Printing and Trimming Embedded Passives Using DOD Ink Jet Technology

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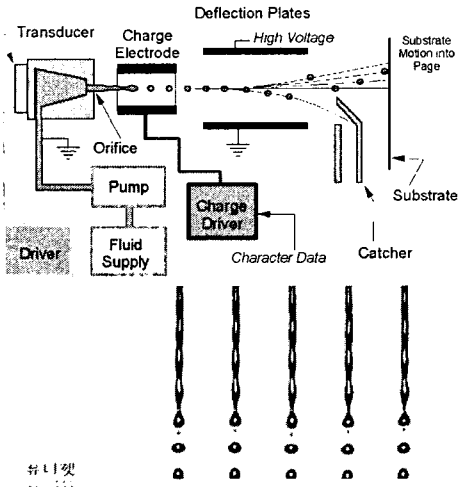
Agenda

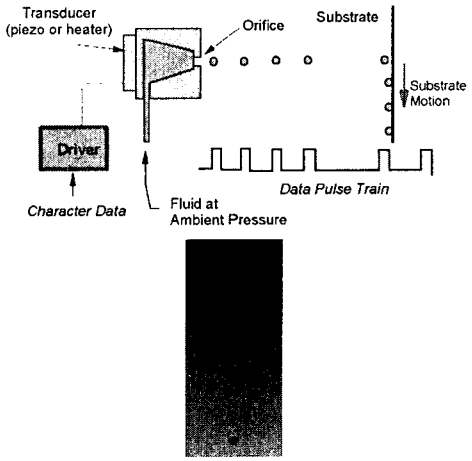
- Background on Ink Jet Technology
- Equipment/Print Heads
- Industrial Applications of Ink Jet Technology
- Trends of Embedded Passives
- Embedded Resistor Printing
- Embedded Resistor Trimming
- Cost Analysis
- Interface Reliability Results
- Other Passive Elements
- Conclusions

Continuous vs. DOD Ink-Jet

Continuous Ink-Jet Technology



Demand Ink-Jet Technology



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Ink-Jet Technology - Advantages

- **High Precision Deposition**
- **Non-contact Printing**
- **Data Driven – Digital Process**
- **Flexible Manufacturing Process**
  - Lot size of 1
  - No tooling
  - Rapid Change Over
  - Multiple Heads
  - Different Materials
- **Low Cost**
- **Environmentally Friendly**

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Ink Jet Technology- Advantages

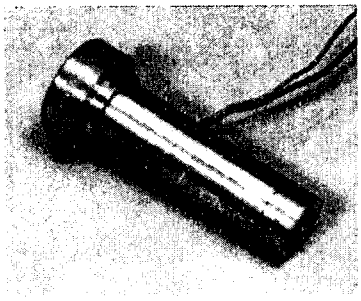
- **Accurate volume control of Droplet**
  - Control ball size up to ± 2%
- **Fine Pitch (< 50㎛) and Small Ball Size(20 ㎛)**
- **Direct-write of materials**
- **Wide range of materials**
  - Ink, Paste, Wax, metals, polymers, fluxes, Slurries, ...
  - Wide operating temperature range (0-370℃)
- **Wide range of resolutions**
  - 15-120㎛ drops + N drops per spot
- **Wide range of rates**
  - 1Hz - 1MHz

Jetting: Fluid Properties Requirements

- Newtonian
  - Visco-elastic behavior undesirable
- Viscosity
  - 2-40 cP
- Surface Tension
  - 20-70 dynes/cm
- Particle Laden Fluids
  - particle size < 5 μm; ideal nanoparticles
  - stable dispersion required

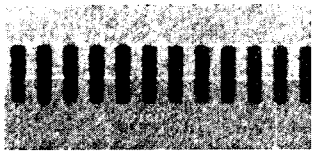
Single Jet Devices

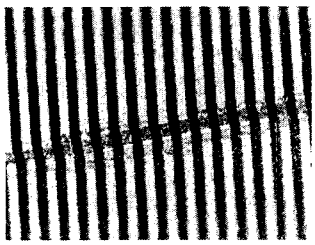
Room Temperature Printheads



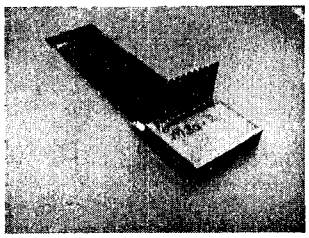
High Temperature Printhead

Multi-channel Array Printhead-cont.

