Fabrication of Printed Passive Wireless Surface Acoustic Wave Sensors by Aerosol Jet System

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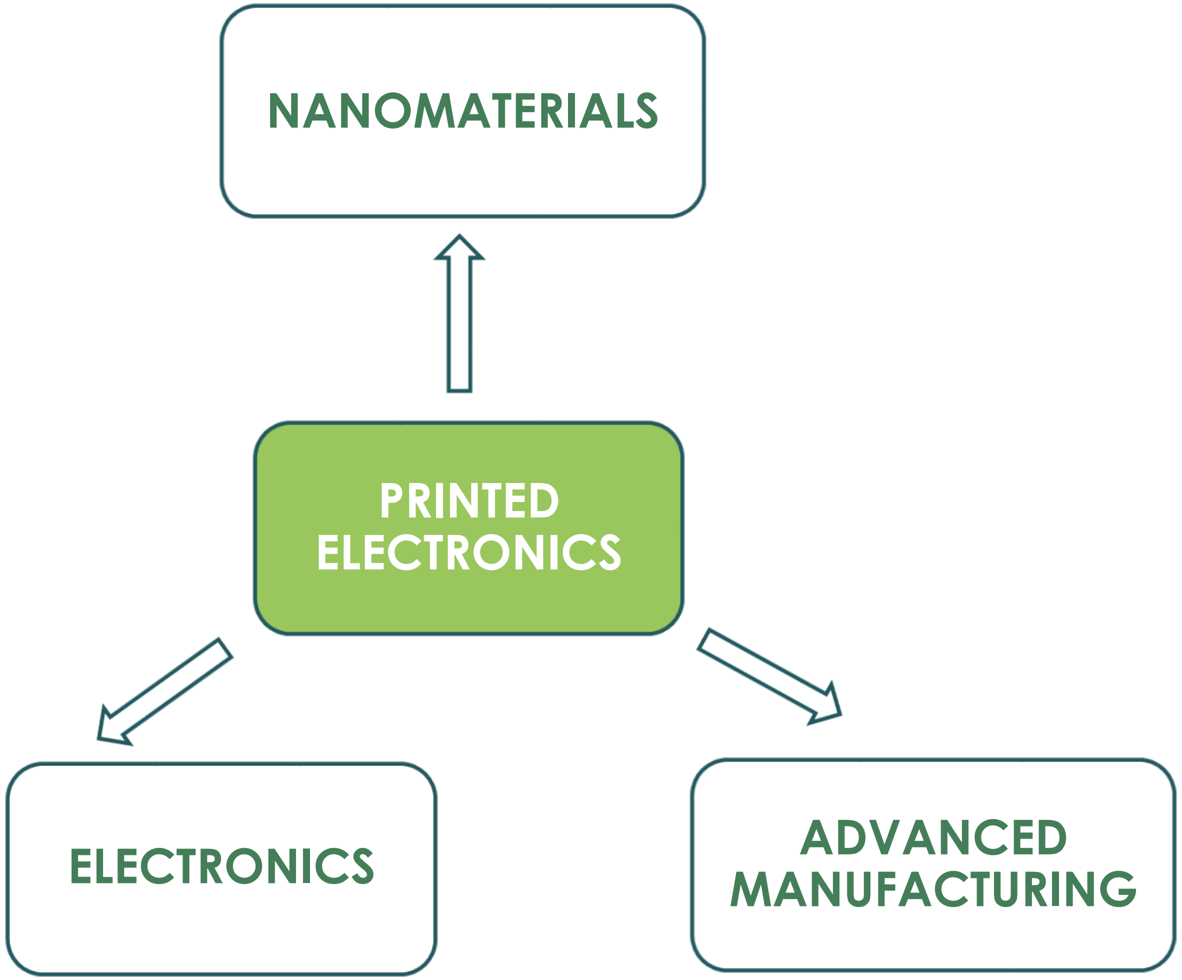
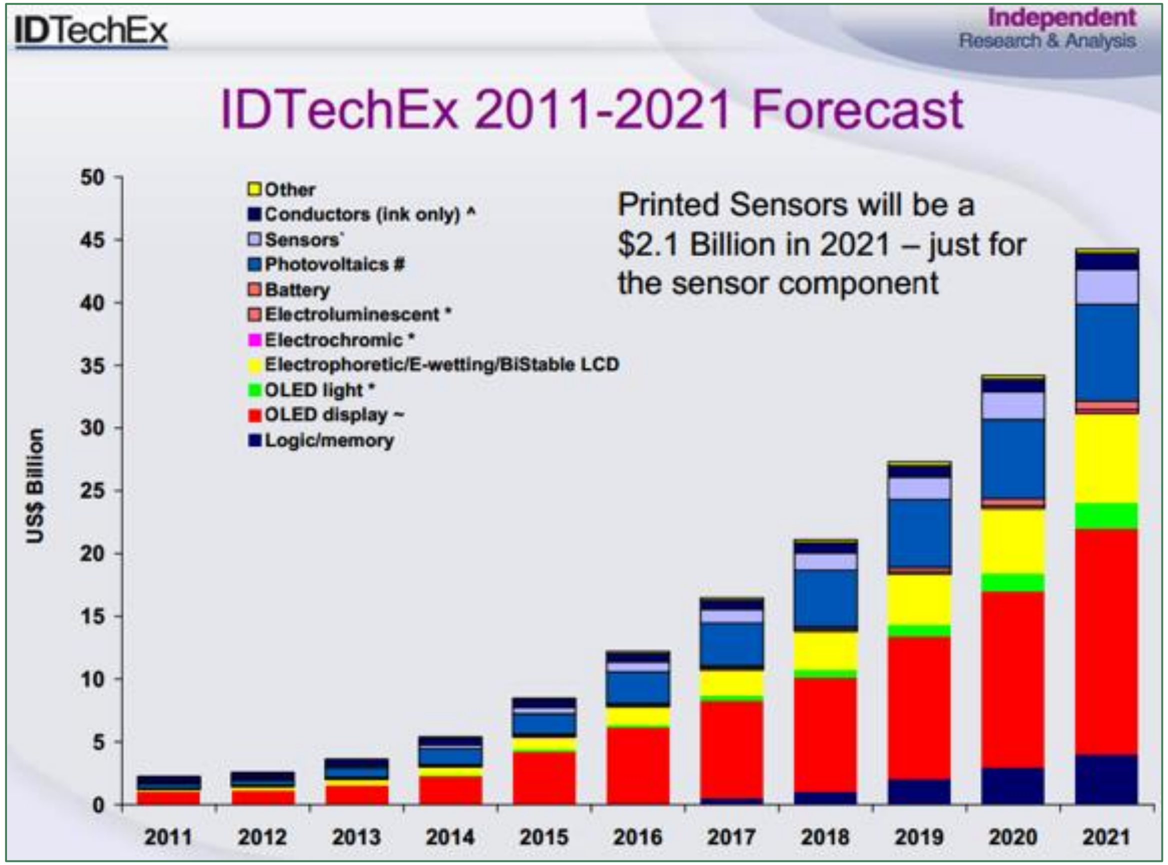
Outline

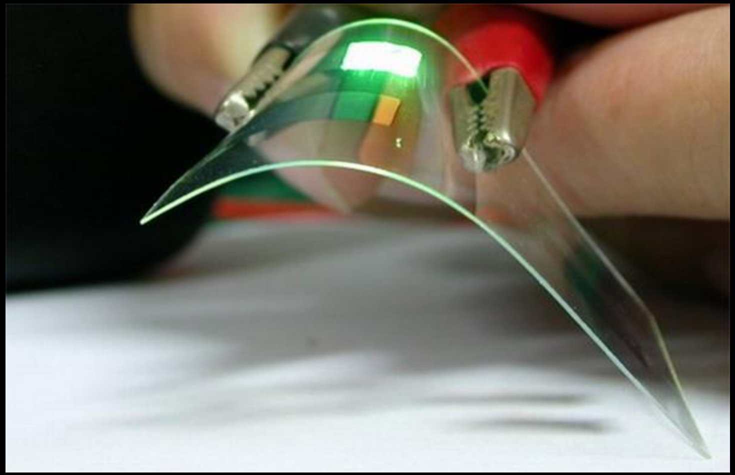
- Printed Electronics
  - Printing Systems
- Aerosol Jet System
- Fabrication of Printed SAW sensors
  - Method Design
  - Results
  - Challenges
- Summary

