adhesion.
- Solution: Ti/Cu/Pt/Au multilayer (total 6.45μm):
  - 0.2μm Ti ⇒ adhesion;
  - 4.0μm Cu ⇒ RF conductivity, pure metal; greater than 2 times skin depth at single digit GHz;
  - 2.0μm Pt ⇒ robust solder connectivity; barrier for cross-diffusion of Cu and Au or Sn;
  - 0.25μm Au ⇒ wire bond connectivity; wetting for solder connectivity; keeps layers inert over time;
  - Thick film cover pads over vias for topography issues;

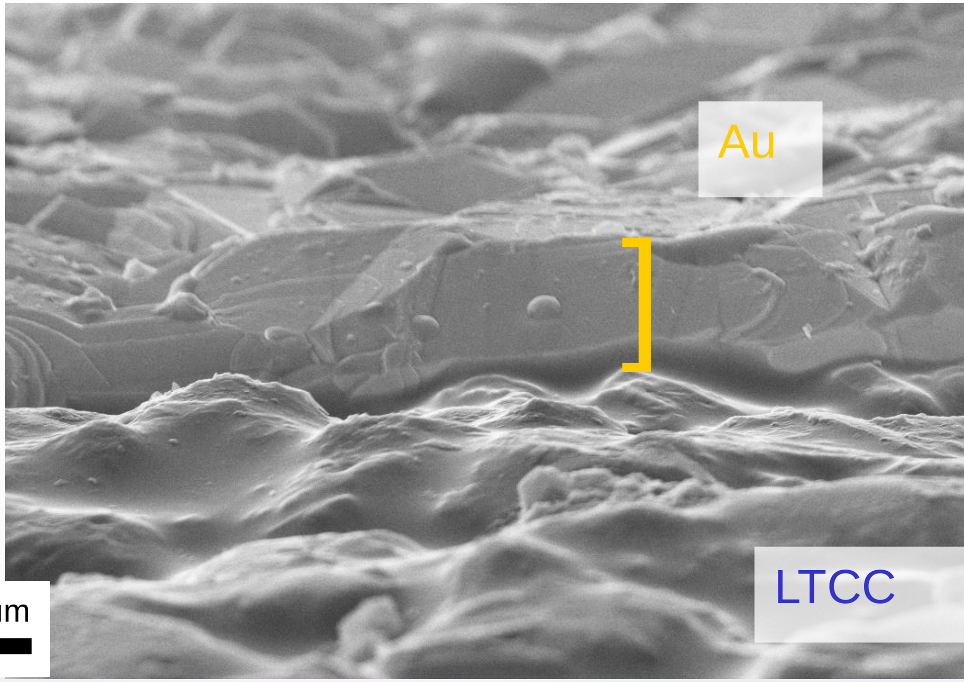


Thin Film Cross Section (not to scale)

Thin Film vs. Thick Film



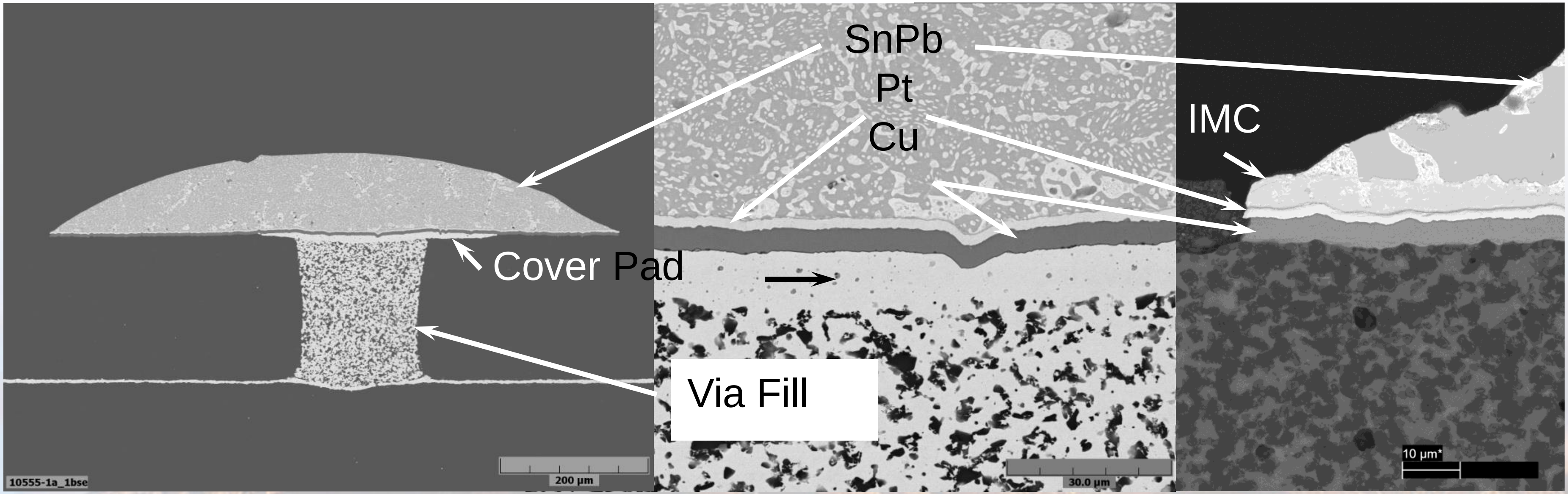
Thin film line edge



Thick film line edge

SnPb Solder Connectivity

- Thin film surface wets extremely well.
- SnPb dissolves Au, forms intermetallic layer (IMC) with Pt.
- Solder joints exhibit excellent strength:
  - Shear test:
    - 0402 from 4.2lbs as soldered to 3.2lbs after aging at 170°C for 25 days;
    - 0603 from 6.0lbs as soldered to 4.6lbs after aging at 170°C for 25 days;
  - Sebastian-like pull test:
    - Soldering at 214°C: 35lbs after 15s up to 37lbs after 120s;
    - Soldering at 290°C: 27lbs after 15s down to 22lbs after 120s;
    - Approximately 24lbs constant after 1 to 15 5s solder-dipping cycles at 290°C.



