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Laser Ablation of Thin Films on LTCC

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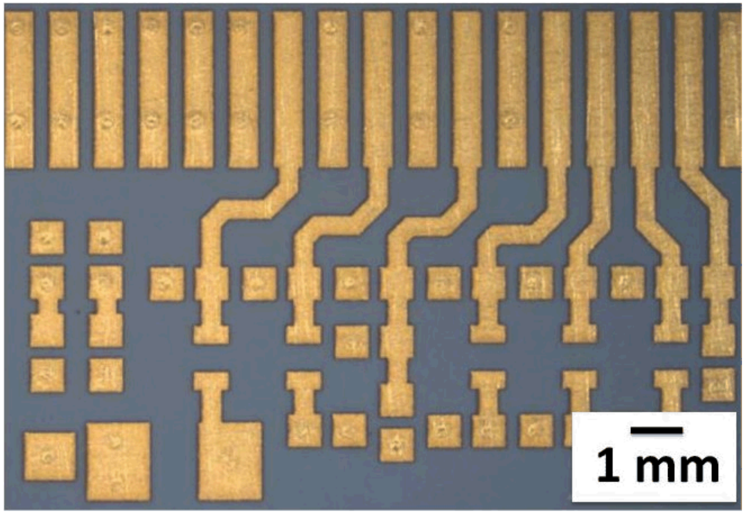
Background

- **LTCC**
  - Thick film is conventional
  - Thin film treated here
  - Ti; 2000 Å, Cu; 4 µm, Pt; 2 µm, Au 3750 Å
    - Multifunctional: Solder, wirebond, RF conductivity
  - Ion-milled fabrication
  - Also: Unfired feature definition
- **LASER**
  - UV laser (355nm diode-pumped, tripled Nd:YAG)
  - Parameters--laser power, pulse frequency, travel speed, and configuration definition for the hatch/contour modes

Requirements

- Preserve solderability
  - Edge effects
- Wire bondability
  - Contamination by redeposition of Ti/Cu/Pt/Au metal stack
- Preserve adhesion
- Preserve LTCC mechanical integrity
  -Microcracking
- Preserve metal stack integrity
- Improve yield
  - 'Right-sizing' the conductor pattern to as-fired LTCC
- Increase throughput
- Reduce flow time
- Reduce cost



Process Comparison

ION Milling

- High equipment cost
- Batch process, parallel
- Requires photolithography (equipment and effort)
  - Glass masks
  - Photoresist
  - Mask aligner
  - Develop
  - Strip
- Automated loading

Laser Ablation

- More affordable equipment (4:1)
- Batch process, serial
- Requires ‘cleaning’
- Larger ‘heat-affected-zone’
- Artifacts
  - Deep cut at line edges
  - Other edge effects
  - Secondary cracking in open areas
- Manual loading
- Agile programming

Applications of Laser Etching

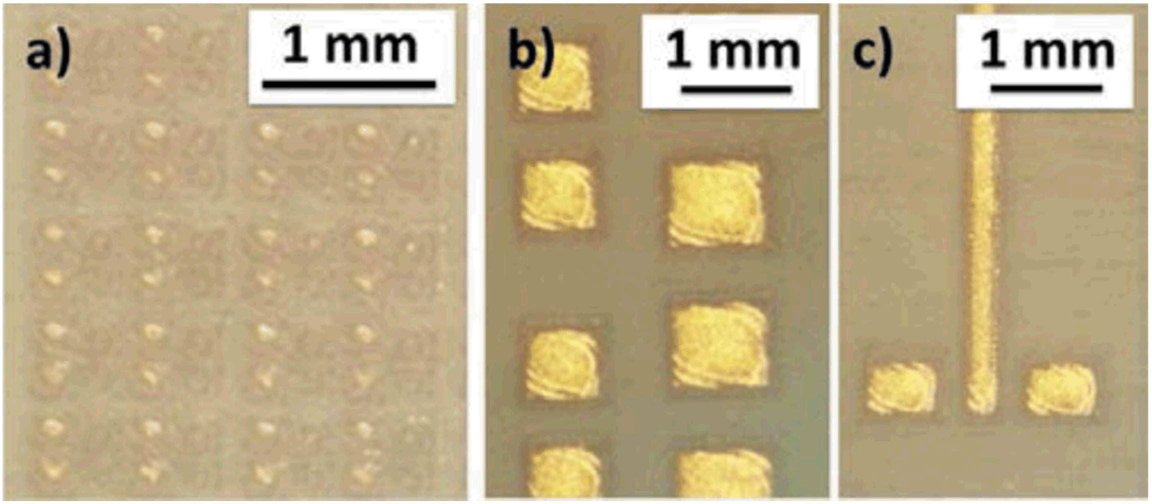
- Definition of conventional circuitry
- Minimal etching approach
- Definition of unfired circuitry
- Depth engraving to a buried ground plane