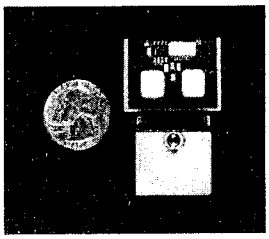




Micro fabricated structures 170um pitch



10-fluid printhead

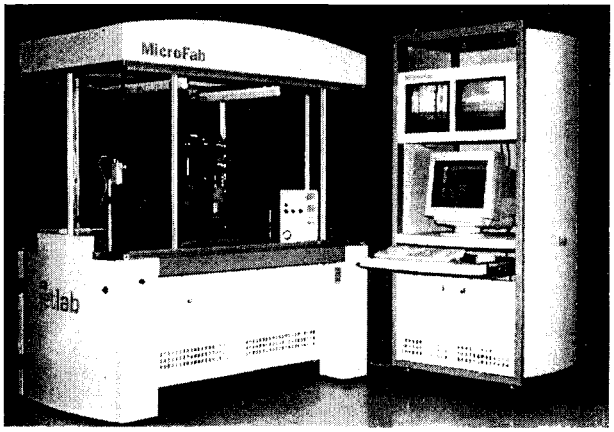


120 channel printhead with onboard drive electronics

Polymer orifice array, 170um pitch

Printhead in operation

jetlab® Printing Platform



- High Accuracy and repeatability
- Ideal prototyping and process development

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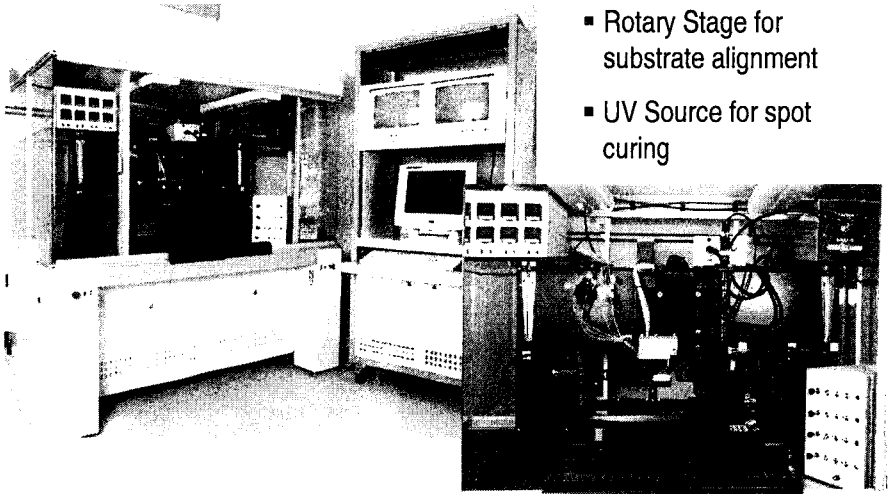
jetlab® Upgrade



- Rotary Stage for substrate alignment
- UV Source for spot curing

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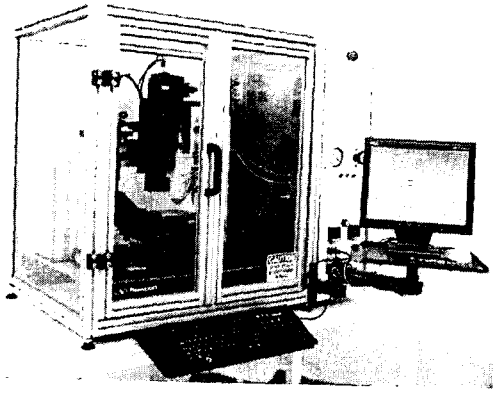
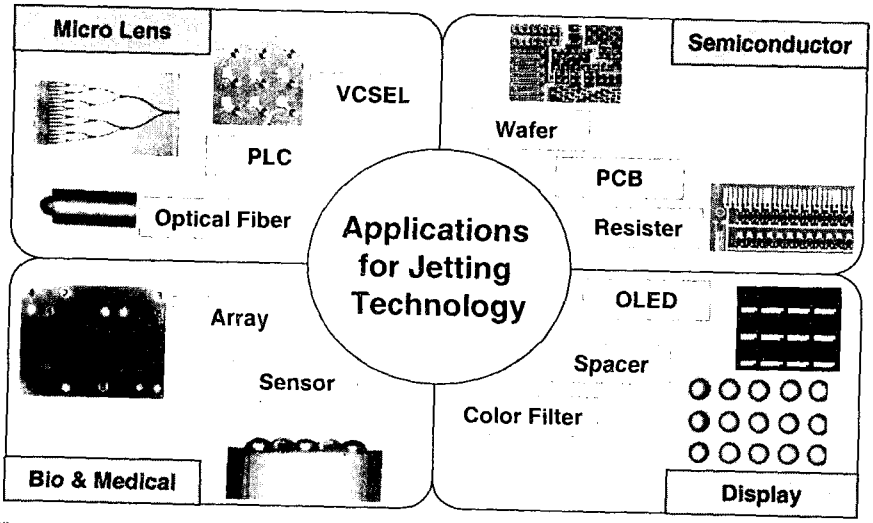
Jetlab® II - Table Top Printer

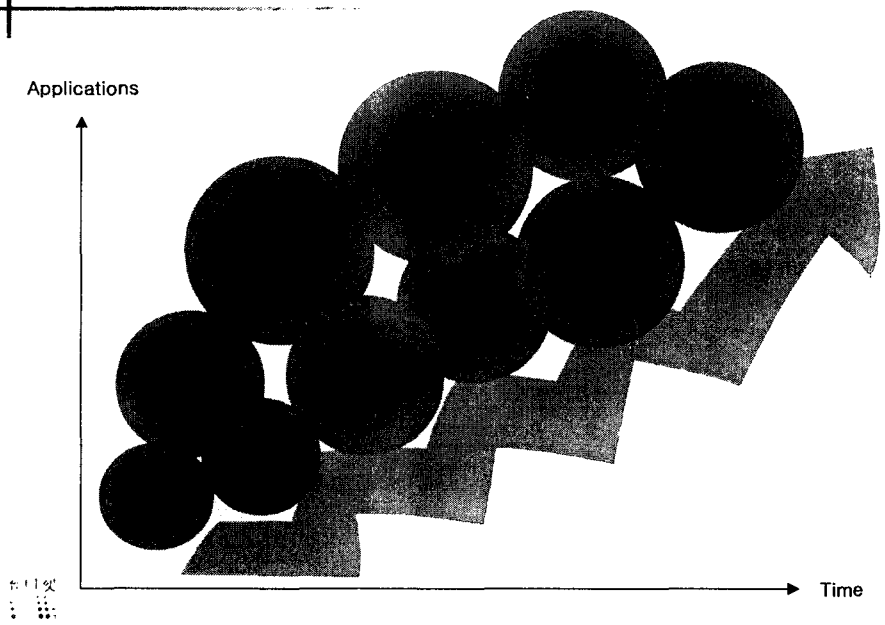


- Smaller foot print
- Similar capabilities
- Ideal for development of processes and materials in laboratories