Printed Electronics





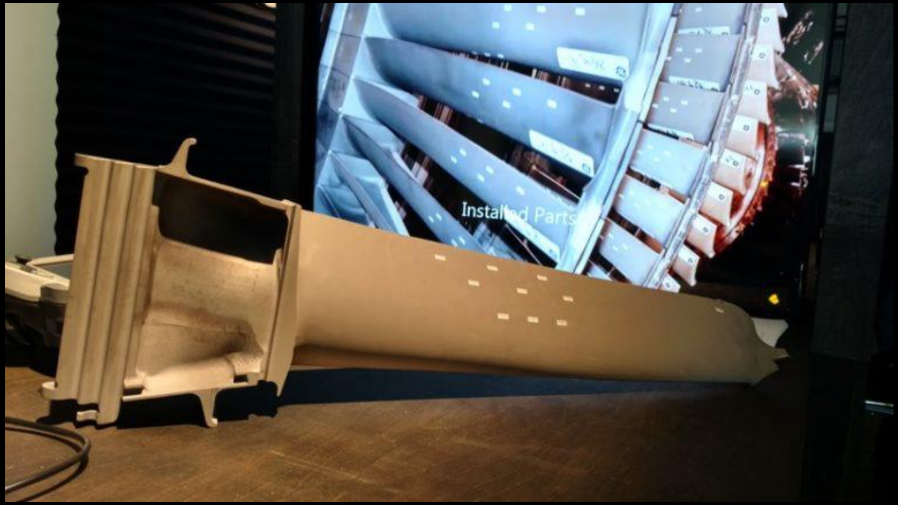
Smart whiskey bottle (RFID tags)
Source: Thinfilms



OLED flexible screen by inkjet printing
Source: LG image factor-tech.com

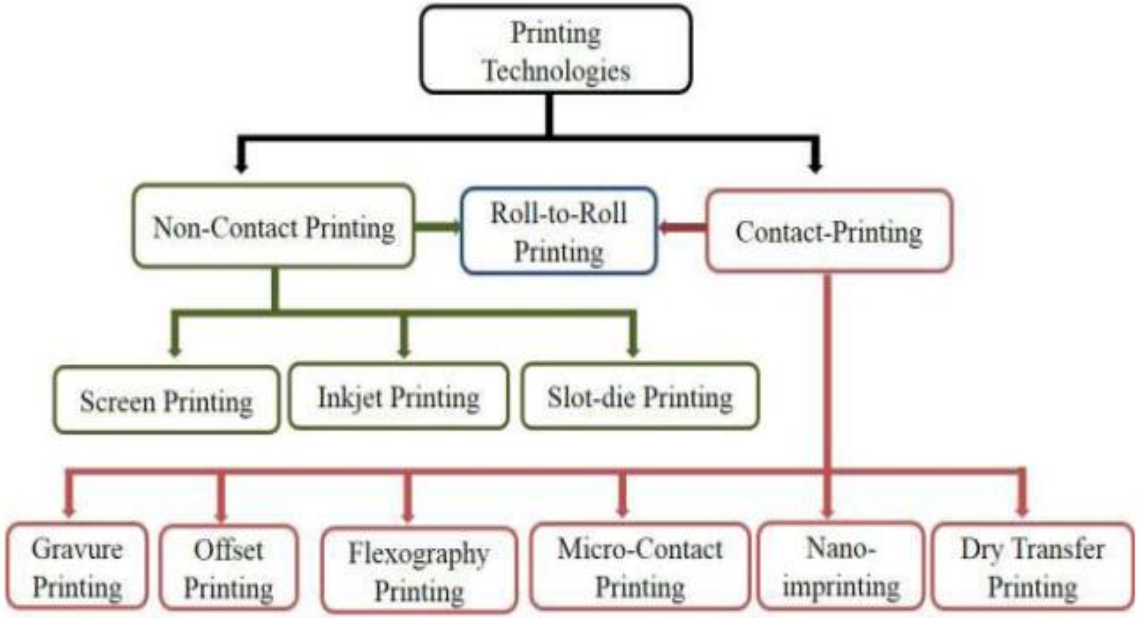
Printed solar cell.
Source: inhabitat.com