DOE Summary

- 355 nm diode-pumped, tripled Nd:YAG UV Laser
- Thin film stack:
  - 0.20 um Ti
  - 4.0 um Cu
  - 2.0 um Pt
  - 0.38 um Au
- Hatch – parallel raster, single direction
- Cross-hatch – two hatch cuts in orthogonal directions
- Analysis (top view, cross section)
  - Optical photos
  - SEM
    a) Secondary electron
    b) Back scattered electron - EDX maps of elements

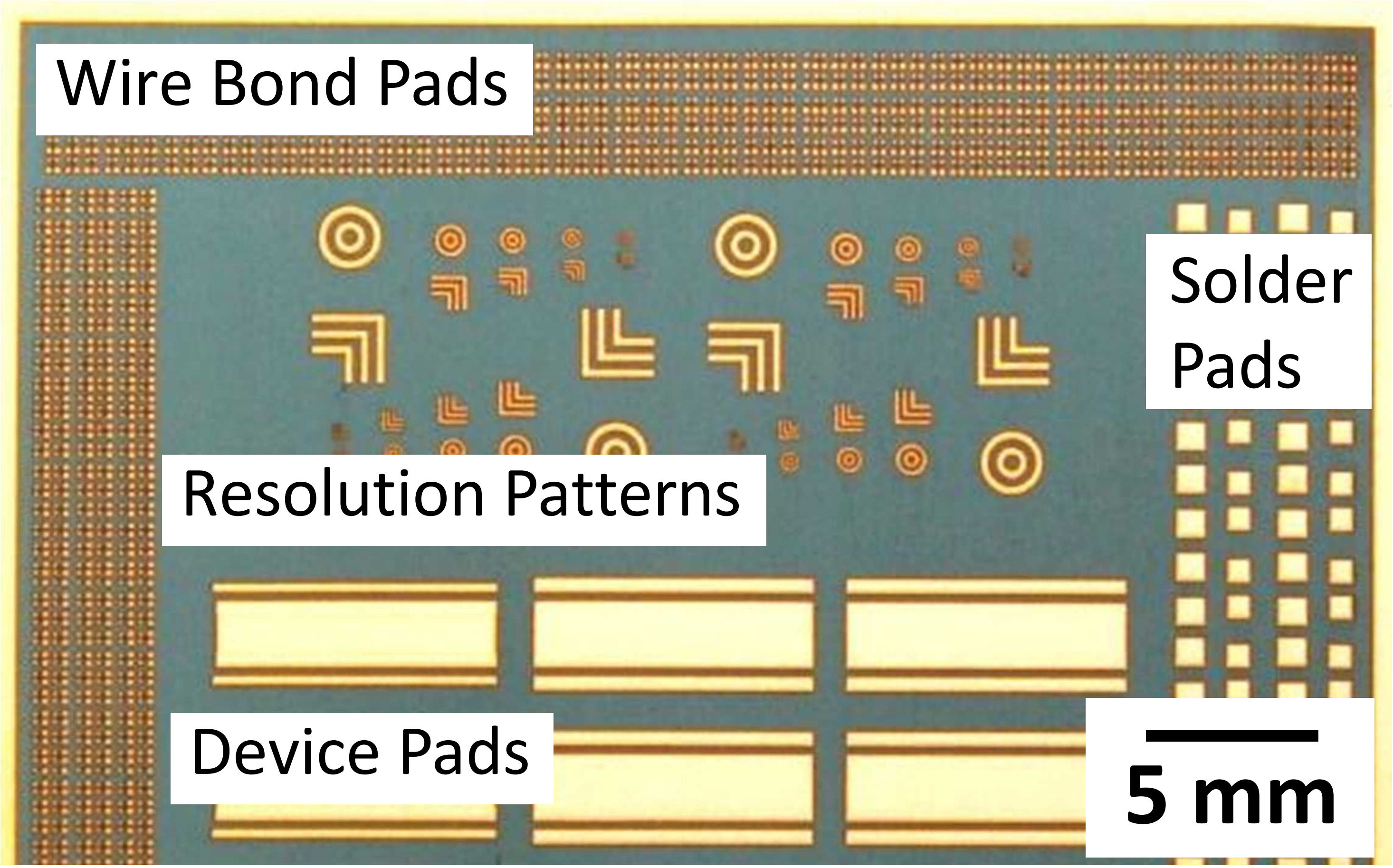
Experimental Phase	1	2	3	4
Laser Model	U	U	U3	U3
Power (W)	2.5 - 3.0	2.5 - 3.0	6.7	1.1 / 0.5
Frequency (kHz)	150	150	150	75
beam spot size (µm)	20	20	15	14
beam pulse (µm)	15	15	12	7
Travel Speed (mm/sec)	75	100	100 - 250	600
Air Knife	NO	NO	NO	YES
Contour Reps	2	1	1	0 - 2
Hatch Reps	2	1	1	1-6*
			* Cross-hatch used	