Industrial Applications of Ink Jet Technology



Roadmap of Ink Jet Technology



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Trends of Embedded Passives

- Applying the various materials
  Resistors: MacDermid Ni/P, Dupont LaB_6, Polymer Paste
  Capacitors: 3M C-ply, Dupont $BaTiO_3$
- Producing the various prototypes with embedded passives
  Nortel Emulator: 49 buried resistors and 29 buried capacitors
  Delphi Emulator: 205 buried resistors and 25 buried capacitors
  HP Emulator: replaced 44% of decoupling capacitors
- Developing Embedded PCB Manufacturing Technique
  MacDermid, Merix, CORETEC, E TOUCH, and etc
- Expecting the embedded passives products at the market in 2004.
  - Consistency of Product, Change of Resistor Value in Lamination, Material Handling (Equipment), Design Tool, & Productivity,

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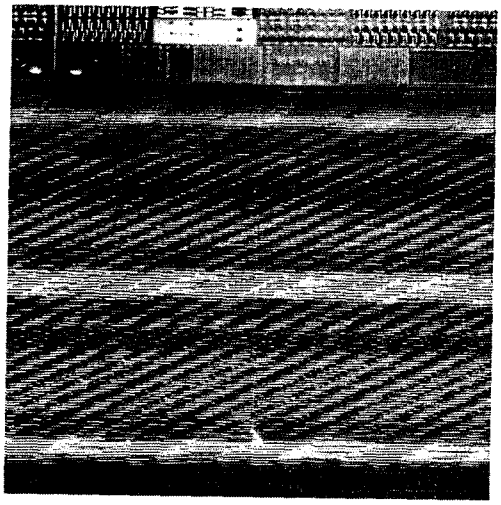
Printed Embedded Resistors



- Polyimide resistors
- Resistor size: 5-55 mils (0.125-1.375 mm)
- 125, 250 and 500 μm Cu conductors

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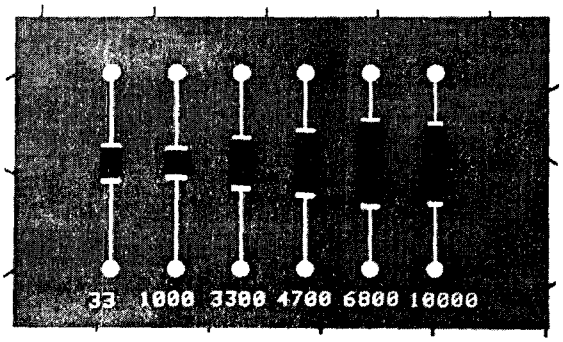
Printed Embedded Resistor-cont.



A Test Vehicle showing printed resistors of different aspect ratios

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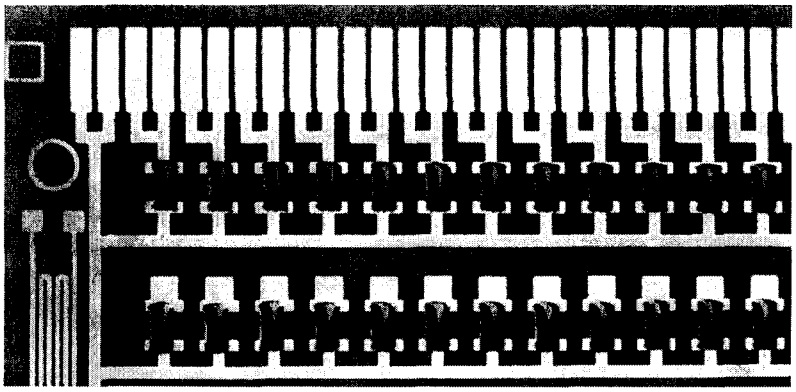
Printed UV-Curable Resistors



A Test Vehicle Printed with Nanotube containing Resistor Ink

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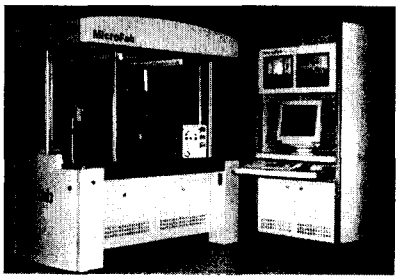
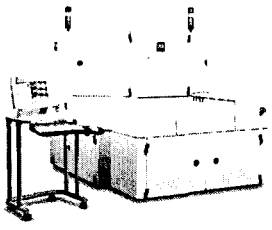
Ink Jet Printing and Laser Trimming

Complementary

- IJ printing lowers the resistance of embedded resistors by adding conductive material.
- Automated rework of fabrication and laser trim defects.
- Laser trimming increases the resistance by taking material out.





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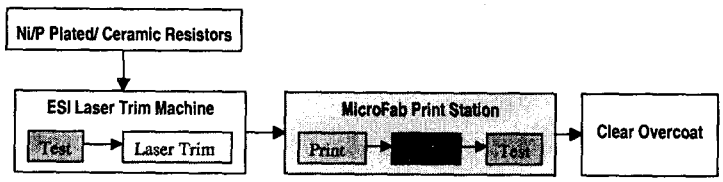
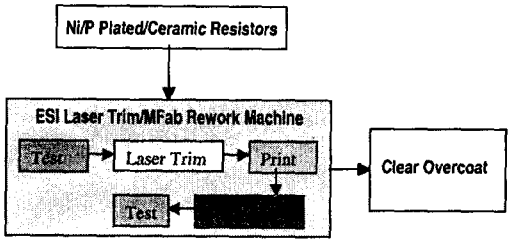
Partial Process Flow
Embedded Resistors

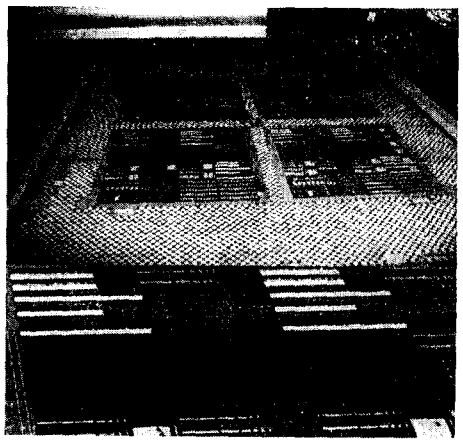
Option 1.



