Process Study and Reliability Assessment of Seed Paper Based Additively Printed 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, Flex to install and dynamic flexing performance of the traces and SMDs.
- ❑Testing performance of the functional circuit.

Print Parameters and Material Properties

Print Platform

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

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

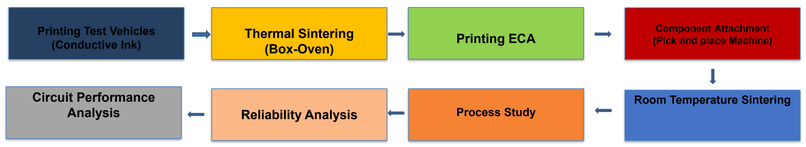
Adhesive properties	
Hardness, Shore D	85
Volume Resistivity	<0.0001 Ω.cm
CTE	1.5*10^{-5} /°C
Cure Time	24 hrs, 45 min, 15 min
Cure Temperature	Room Temp., 50°C, 100 °C

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

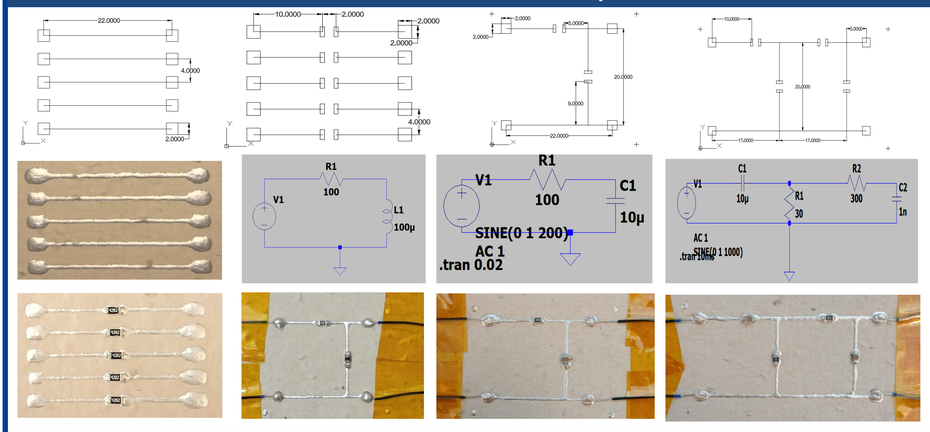
Encapsulant Properties	
Viscosity	450 cps
Hardness, Shore A	40
Volume Resistivity	1.55 x 1014 Ω.cm
Operating Temperature	-40 °C to 200 °C
Dielectric Strength	> 13.5 kV/mm
Specific Gravity	0.98
Cure Condition	Room Temp. for 7 days

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

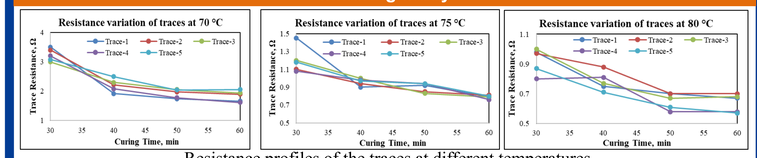


Test Vehicles & Printed Samples

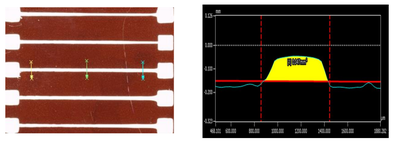


Results

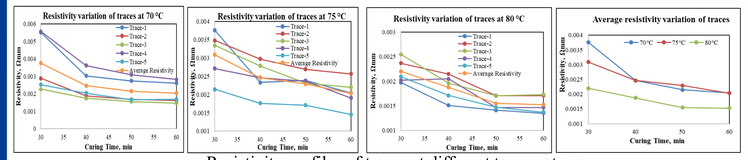
Sintering Study



Resistance profiles of the traces at different temperatures.

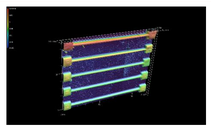


Laser profilometry for trace cross sectional area measurement.

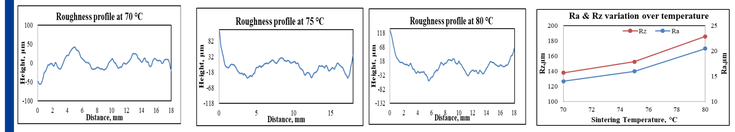


Resistivity profiles of traces at different temperatures.