Phased Development Approach: Phase One



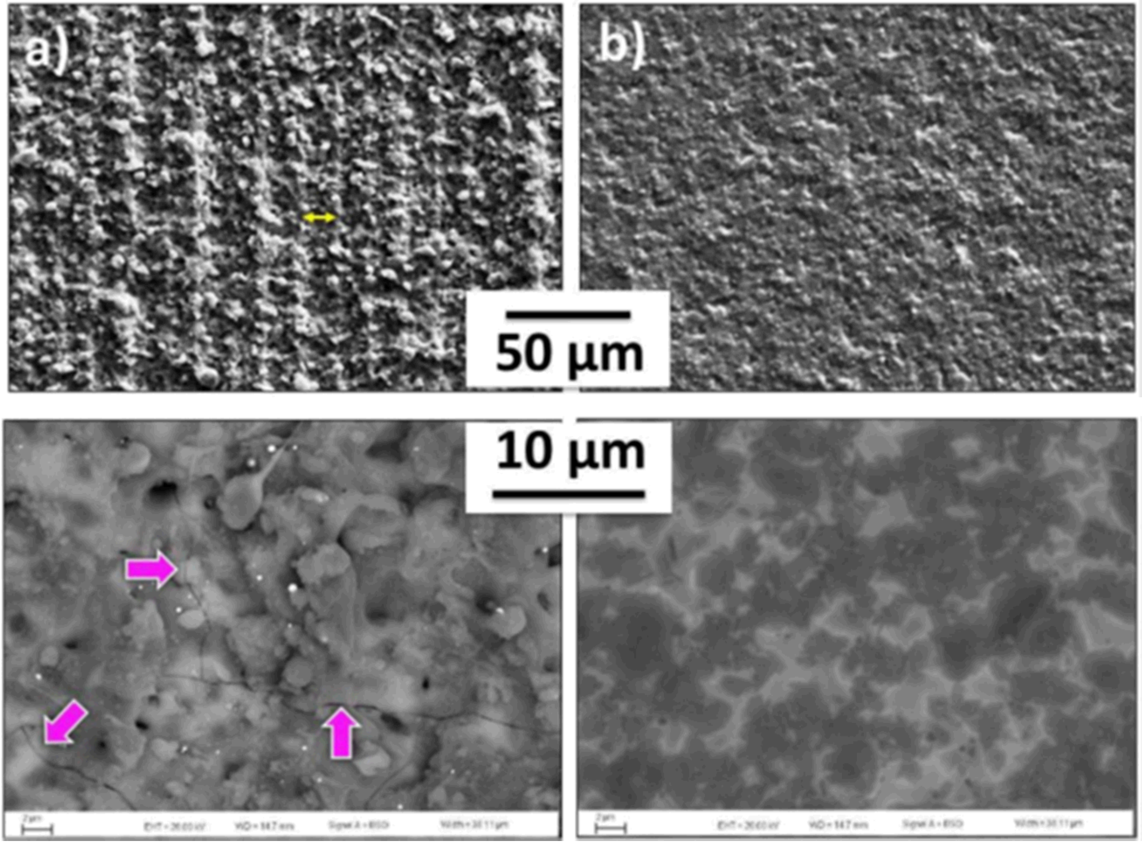
- LPKF U uv laser
- Square 150 µm and 200 µm wirebond pads
- Square 0.86 mm and 0.97 mm solder pads
- S- band (2- 4 GHz) transmission lines
- Wirebond pads not resolved
- Open areas, excessive loss of substrate material
- Wire bondability and solderability not tested