Option 2.

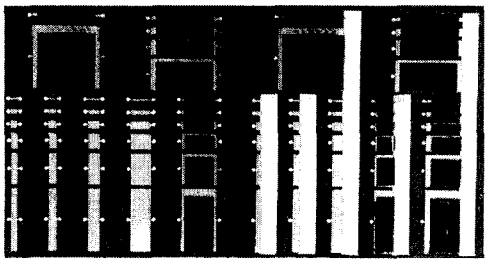


Embedded Resistor Trimming



- **Ni/P plated resistors trimmed using inherently conductive polymer**
- **12"x18" (300mmx450 mm) four-up PWB inner layer panel**
- **Demonstrated trim down: up to 35%**
- **Resistor size trimmed**
  - 10 mil – 330 mil

Embedded Resistor Trimming Results-Initially



A portion of Ni/P plated Test Vehicle inner layer trimmed down using ICP and Ink jet printing

Trimming Target: 40 ohm/square

TV-2R Inner Layer-4				
Size	Before Trimming		After Triming	
mil	Average	Std Dev	Average	Std Dev
320X170	51.4	8.1	38.7	5.8
160X170	54.4	11.4	42.2	9.6
80X170	53.9	9.3	40.9	9.1
40X170	53.7	9.3	38.9	7.2
20X170	55.7	12.0	40.4	9.4
10X170	53.9	6.3	42.8	9.5

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Embedded Resistor Trimming Results

After Optimizing Print Process

TV-2R Inner Layer-2				
Resistor	Before Trimming		After Triming	
Size	Average	Std Dev	Average	Std Dev
320X90	30.0	0.2	26.8	0.8
160X90	30.2	0.4	26.5	0.5
80X90	29.9	0.8	26.2	1.5
40X90	30.6	0.7	25.9	0.9
20X90	32.0	0.7	26.0	1.1
10X90	31.7	1.0	25.0	0.9

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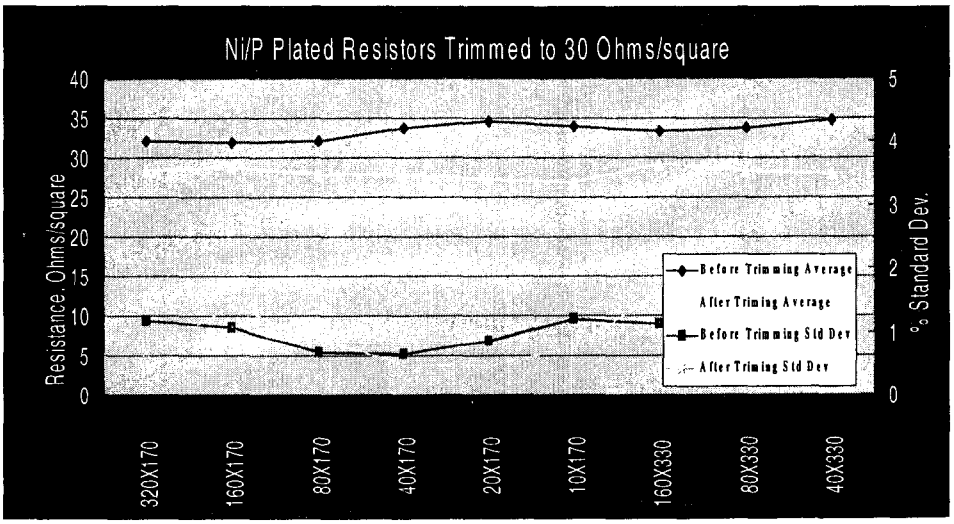
Embedded Resistor Trimming Results

After Optimizing Print Process

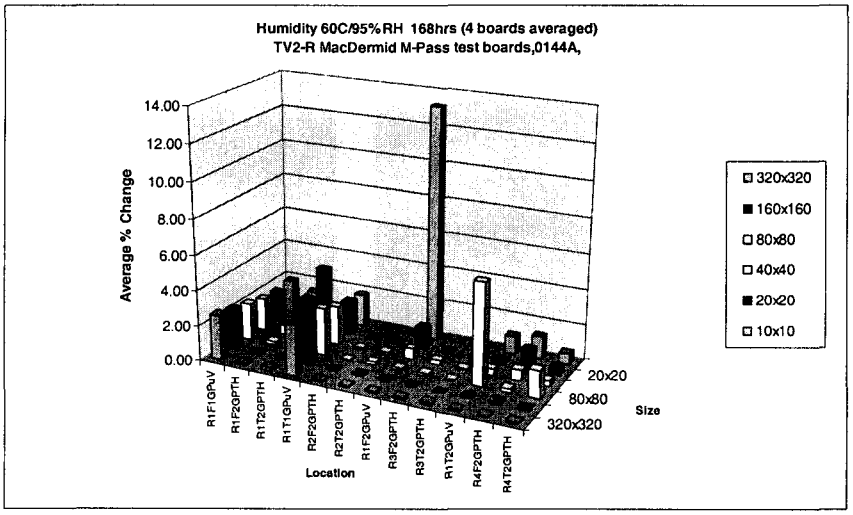
TV-2R Inner Layer-2				
Resistor	Before Trimming		After Triming	
Size	Average	Std Dev	Average	Std Dev
320X50	25.8	0.3	24.5	0.6
160X50	25.6	0.6	24.8	0.3
80X50	25.7	0.5	24.4	0.7
40X50	26.7	0.5	24.8	1.1
20X50	28.3	0.6	24.5	0.8
10X50	29.2	1.3	24.4	0.9

