Seed Paper Based Sustainable Electronics with Water-Based Inks and Low-Temperature Processing for Additive Electronics

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Motivation and Objectives

- ❑Current technology in electronics manufacturing includes uses of harmful substrates contributing to the environmental pollution.
- ❑Electronic manufacturing produces huge amount of volatile organic compound and carbon deposit to the surrounding every year.
- ❑It has become a necessity to introduce eco-friendly and efficient alternative solution for producing electronics system in order to get sustainable manufacturing.
- ❑Using paper substrate embedded with seed instead of traditional plastic polymeric substrates can decrease the huge production of carbon deposit every year.
- ❑Flexible electronics built with seed paper can contribute to reducing the decomposition period after the life cycle of electronics which currently takes excessive time because of traditional substrates.
- ❑Printing with water-based ink instead of solvent-based ink for circuits will reduce the VOC production.
- ❑Use seed paper to print test vehicle with water-based sustainable ink.
- ❑To do a sintering study based on suitable sintering time and temperature and cure it for good conductive resistance.
- ❑Use of electrically conductive adhesive (ECA) material for component attachment.
- ❑Testing HTOL performance of the traces and SMDs.
- ❑Testing performance of the functional circuit.

Print Parameters and Properties

Print Platform

Ink properties	
Silver Content	75 wt%
Viscosity @ 0.1s^{-1}	26000 cps
Viscosity @ 100s^{-1}	800 cps
Specific Gravity	3.1
Particle Size	2-4 µm
Flash Point	Non-flammable

Substrate-1 Properties	
Material	Seed Paper
Blend Name	Wildflower seed paper blend
Thickness	16.5 mil
No. of types of seed	6

Print Parameters	
Nozzle ID & OD	159 & 244 µm
Ink Pressure	15 Psi
Print Speed	3 mm/s
No. of Passes	1
Standoff Height	50 µm

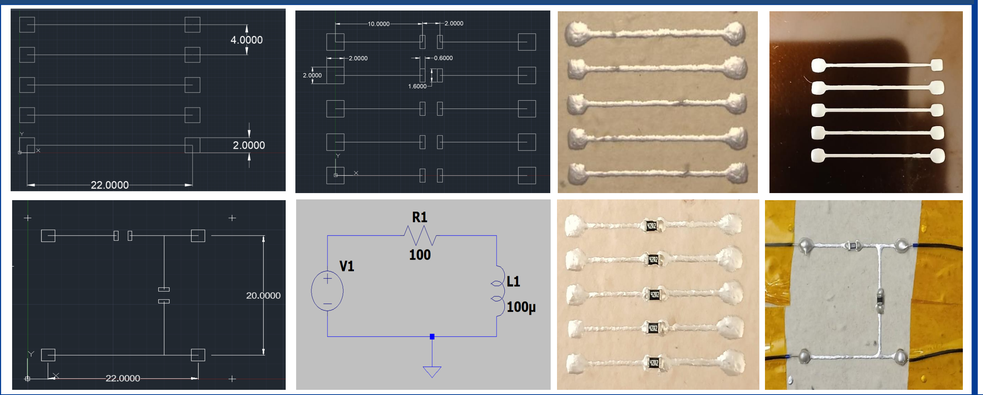
Adhesive properties	
Hardness, Shore D	85
Volume Resistivity	<0.0001 Ω.cm
CTE	1.5*10^{-5} /°C
Cure Time	24 hrs, 45 min, 15 min
Cure Temperature	Room Temp., 50°C, 100 °C

Substrate-2 Properties	
Material	Polyamide Sheet
Name	Kapton® HN
Density	1.42 g/cc
Thickness	5 mil
Operating Temperature	-269 °C to 400 °C
CTE(100°C to 200°C)	32 ppm/°C

Workflow

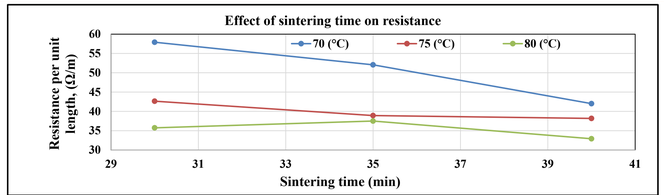
Printing Test Vehicles (Conductive Ink) → Thermal Sintering (Box-Oven) → Printing ECA → Component Attachment (Pick and place Machine) → Room Temperature Sintering → Process Study → HTOL Analysis @ 40 °C → Performance Analysis

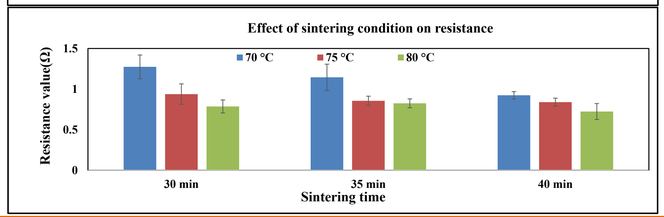
Test Vehicles



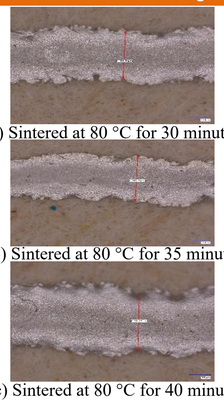
Test Results

Effect of Sintering Temperature on Resistance





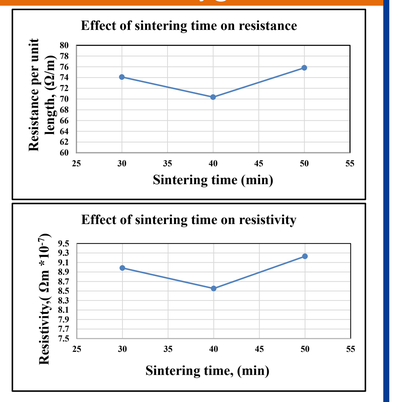
Effect of Sintering Time on Resistance and Resistivity @ 80 °C



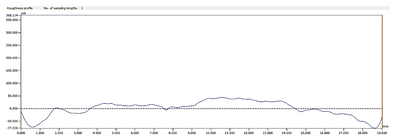
(a) Sintered at 80 °C for 30 minutes.