Food and drugs sensors.
Source: packworld.com



Turbine blade with printed strain sensors.
Source: Optomec

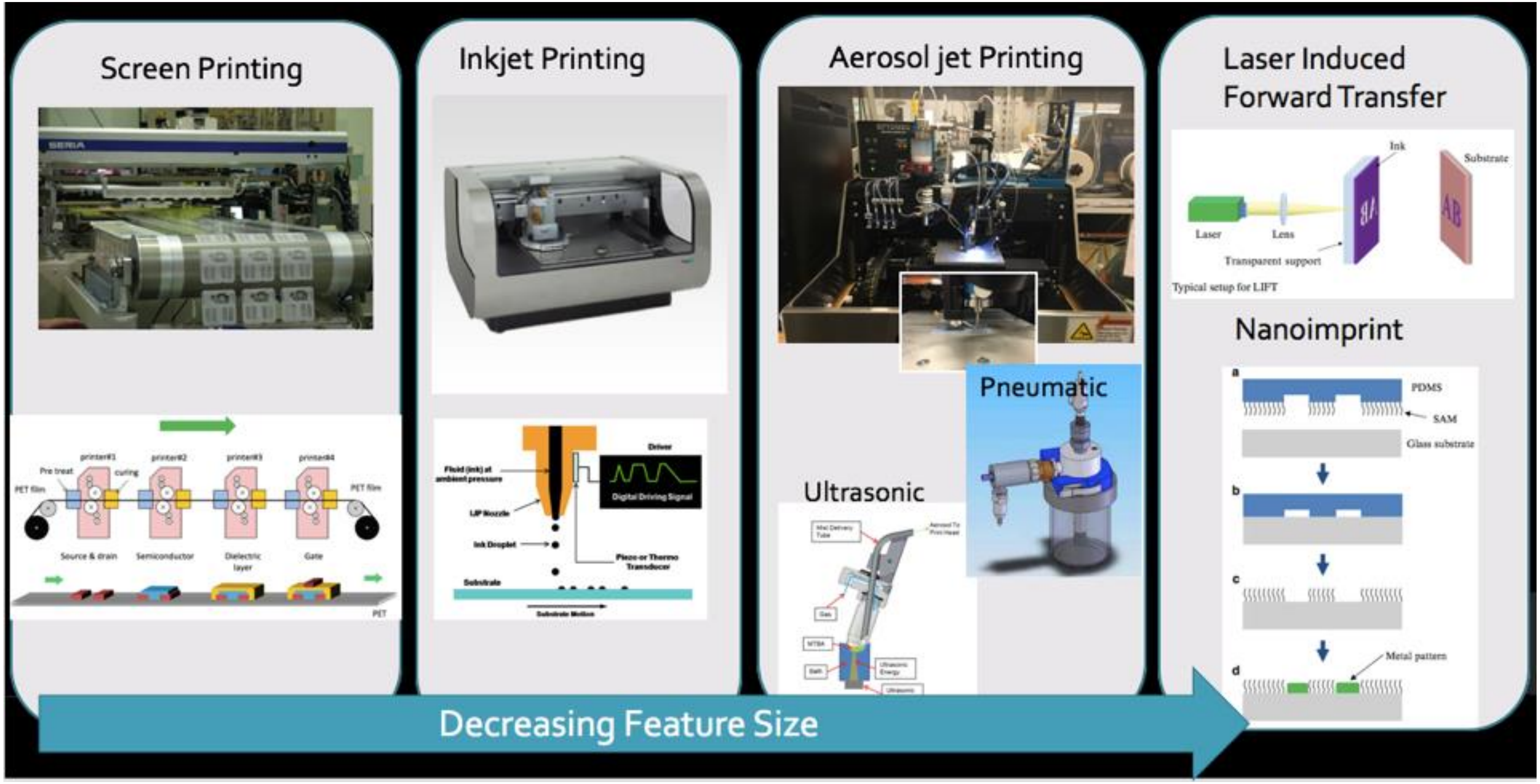
Printed Electronics Techniques



Printing method	Ink viscosity (cP)	Line width (µm)	Line thickness (µm)	Speed (m/min)	Other feature
Inkjet	10–20 (electrostatic inkjet: Approx. 1,000)	30–50 (electrostatic inkjet: Approx. 1)	Approx. 1	Slow (rotary screen: 10 m/s)	Surface tension: 20–40 dyn/cm On demand Noncontact
Offset	100–10,000	Approx. 10	Several –10	Middle—fast Approx. 1,000	
Gravure	100–1,000	10–50	Approx. 1	Fast Approx. 1,000	
Flexo	50–500	45–100	<1	Fast Approx. 500	
Screen	500–5,000	30–50	5–100	Middle Approx. 70	
Dispense	$1{,}000$–10^6	Approx. 10	50–100	Middle	Single stroke
µCP	–	Approx. 0.1	Approx. 1	Slow	
Nanoinprint	–	Approx. 0.01	Approx. 0.1	Slow	

Source: Introduction to Printed Electronics-K. Suganuma
IEEE Sensors Journal 2015, 100

Printed Electronics Systems

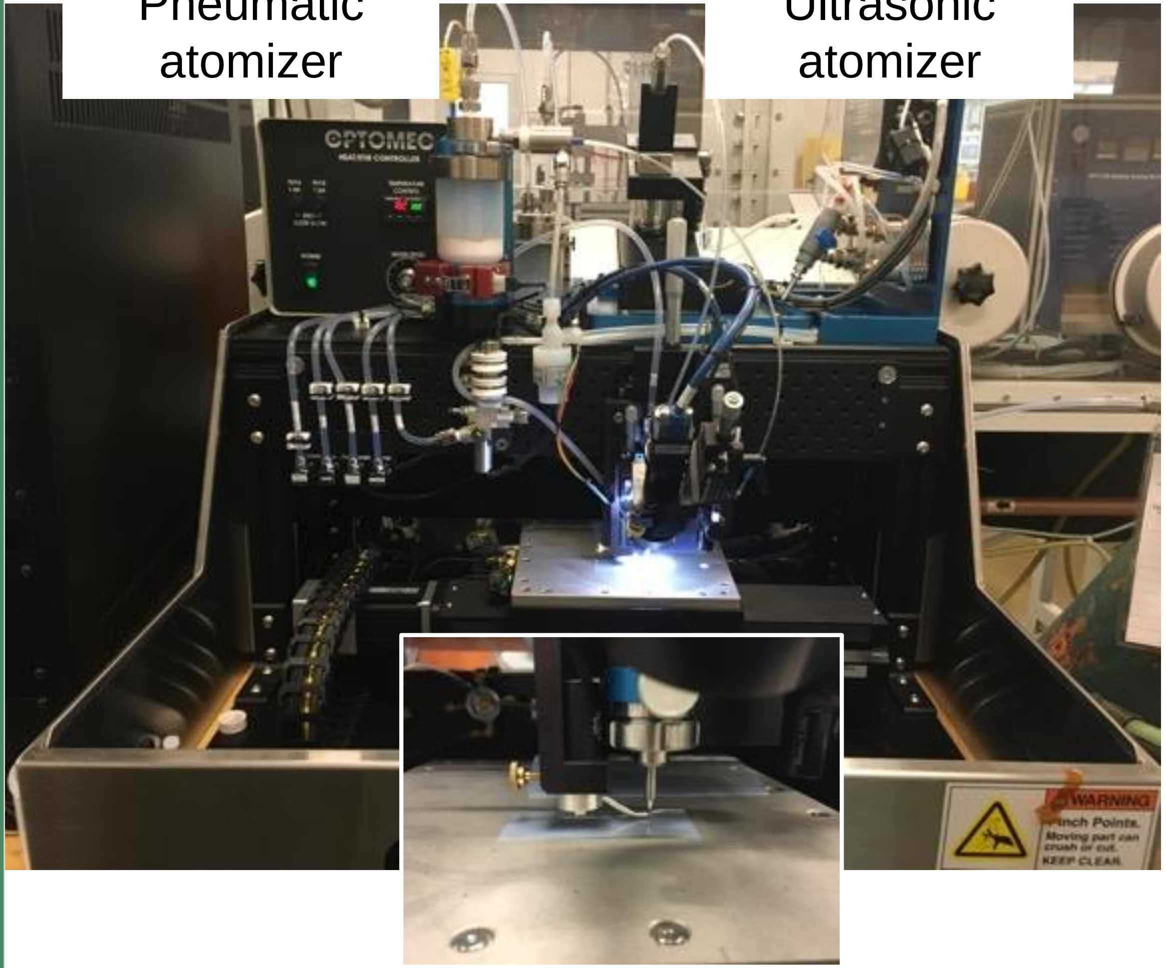


Source: Introduction to Printed Electronics-K. Suganuma
Source: SPIE.org
Source: Introduction to Printed Electronics-K. Suganuma

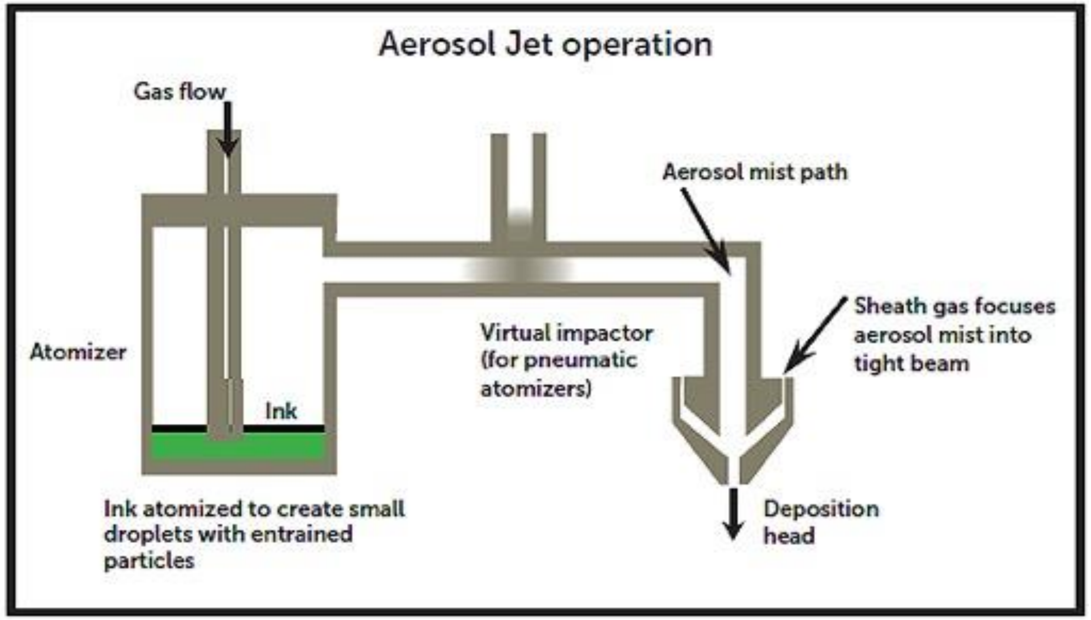
Aerosol Jet Printing System

Pneumatic atomizer

Ultrasonic atomizer



Optomec AJ200



Ink Specifications for Aerosol Jet Printer by Atomizer

Atomizer	Ultrasonic	Pneumatic
Viscosity Range	1-5 cP	1-1000 cP
Particle size	<50 nm	<500 nm