Phase Two



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

Phase Two Continued

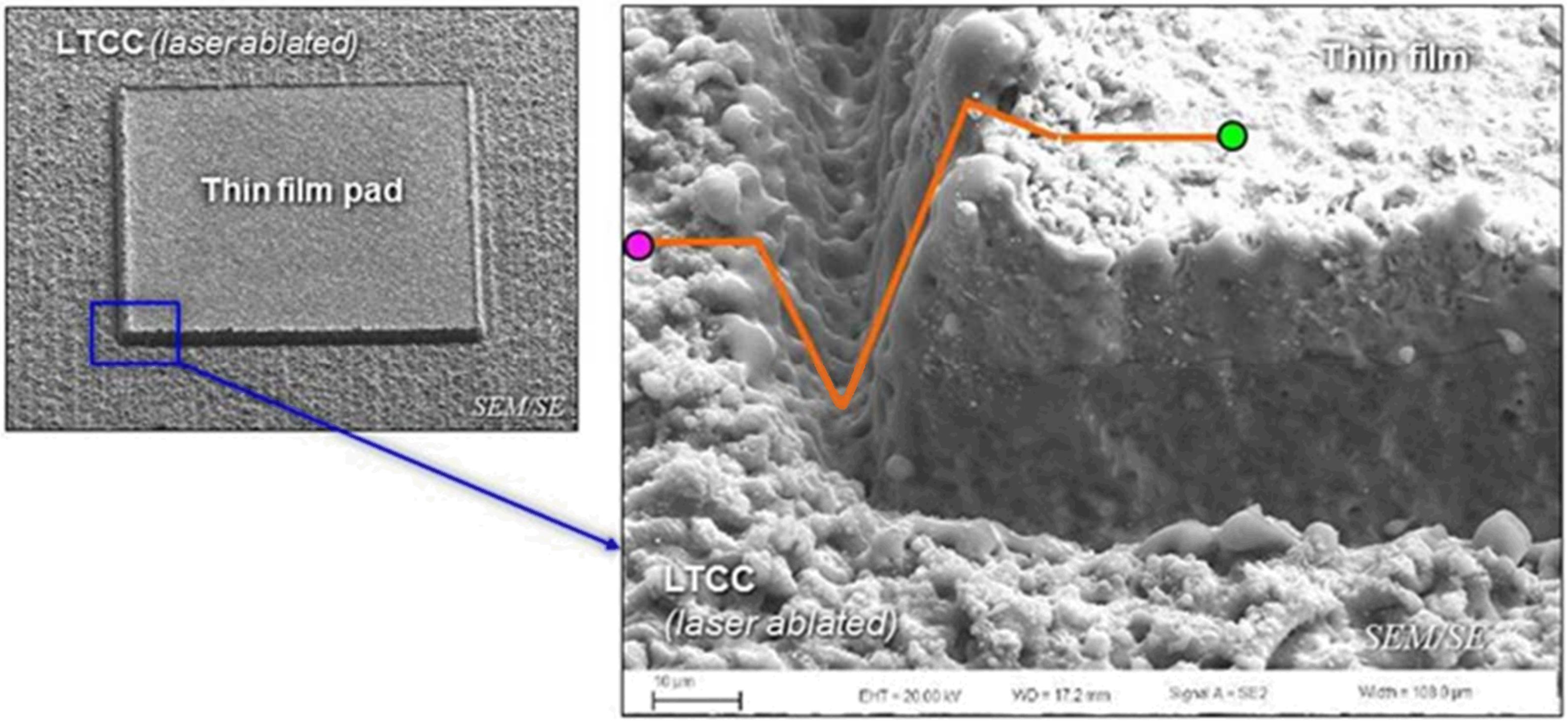


- Hatch cut, single orientation (top-to-bottom)
- Grooves, 10-15 µm wide (yellow arrow)

- Redistribution of the SiO2 and Al2O3 phases.
- Increased porosity
- Rapid melting/resolidification of the LTCC surface (rounded particles).
- Surface cracks (magenta arrows)

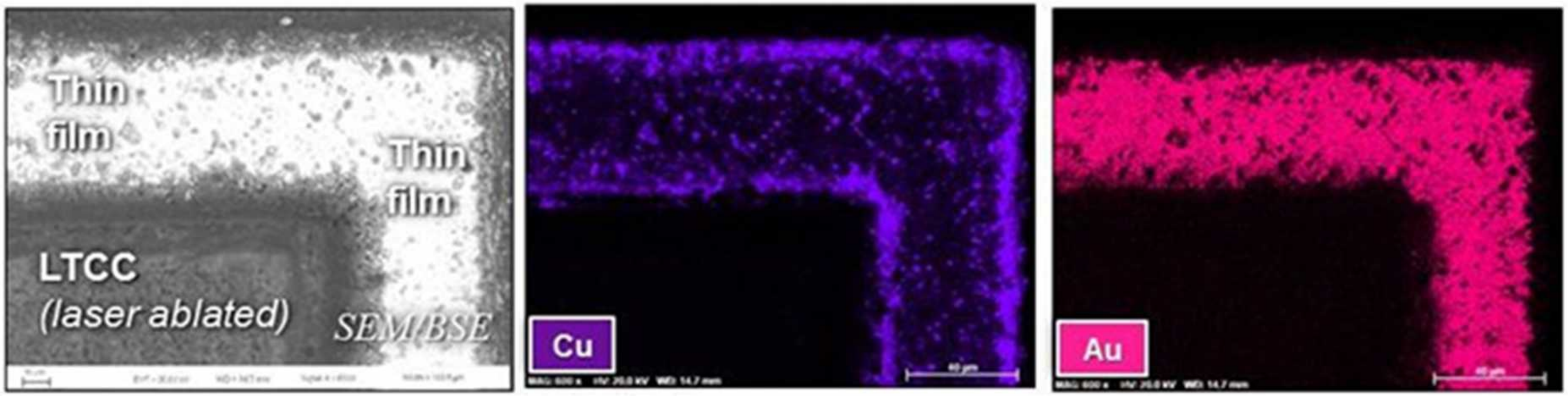
- Can next-assembly environmental shock-and-vibration conditions cause catastrophic failures ?