(b) Sintered at 80 °C for 35 minutes.

(c) Sintered at 80 °C for 40 minutes.

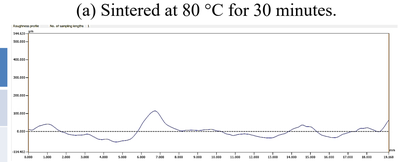


Trace Roughness Profile

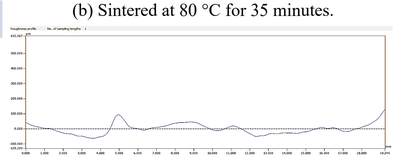


(a) Sintered at 80 °C for 30 minutes.

Time (min)	Ra (µm)	Rz (µm)
30	24.243	121.943
35	25.522	173.026
40	26.670	192.105

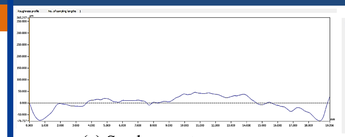


(b) Sintered at 80 °C for 35 minutes.

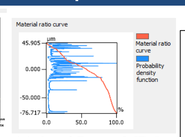


(c) Sintered at 80 °C for 40 minutes.

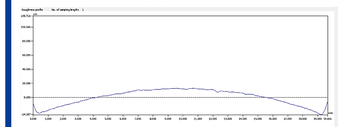
Result Comparison with Polyamide



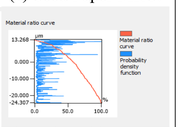
(a) Seed paper trace.



(a) Seed Paper MRC.

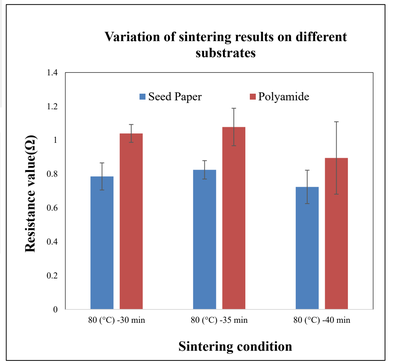


(b) Polyamide trace.

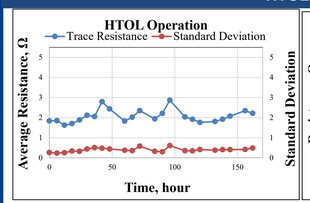


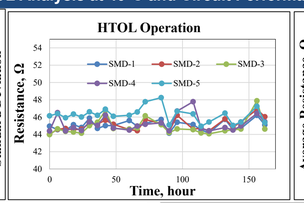
(b) Polyamide MRC.

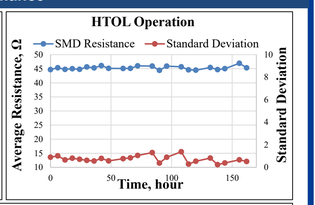
Substrate	Ra (µm)	Rz (µm)
Seed Paper	23.497	122.622
Polyamide	9.513	37.575

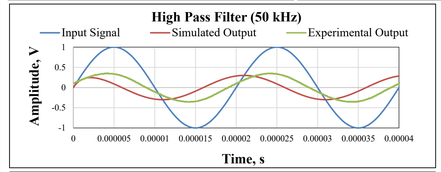


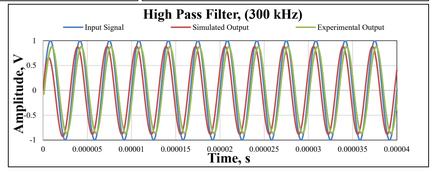
HTOL Analysis at 40°C and Circuit Performance

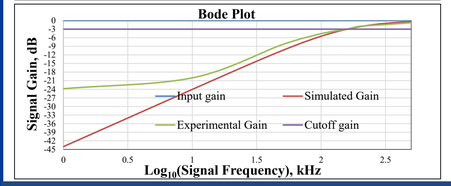


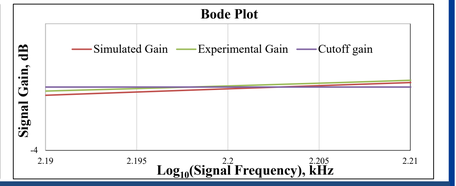












Summary and Conclusion

In this study,

- Seed paper has been investigated as an alternative to the traditional printing substrate.
- Process study on sintering time and temperature has been done to find out the optimum condition for best possible conductive traces.
- Electrically conductive adhesive has been applied to do SMD attachment.
- HTOL operation has been investigated on the traces and SMDs till 162 hours.
- Circuit performance of High Pass filter has been analyzed.
- Seed paper-based electronics can be a next generation solution for sustainable electronics in additive manufacturing.

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