The aerosol jet is formed by droplets as small as 1-5μm

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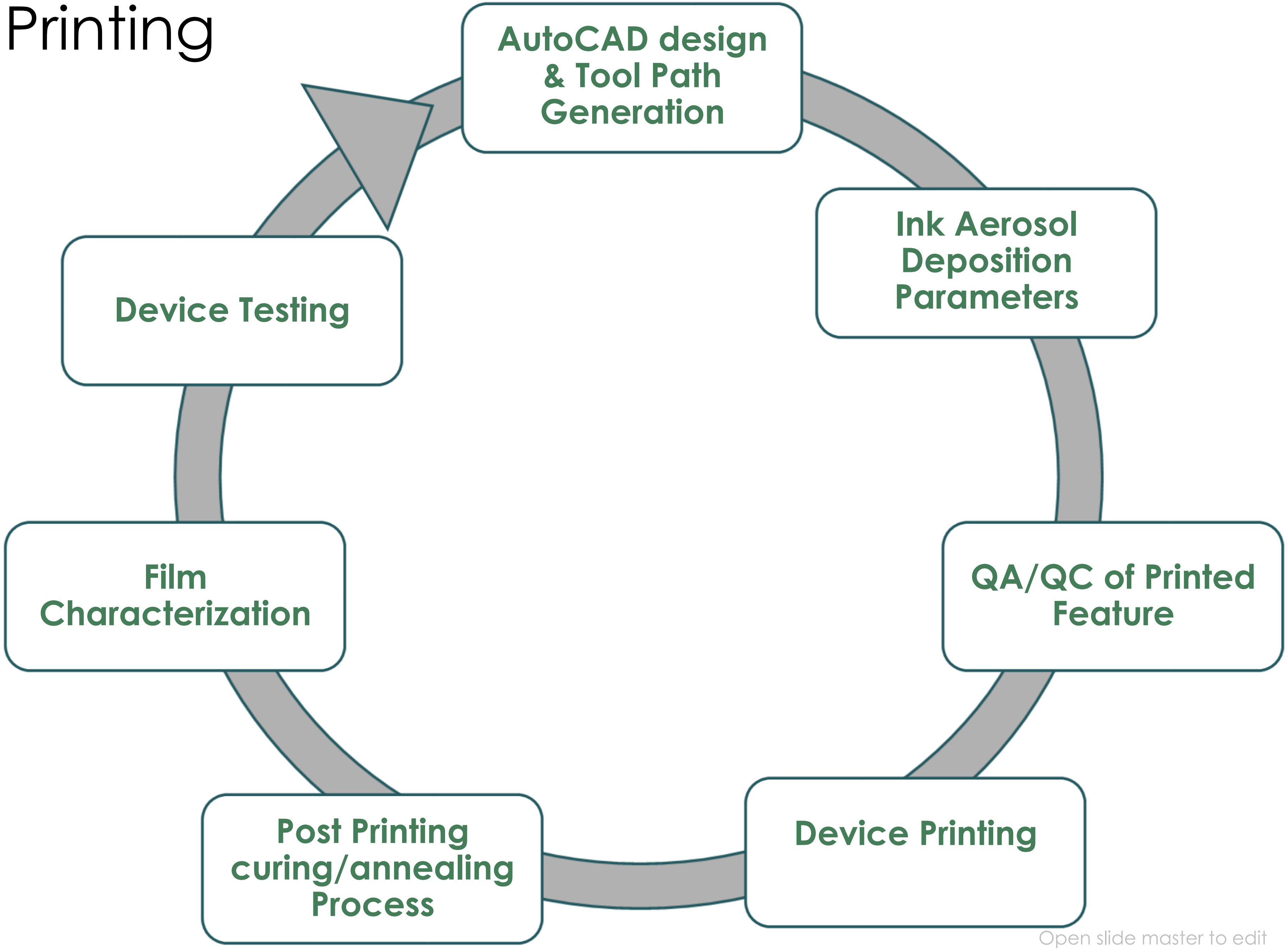
Design of the Printing Process



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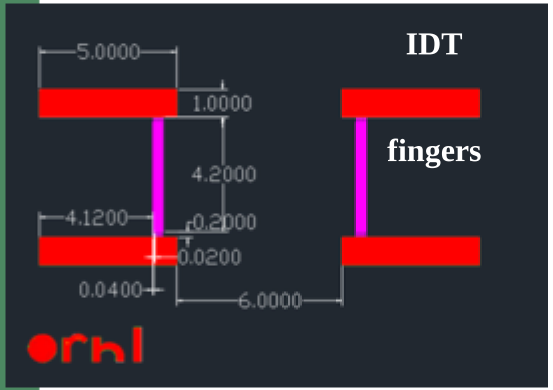
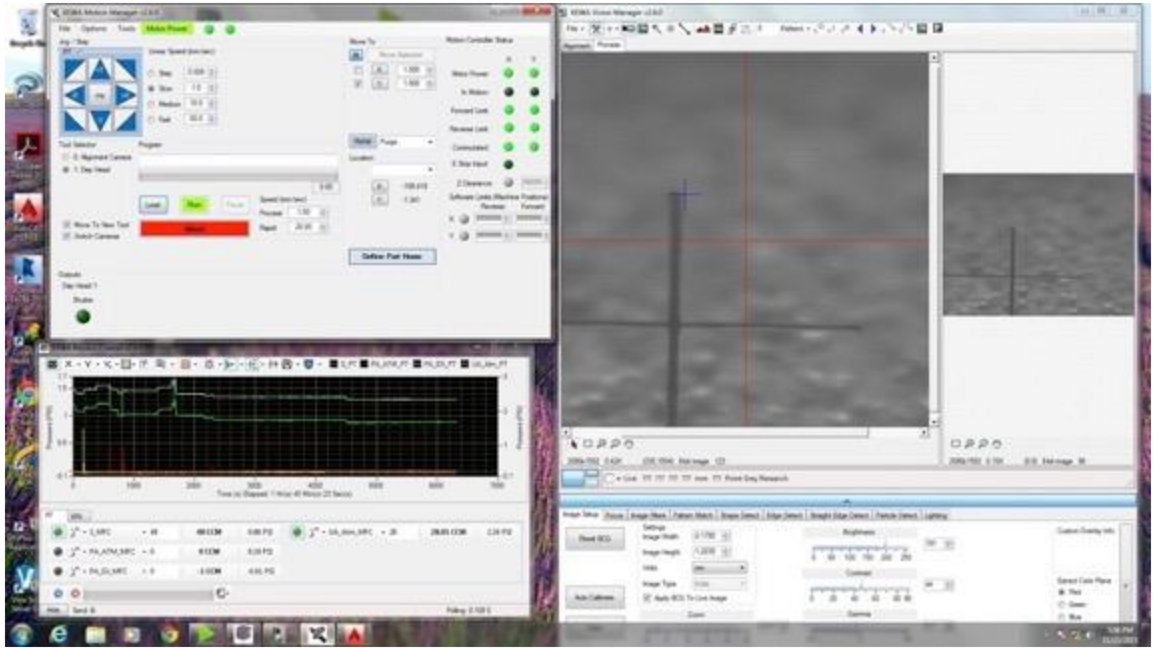
Printing Process for SAW Sensors

AutoCAD Design and Toolpath Generation → Ink Deposition, Visual Control and Line measurement → Printing Parameters