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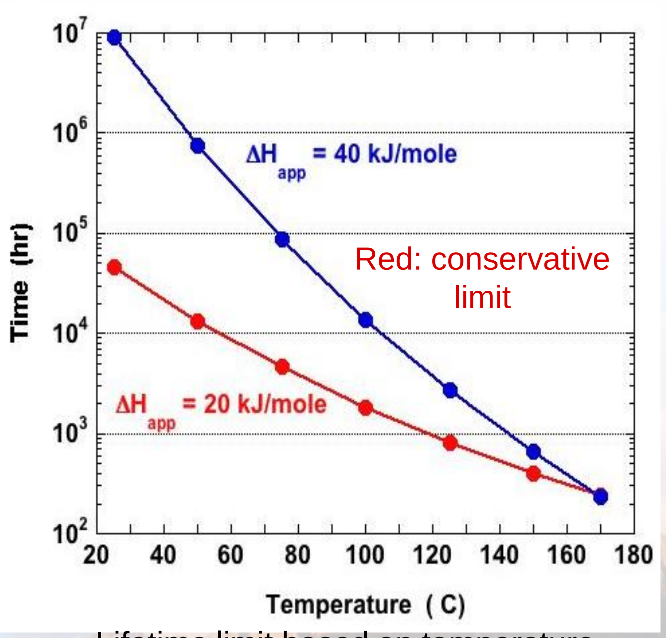
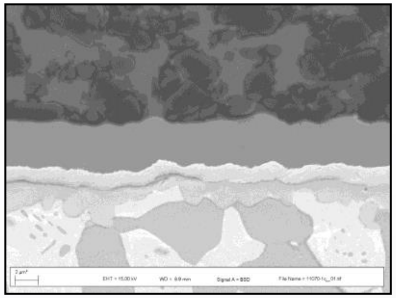
SnPb Solder Solid State Aging

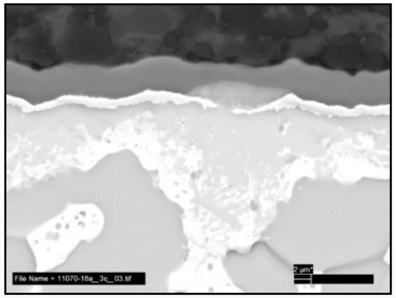
- Temperatures between 55°C and 170°C.
- Times between 2 and 25 days (longer times still under evaluation).
- Without solder: thin film layer thicknesses constant.
- With solder:
  - Breakdown of thin film structure at 170°C between 10 and 25 days;
  - Adhesion not lost after 25 days at 170°C;
  - Assume aging limit is 10 days at 170°C.

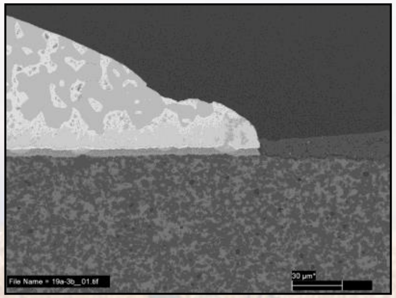
⇓

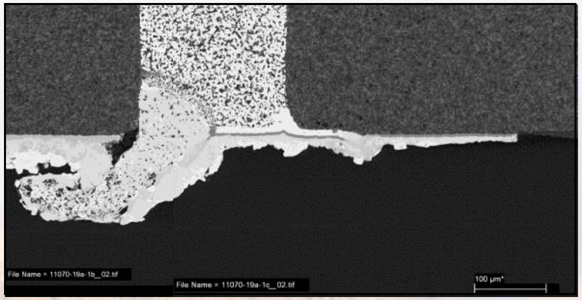


Lifetime limit based on temperature


135°C, 10 days
large solder amount


170°C, 10 days
large solder amount


170°C, 25 days, edge,
small solder amount


170°C, 25 days, large solder amount

Kansas City Plant National Security Asset

Sandia National Laboratories

Benefits from Thin Film on LTCC

- Increased reliability.
- Robust in assembly.
- Versatile in assembly, multifunctional single metallization for soldering and wire bonding.
- Superior reworkability, hand soldering.
- Superior electrical and RF performance.
- Finer Lines and Spaces, smaller geometry.
- Enables higher frequencies.
- Positioning for thin film passives (e.g. Band Pass Filter (BPF), capacitors).
- Open to further development, e.g.:
  - AuSn soldering;
  - Fully integrated thin film passives.

Bulk Inclusions

- EMI shielding structures
- Heat sinks
- Filters
- Familiar problem: What metamaterial achieves primary purpose while remaining integral to structure?
  - Adequate thermal conductivity with proper CTE?
  - Cofirable
  - Assembly (post-processing)

Adaptive Techniques

- Laser direct imaging
- Laser ablation
- Additive manufacturing-direct write
- Relaxed design rules

Summary

- Structuring techniques continue to progress.
- Shrinkage tolerance control is paramount.
- Thin films are effective, if not conventional

Thank you for your attention