Phase Two Continued



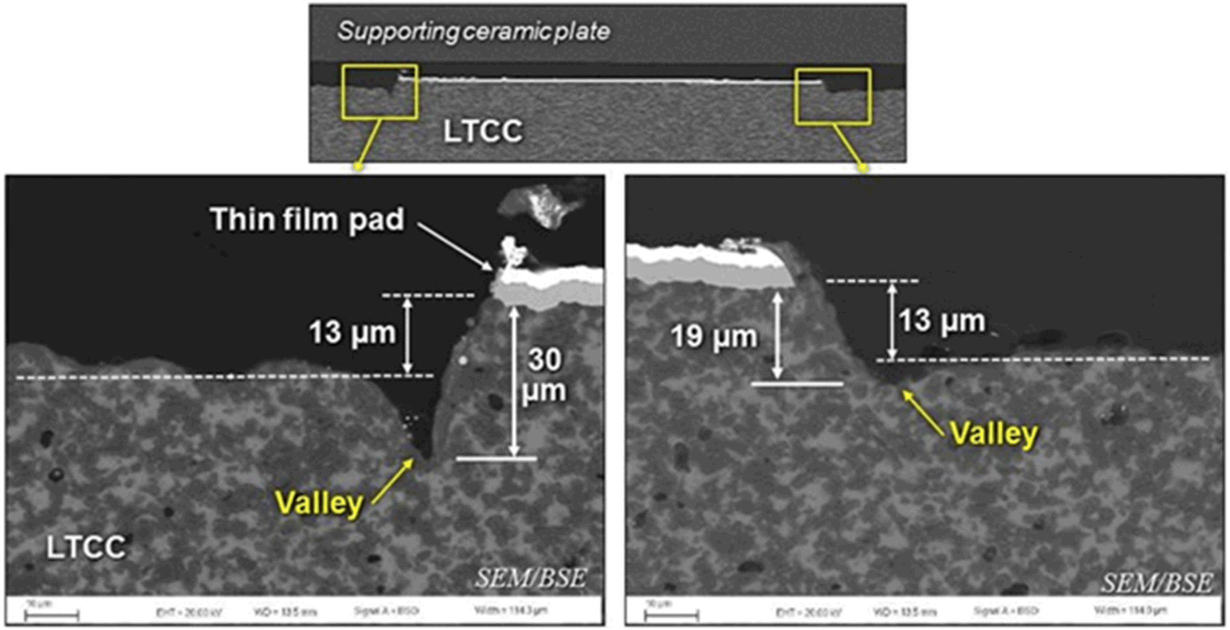
- Note the contour at the pad perimeter

Phase Two Continued



- Energy-dispersive X-ray analysis
- Cu is the primary constituent at the pad edge.
- Cu (purple map) is the primary element that is redeposited on top of the Au layer (strawberry) of the pad.
- Redeposited Cu on top of the thin film pad is oxidized.
- Degradation to the wire bond pull strength, 5.01g avg pull strength, 2.13g std