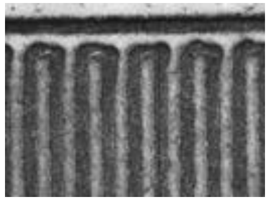




Structure fill: Rastering Line overlap: 50%

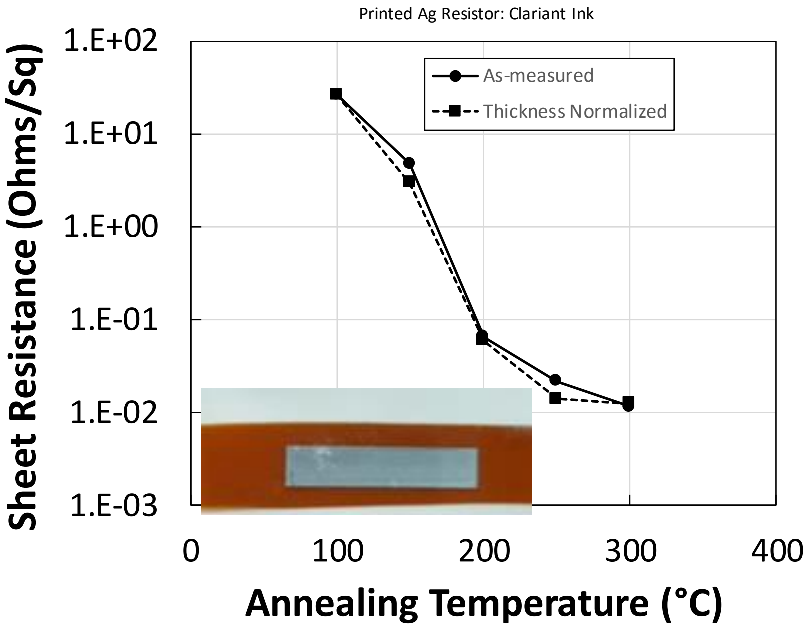
Feature Size	10 µm	40 µm
Deposition Head Tip	100 µm	150 µm
Platform Temperature	70 C	70 C
MFC Sheath	52 sccm	33 sccm
MFC UA Atomization	25 sccm	23 sccm
UA current	0.3 mA	0. 3mA
Process Speed	2 mm/sec	2mm/sec
Curing Process 30 mins	125C	125C
Total Print Time	~40 mins	~35 mins

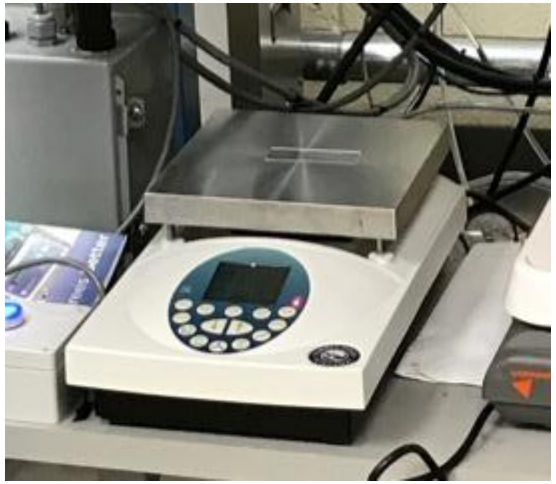
Printed Test Structures



Post Printing Process

- Clariant EXPT PRELECT TPS 50 G2, a silver colloidal formulation was used for this study
- The silver content in the dispersion is slightly less than 50 w% of silver, <20 w% ethenediol and water to maintain the physical properties of the dispersion.
- The particle size range in this solution was about 10-100 nm.



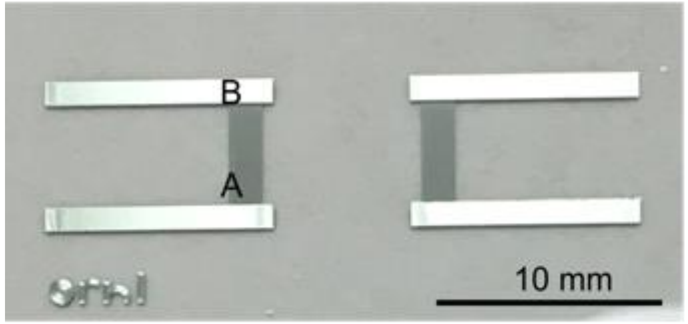


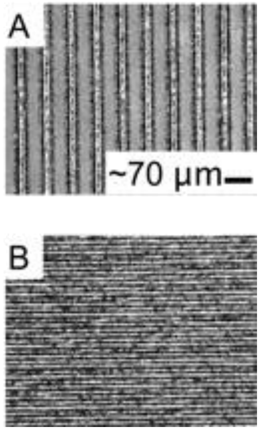
Hot plate

$$R = \frac{\rho}{t}\frac{L}{W} = R_s\frac{L}{W}$$

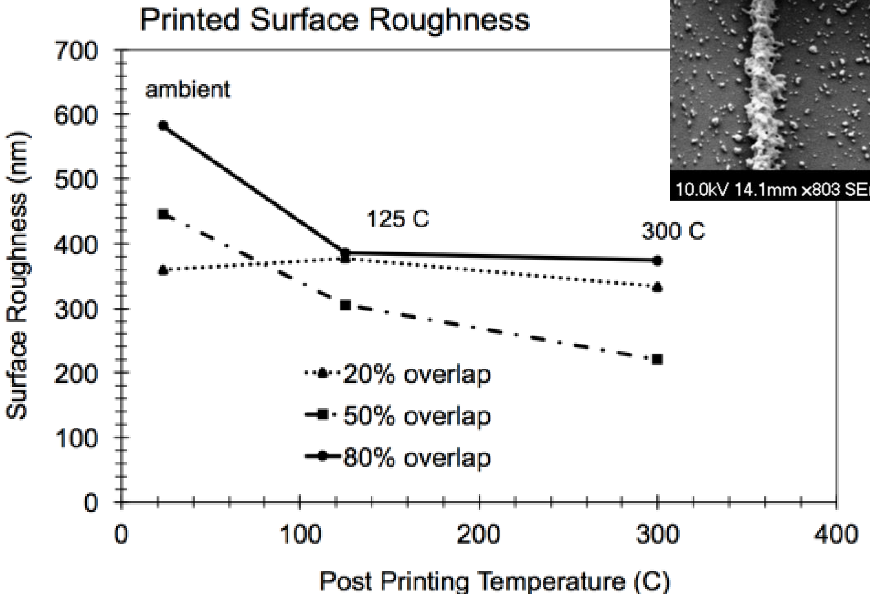
Sheet resistance is a metric for the characterization of printed conductor, where L is length of the film and W is the width