Embedded Resistor Trimming Results



Temperature/Humidity Test Results

Boards with NO Ink Jet Trimming



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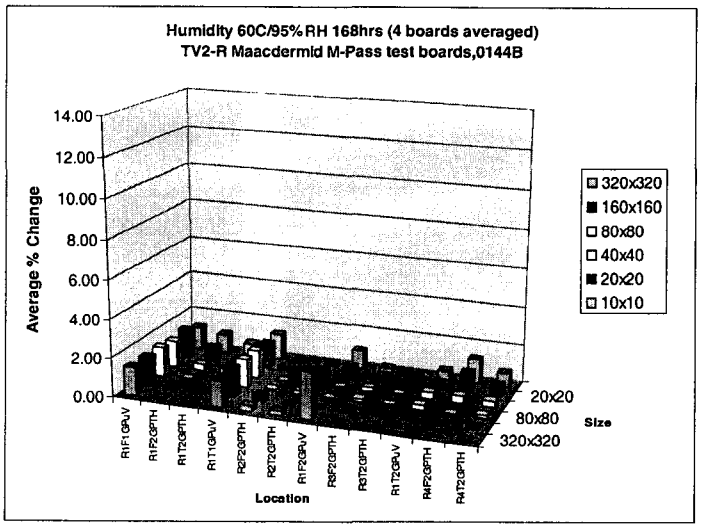
Temperature/Humidity Test Results

Boards with Ink Jet Trimming



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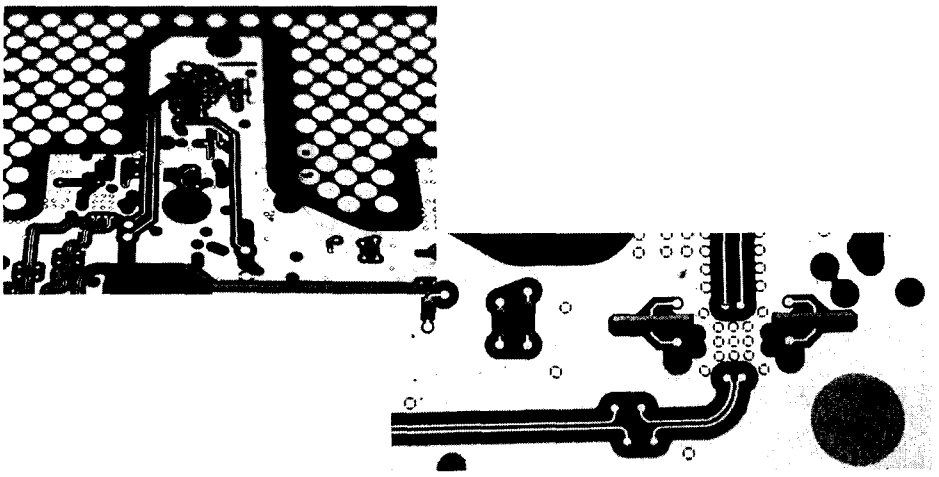
Emulator Trimming



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Emulator Trim Results

Emulator Trim Results (N=6)

1 drop per spot; Drop Pitch 50 micron in both X and Y print directions

Resistor Size (mils)	Average (ohm/sq)	Standard Deviation	Average (Ohm/sq)	Standard Deviation
40 x 20	37.0	1.8	33.2	2.7
50 x 20	35.7	1.2	30.7	2.7
120 x 20	39.8	1.7	32.9	2.4
220 x 10	32.8	4.5	27.1	2.4

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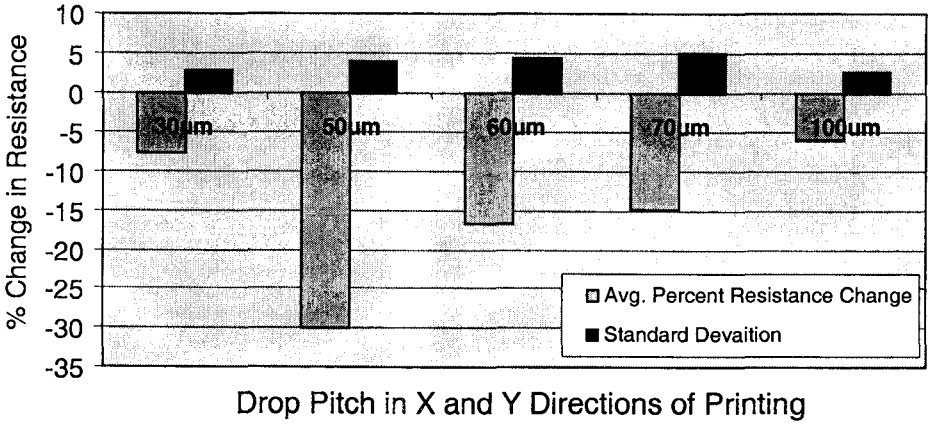
Trim Variables

- Optimum curing temperature and time key to resistor rework process in addition to the thickness of the conductive polymer.