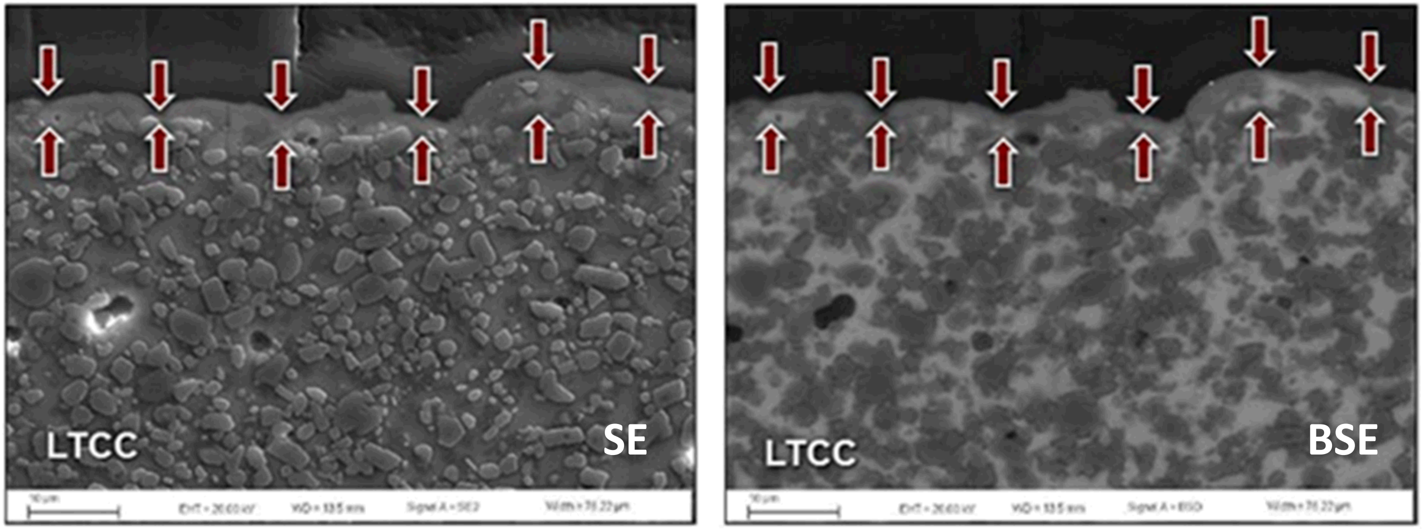
Phase Three



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

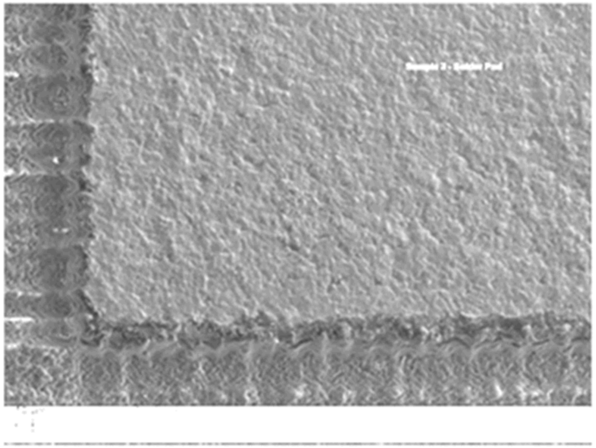
Phase Three Continued

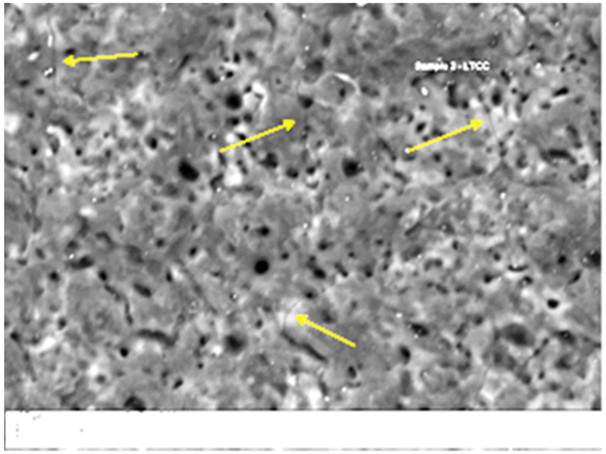


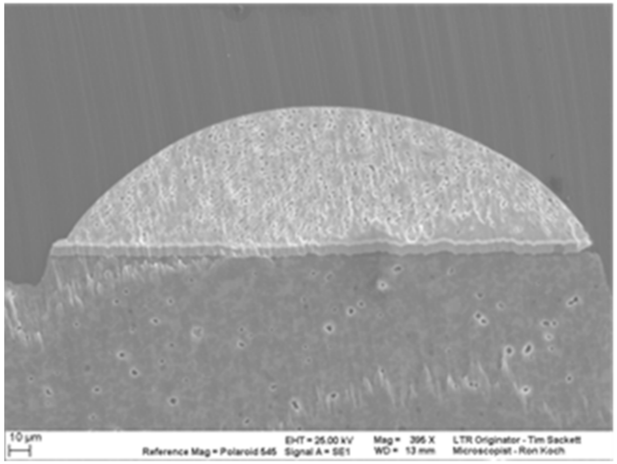
Results:

- 13 um of LTCC removed
- 30 um removed at pad edge
- Asymmetry of pad edge depth due to laser path overlap
- Melting and resolidification (red arrows)
- Minor cracking (substrate fracture strength studies required)
- Thin film delamination near laser ablation edge
- 11.35gm avg pull str., 0.7gm std dev, issues related to pad edges