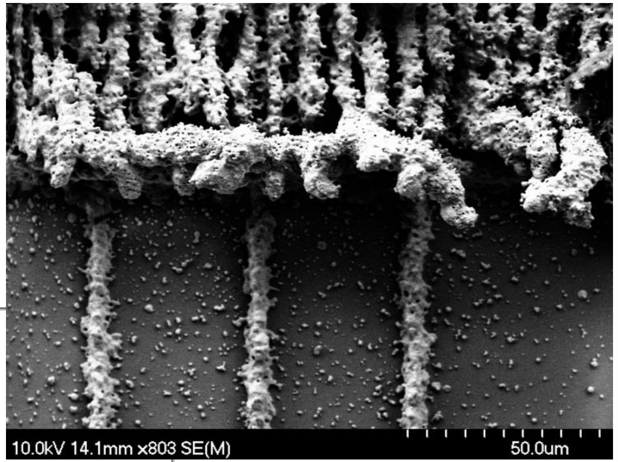
Characterization of the Printed Film



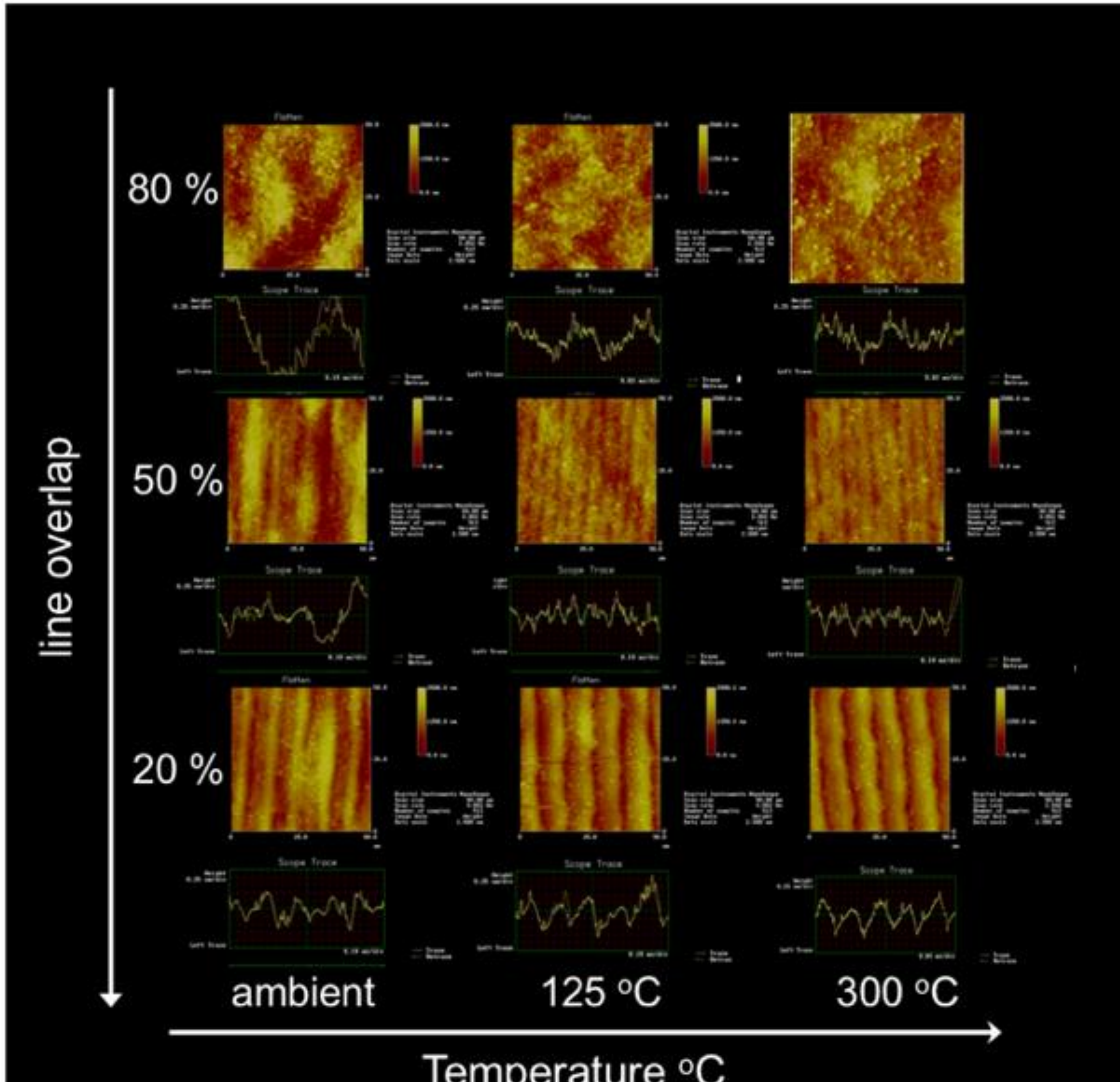


Printed films with 50% line overlap and exposed to 300 C for 30 minutes exhibit lower roughness.





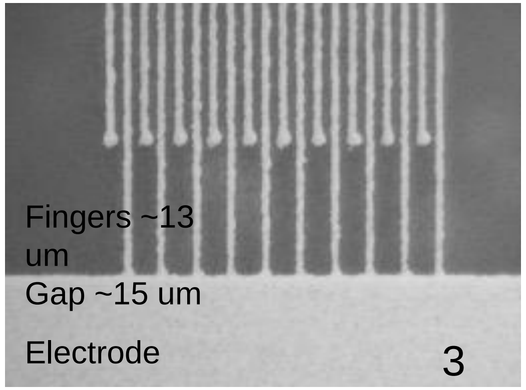
SEM image

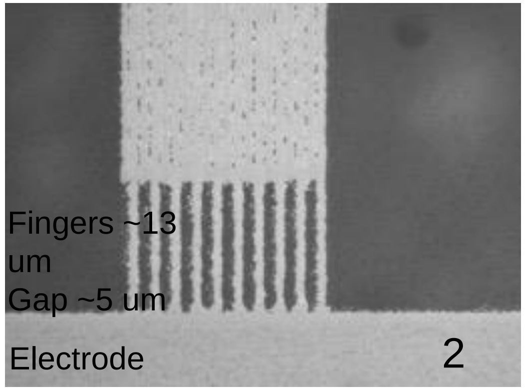


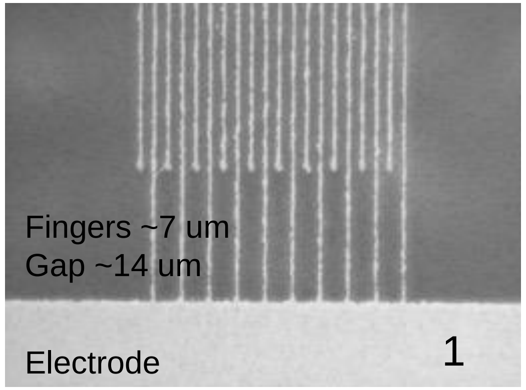
AFM images

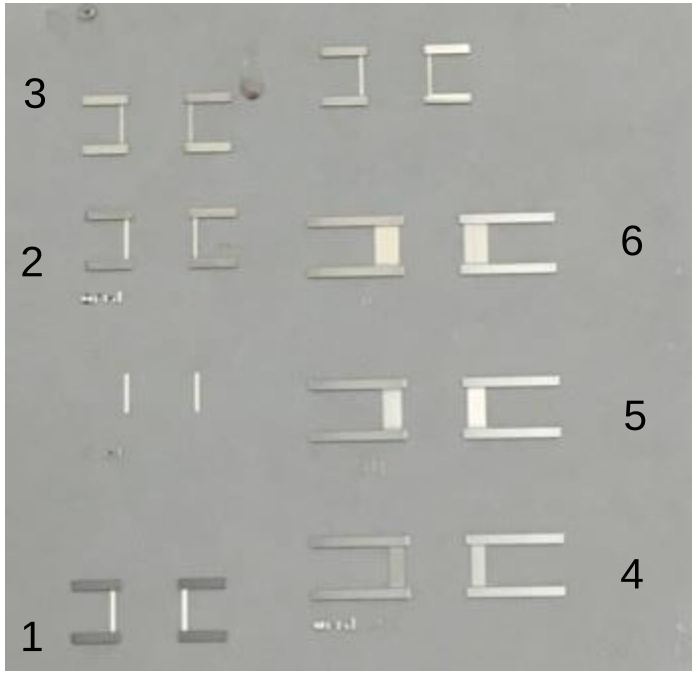
Direct Printed SAW devices: 10 µm and 40 µm feature size

Ultrasonic Atomizer

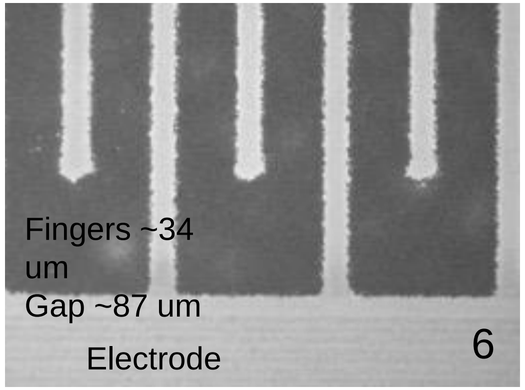


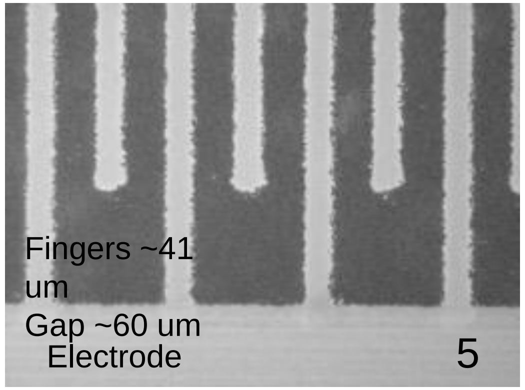


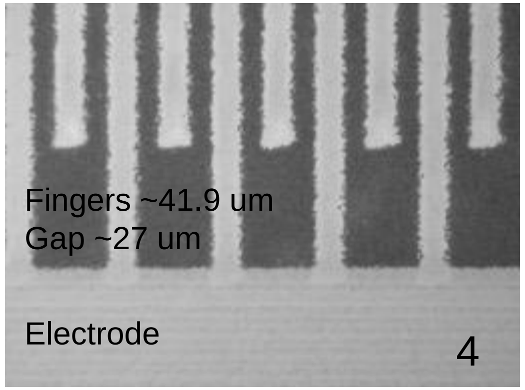




$LiNbO_3$ Y cut wafer with direct printed SAW devices of 10-40 µm feature size.
Wafer size is 76.2 mm^2