Variables for Optimum Trimming of Ni/P Plated Resistors							
Print Variables							
Pitch in X (μm)	30	40	50	60	70	100	Vary
Pitch in Y (μm)	30	40	50	60	70	100	Vary
Number of drops per Spot	1	2	3	4			Fixed
Drop Size	50	60					Fixed
Number of print passes	1	2	3	4			Fixed
Cure Variables							
Temperature(℃)	150	160	170				Fixed
Time (secs)	30	15	10				Fixed

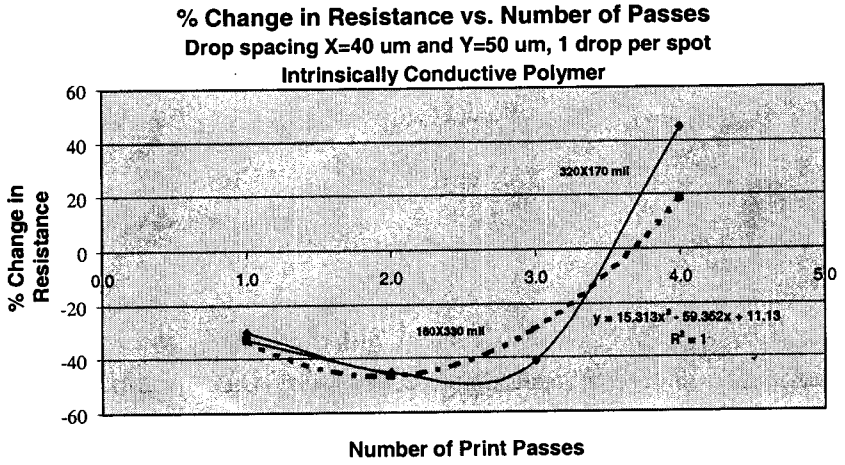
Embedded Resistor Trimming Guideline

Guideline for Trimming Resistors Using Conductive Polymer

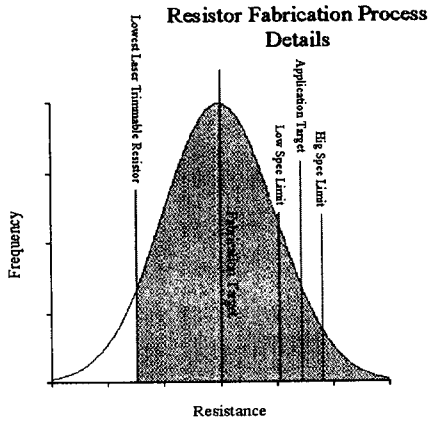


Drop Pitch in X and Y Directions of Printing

Embedded Resistor Trimming
Guideline-cont.



Cost Analysis



Courtesy: CALCE

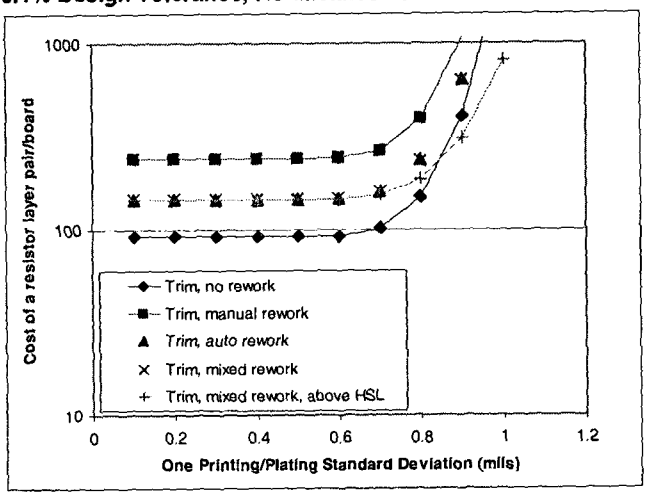
Ink Jet Trimming

- **Automated process**
- **Less scrap**
- **Low cost**
- **Reliable**
- **Repeatable**

Cost Analysis-cont.

Storage Tek Fiber Channel Board

0.1% Design Tolerance; No thickness variation

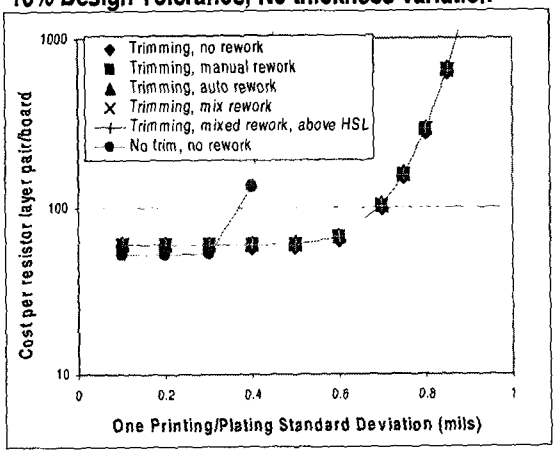


Courtesy: CALCE

Cost Analysis-cont.