Phase Four



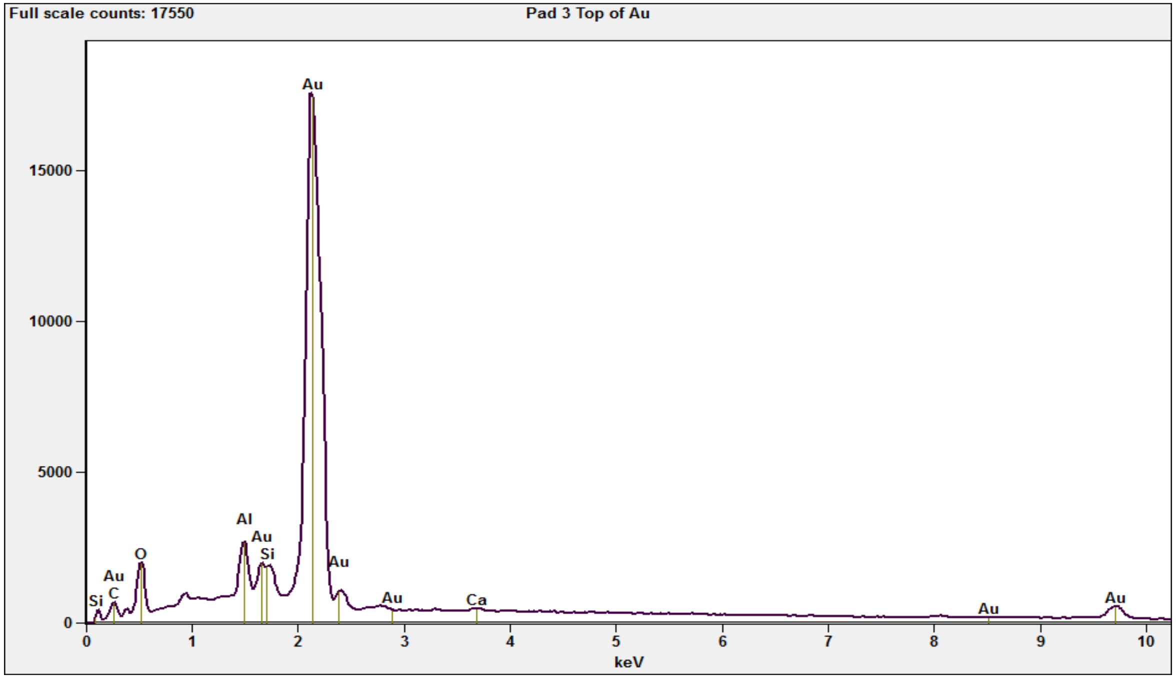




<u>U3 process parameters:</u>

- 1.1 watts laser power
- 75KHz beam frequency
- 14um beam spot size
- 7um beam pulse width
- 600 mm/s travel speed
- Four cross hatch cuts
- No contour cuts

Phase Four Continued



Results

- Micro-cracking was reduced.
- Surface contamination by redeposition was eliminated (EDX spectrum).
- Excellent wire bonding strengths, 12.25g avg pull strength, 0.77 std dev
- Solderability was excellent.
- Cleaning step was necessary to removal laser slag and FOD.

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DOE Summary Continued

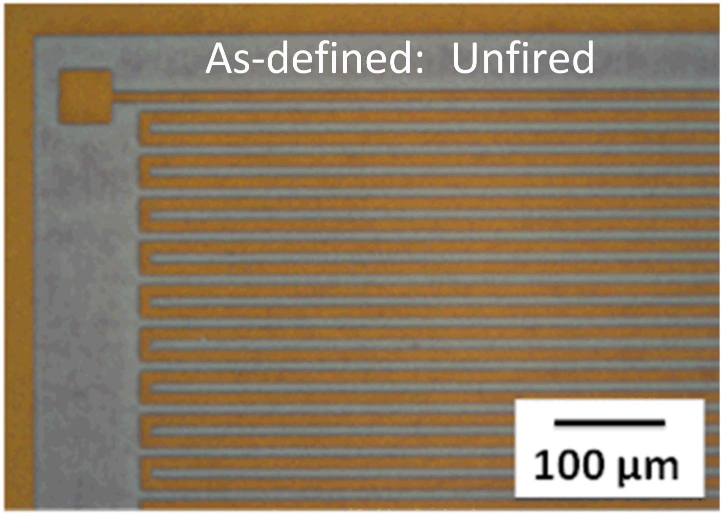
Phase	1	2	3	4
Average Pull Strength	N/A*	5.01g	11.35g **	12.25g
Standard Deviation	N/A*	2.13g	0.70g **	0.77g
Mean minus 3 Standard Deviation	N/A*	> Zero	9.25g **	9.94g

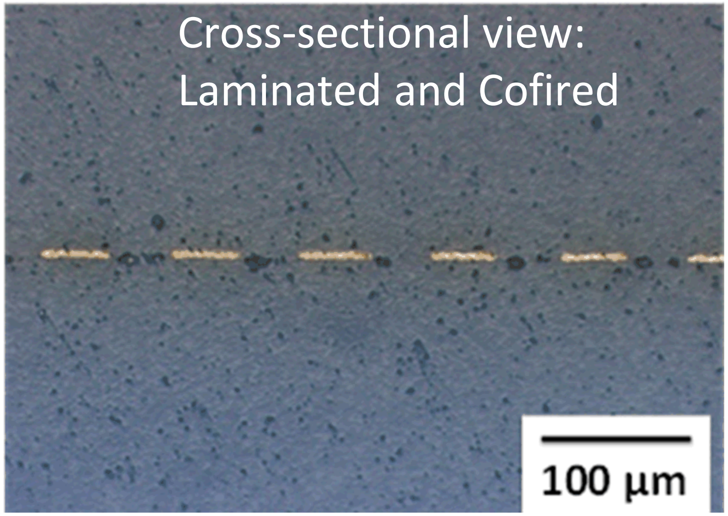
*6 x 6 and 8 x 8 mil pads not defined, not tested