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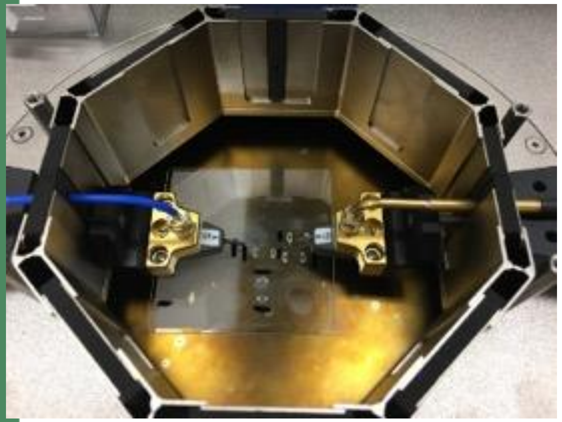
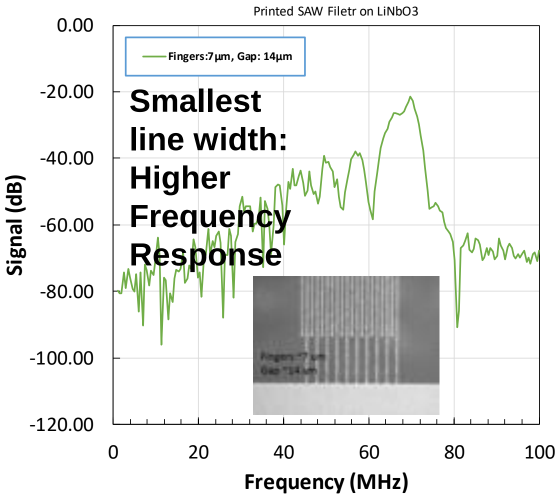
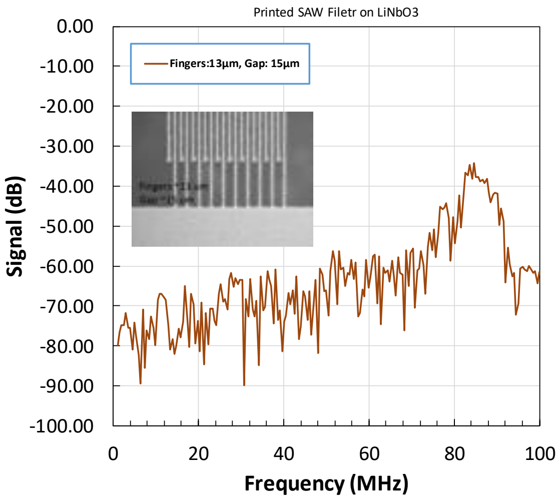
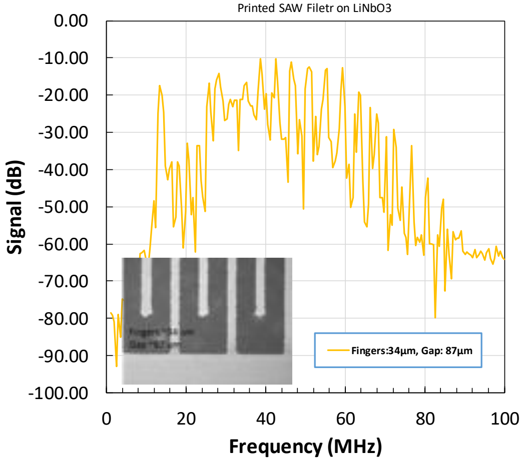
Printed SAW Sensors

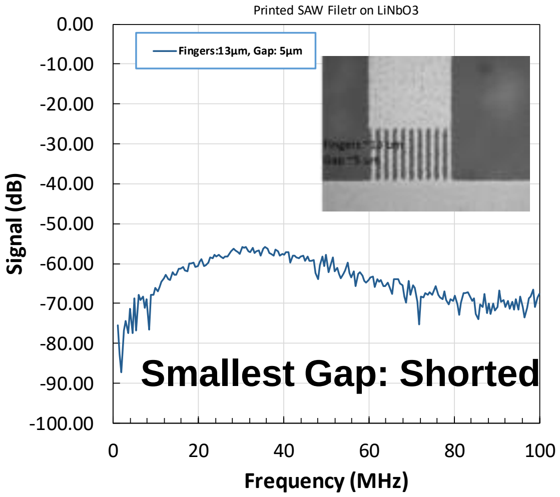


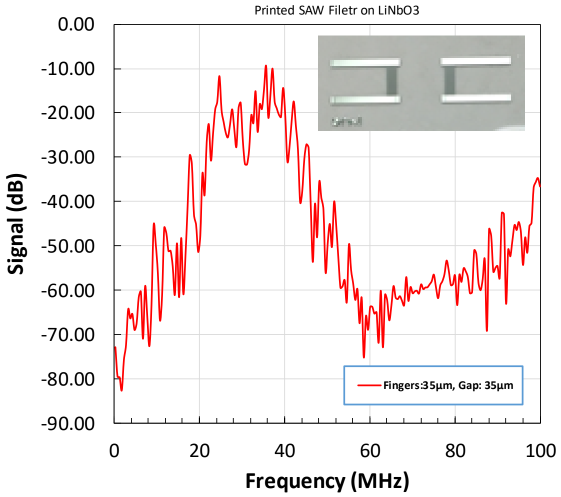
Picture of high frequency probe lab station