Storage Tek Fiber Channel Board

10% Design Tolerance; No thickness variation

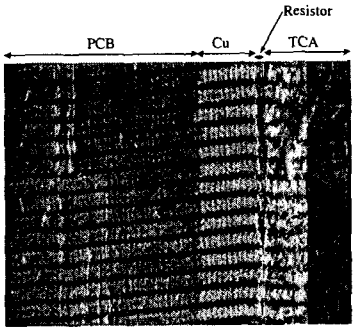


Courtesy: CALCE

Interface Reliability Test Results

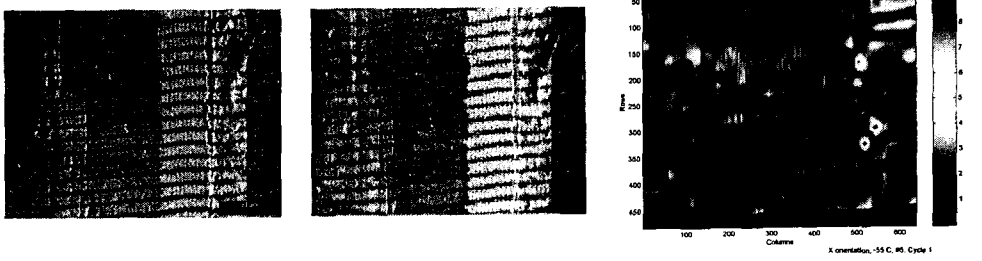
Electron-Beam Moire Test

Center of Specimen U-Field Image



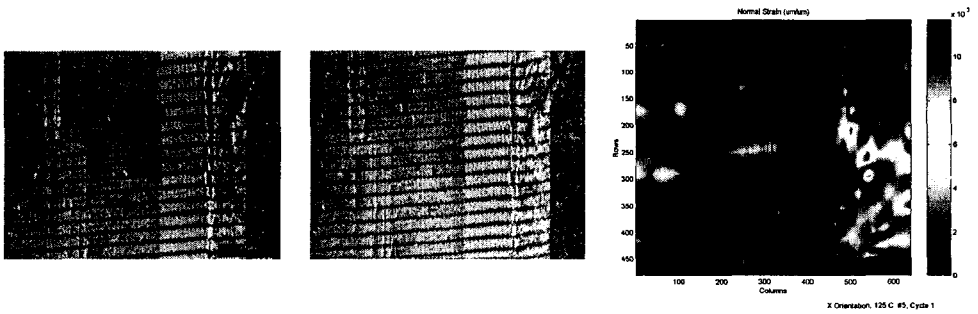
Courtesy: NIST, Boulder

Center of Specimen, -55 ℃ U-Field Image



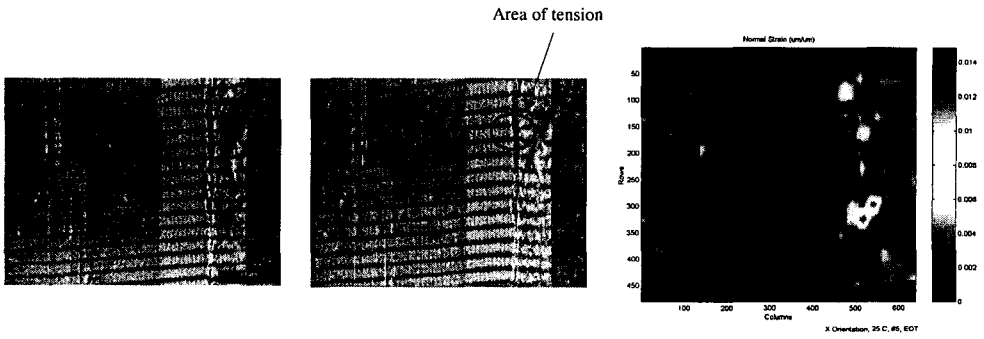
Courtesy: NIST, Boulder

Center of Specimen, 125 ℃ U-Field Image



Courtesy: NIST, Boulder

Center of Specimen,
25 ℃, End-of-test U-Field Image



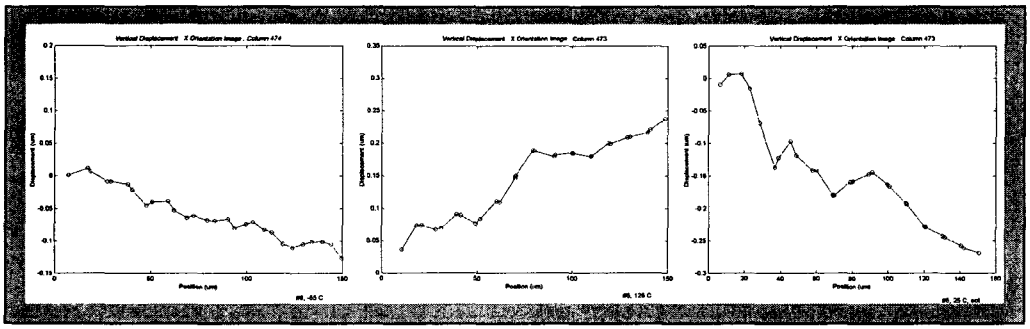
Courtesy: NIST, Boulder

DISPLACEMENT MEASUREMENTS FROM THE RESISTOR

- AT -55, 125 , AND 25 ℃ end-of-test

CYCLE 1

(slope = normal strain)



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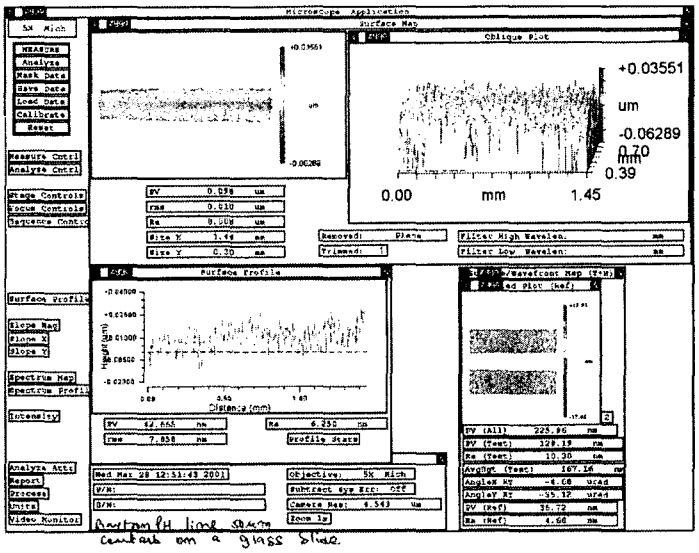
Thickness Measurement