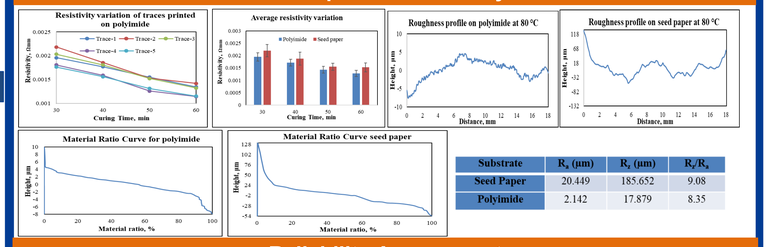
Roughness Profile Using Laser Profilometry



2D coordinate settings	Auto
Measurement type	Roughness
Cutoff	λs = None, λc = None
End effect correction	Enabled
Double gaussian	OFF
Stylus mode	OFF
No. of sampling lengths	1



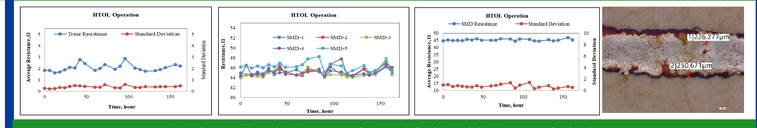
Result Comparison With Polyimide



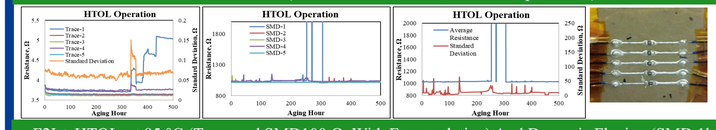
Substrate	R_a (µm)	R_z (µm)	R_z/R_a
Seed Paper	20.449	185.652	9.08
Polyimide	2.142	17.879	8.35

Reliability Assessment

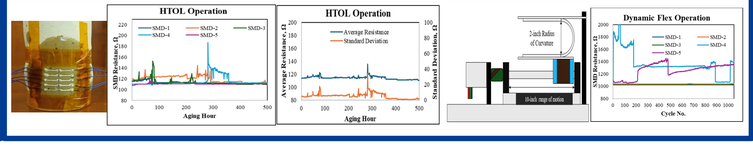
HTOL at 40 °C (Trace and SMD 42 Ω, Without Encapsulation)



HTOL at 85 °C (Trace and SMD1k Ω, With Encapsulation)

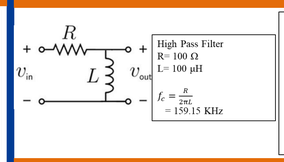


F2I + HTOL at 85 °C (Trace and SMD100 Ω, With Encapsulation) And Dynamic Flexing (SMD 1k Ω)



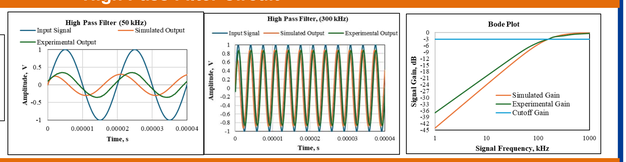
Circuit Performance

High Pass Filter Circuit

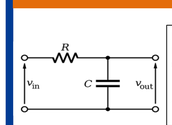


High Pass Filter
R= 100 Ω
L= 100 µH

$$f_c = \frac{R}{2\pi L} = 159.15\ \text{KHz}$$

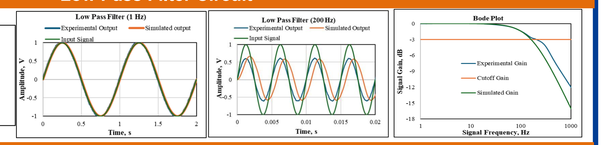


Low Pass Filter Circuit

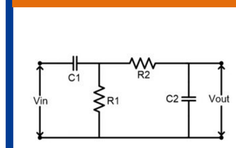


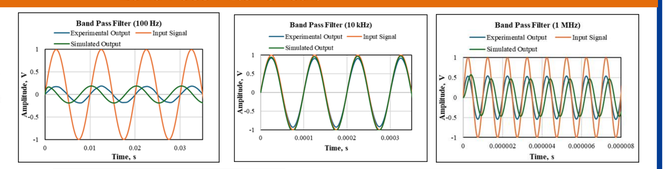
High Pass Filter
R= 100 Ω
C= 100 µF

$$f_c = \frac{1}{2\pi RC} = 159.15\ \text{Hz}$$



Band Pass Filter Circuit

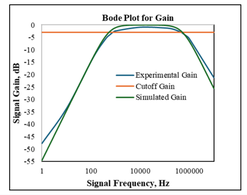


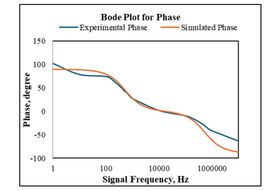


High Pass Filter
R1= 30 Ω
C1= 10 µF
R2= 300 Ω
C2= 1 nF

$$f_L = \frac{1}{2\pi R_1 C_1} = 530.16\text{Hz}$$

$$f_H = \frac{1}{2\pi R_2 C_2} = 530.16\text{kHz}$$





Summary and Conclusion

In this study,

- A bio-degradable substrate seed paper has been investigated for 3D printed electronics with water-based ink.
- Sintering study has been done on seed paper printed traces to find out the optimum time and temperature for good conductive behavior.
- Using laser profilometer, roughness study has been done on the seed paper printed traces due to the uneven surface present.
- The result has been compared with a non-biodegradable substrate polyimide.
- Reliability assessment (High Temperature Operating Life, Flex to Install and High Temperature Operating life and Dynamic Flexing) has been done on traces and SMDs.
- Functional circuit (High Pass Filter, Low Pass Filter and Band Pass Filter) has been developed on seed paper.
- Furthermore, research on biodegradable substrates like seed paper can lead to sustainable future with advanced technologies.

Acknowledgment

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