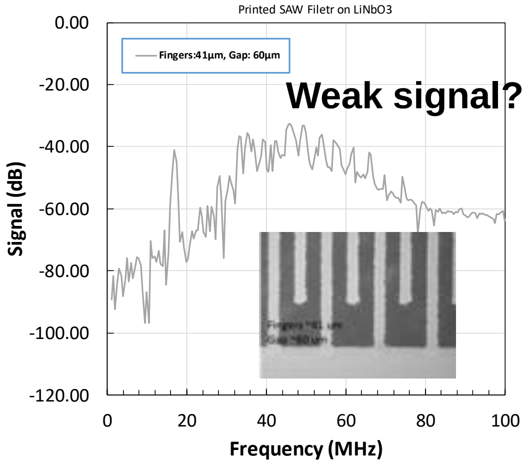


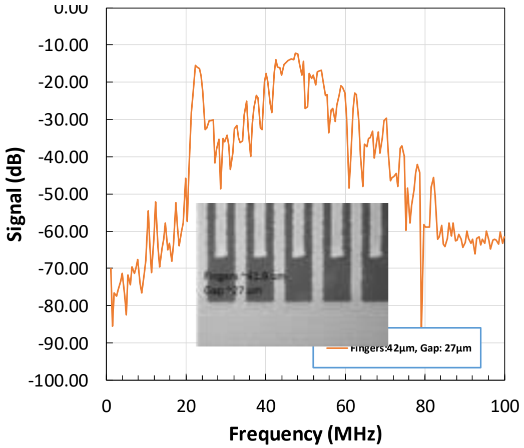












Decreasing gap, Increasing Frequency

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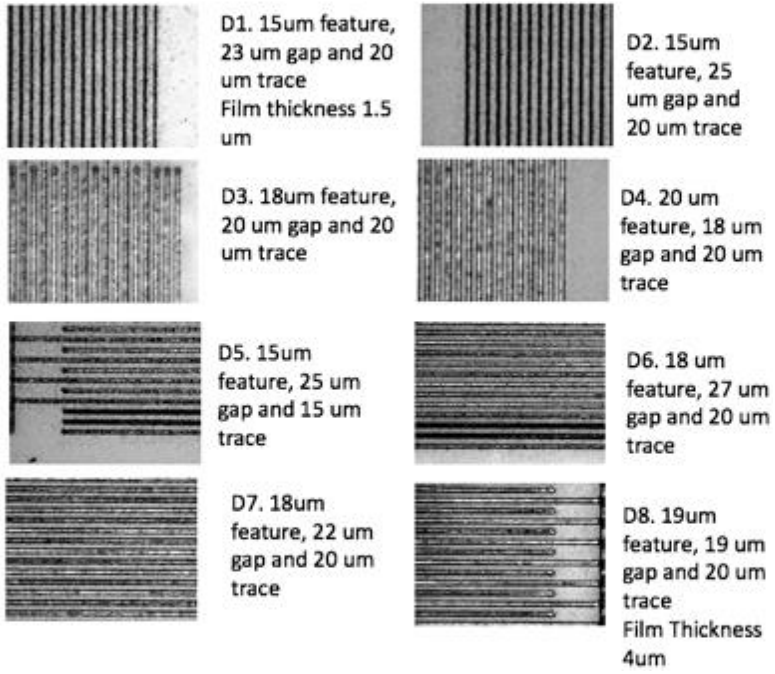
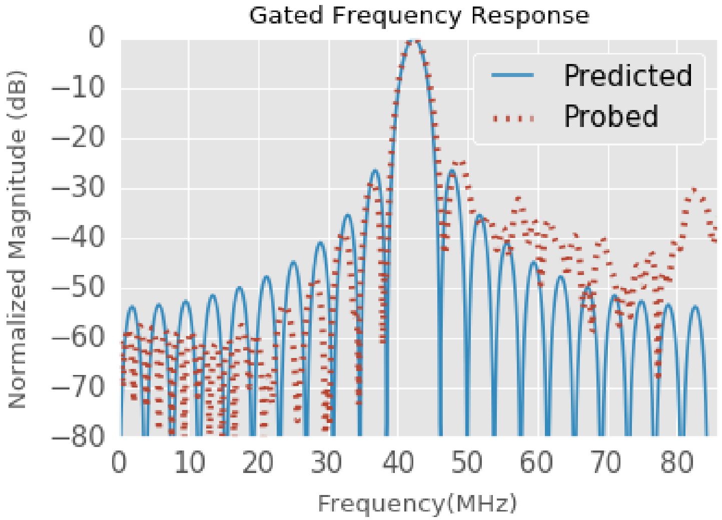
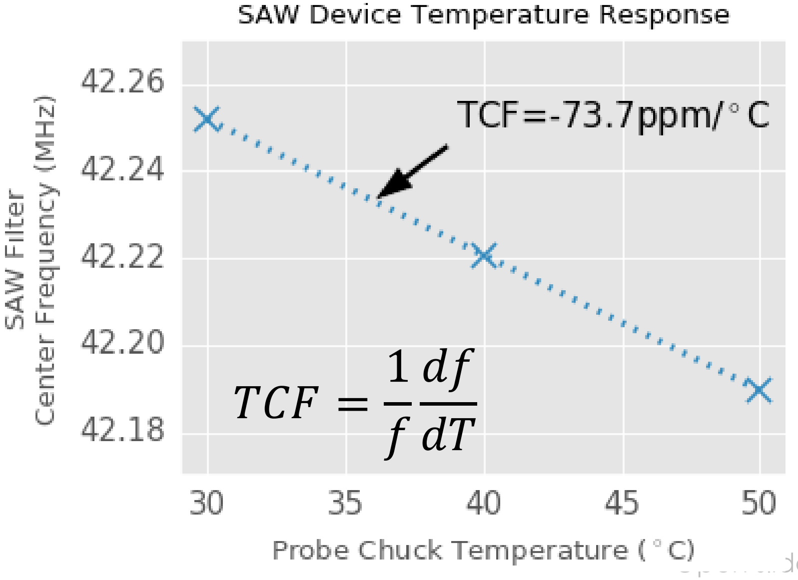
Demonstration of a Printed SAW Temperature

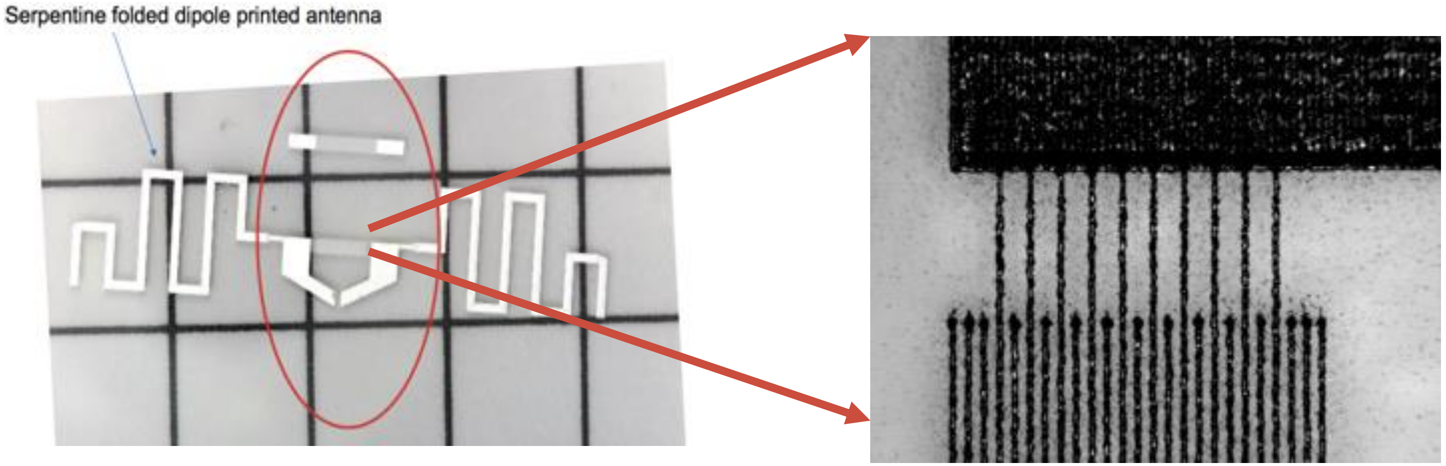






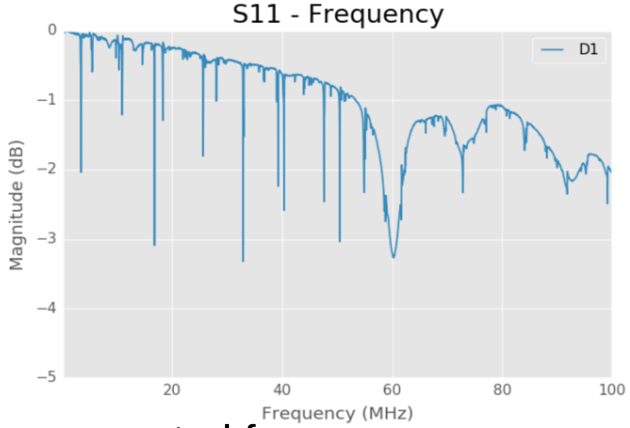
For a 128° Y-cut $LiNBO_3$ the temperature frequency coefficient (TFC) is expected to be 72 ppm/ °C. The experimental results for the printed sensors show a TFC of 73.7 ppm/ °C, only a 2.36 % difference from the expected value.

Challenges & Optimization of Printed SAW Sensors



Picture of SAW device with folded dipole serpentine antenna

Overspray of the ink between the electrodes present a challenge for remote sensing



central frequency response

- A printed surface acoustic wave device with electrode linewidth of 10 µm, has a central operating frequency of approximately 85 MHz requiring the system RF transceiver to operate at that frequency range.

- A companion antenna tuned for 85 MHz should be connected to the sensor. In theory, a full-wave antenna for a device operating at 85 MHz operation frequency should have a length, in air of 3.45 meters

Photograph of EPB Riverside Substation

Summary

- The rapid fabrication of SAW devices with control over feature size by aerosol ink jet direct printing is demonstrated.
- The central frequency of the devices can be tuned from 40-87 MHz.
- Printed SAW devices demonstrated the capability to be used as a temperature sensor.
- The development of printing systems, materials, and manufacturing techniques expand the capabilities for embedded sensors in structural materials, and new functionalities.