**bonding on 38 mil square pads

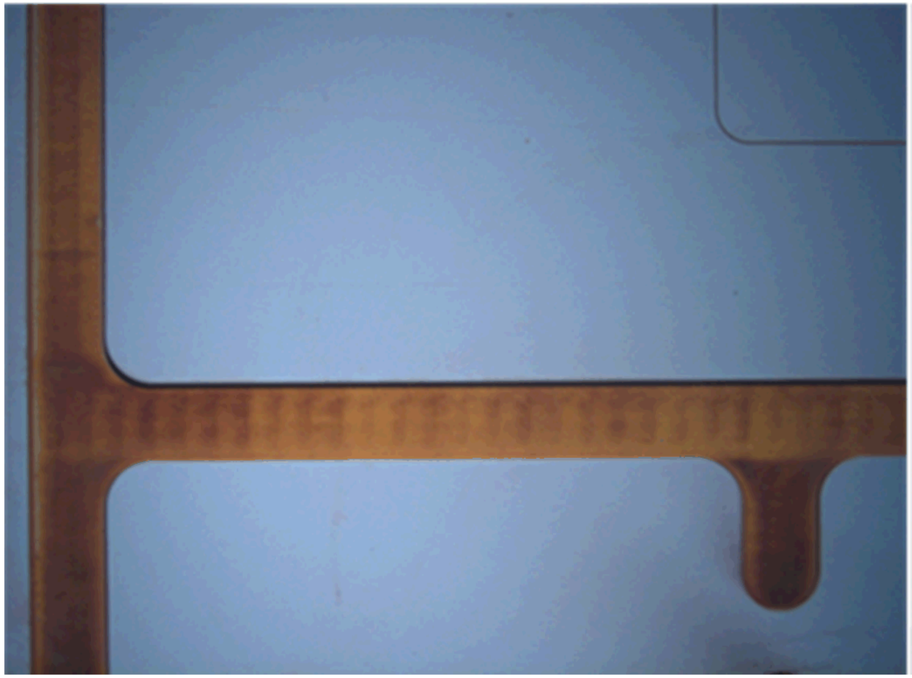
Laser Ablation of Unfired LTCC

- Definition of thick film on unfired tape demonstrated
- 50 um lines and spaces
- Du Pont 951, PX tape
- Du Pont 5734 Au thick film
- Settings:
  - 0.36 watts laser power
  - 75KHz beam frequency
  - 14µm beam spot size
  - 7µm beam pulse width
  - 800 mm/s travel speed
  - Two cross hatch cuts
  - No contour pass





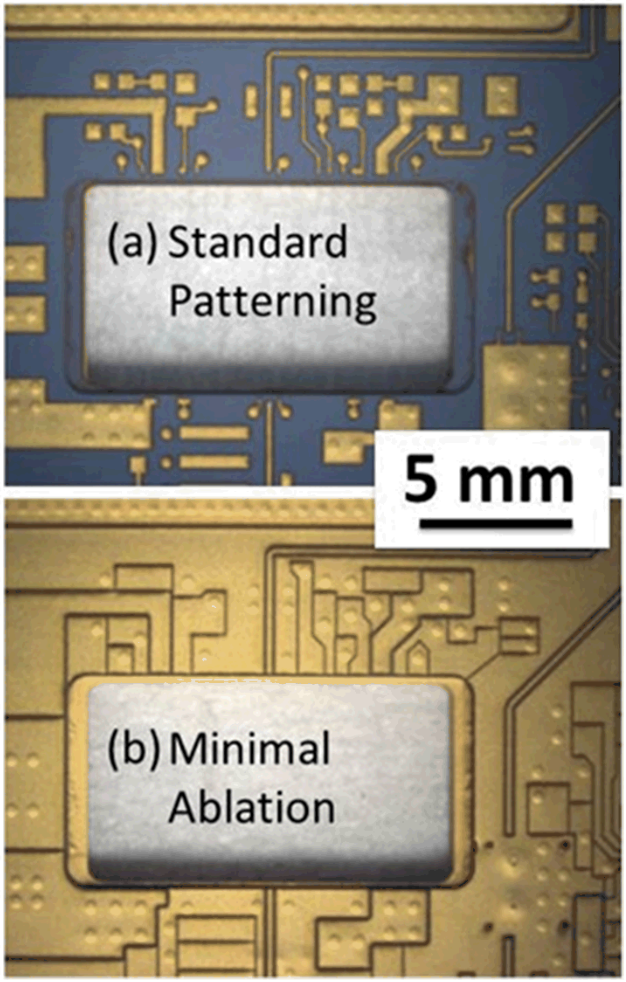
Laser Ablation of Unfired LTCC Continued



- Unfired definition of shielding valleys
- Du Pont 951, PX tape
- Du Pont 5734 Au thick film, 2 layers printed
- 50 mil wide valley
- Possible back-up process to ‘green machining’

Alternate Design Goals for Laser Ablation of Thin Films

- Reduced etching time
- 1/3 process time savings
- Dielectric mask provides pad definition
- Minimum ablation supports coplanar waveguide design requirements.



Conclusions

- Demonstrated successful laser ablation of the thin film metallized LTCC and green LTCC/thick films.
- The advantages of laser ablation over Ion Milling / Photolithograpy were demonstrated.
- The study highlighted the importance of enhanced power mapping via SEM and compositional analysis.
- Laser ablation can be used to deliver fast turnaround prototype units for design validation based on initial electrical results.
- Further work utilizing laser-ablation is underway.
- Confirmation testing: HALT, peel test, aged adhesion, and cross section on fully assembled MCMs.

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