Printed Conductive Polymer



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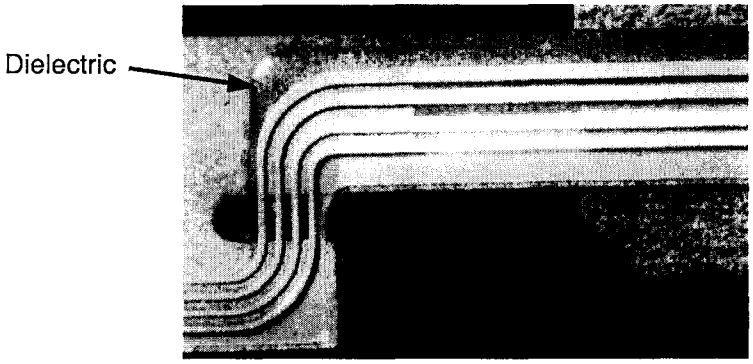
Other Passive Elements -cont.

Dielectrics-Capacitor

- Disk drive head component with UV-cure epoxy printed over 50um wide gold leads



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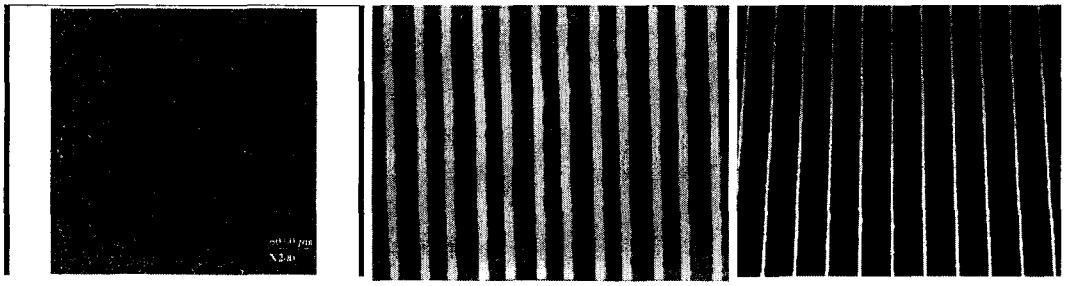
Other Passive Elements

conductor and Ferrite - Inductor



Ferrite nanoparticle layer

250μm Silver lines printed on ferrite

Gold lines printed on FR-4; <200°C cure

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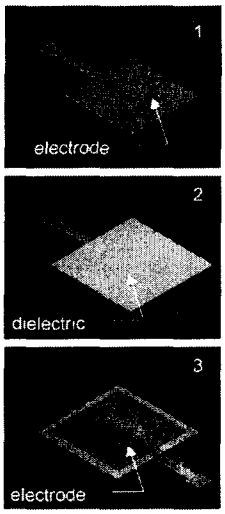
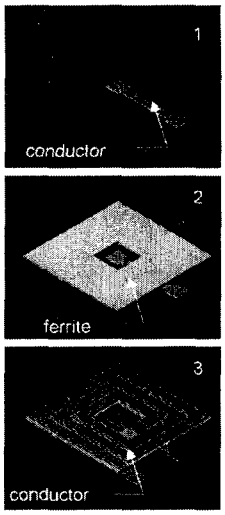
Other Passive Elements

Capacitor and Inductor



Capacitor



Inductor

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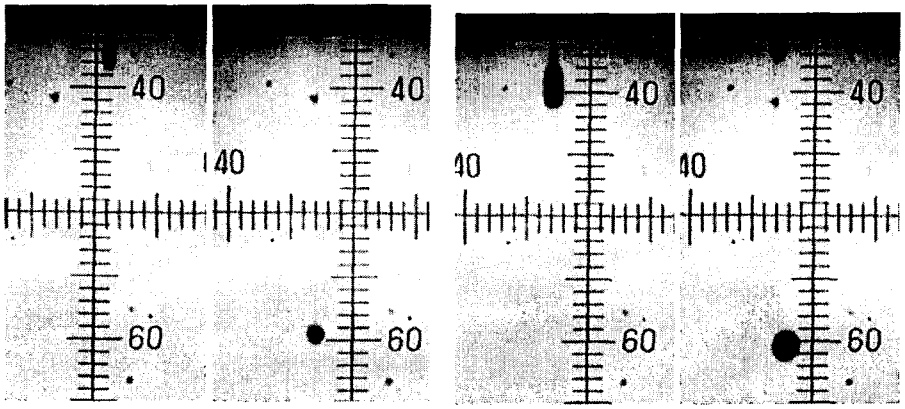
SolderJet™ Drop Formation

Drop Size Modulation 60um to 110 um



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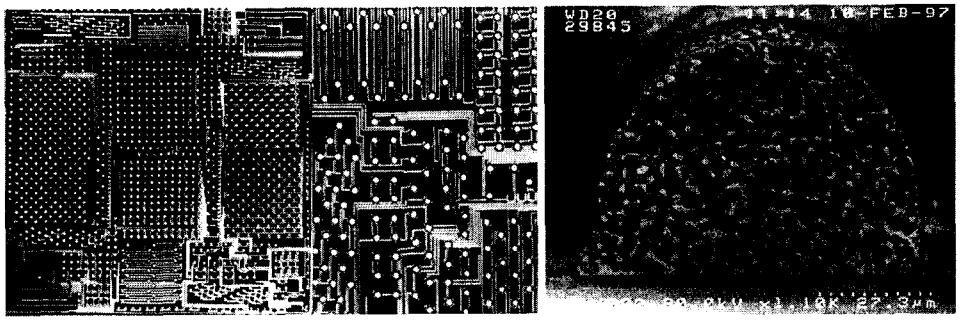
Solder Jet™

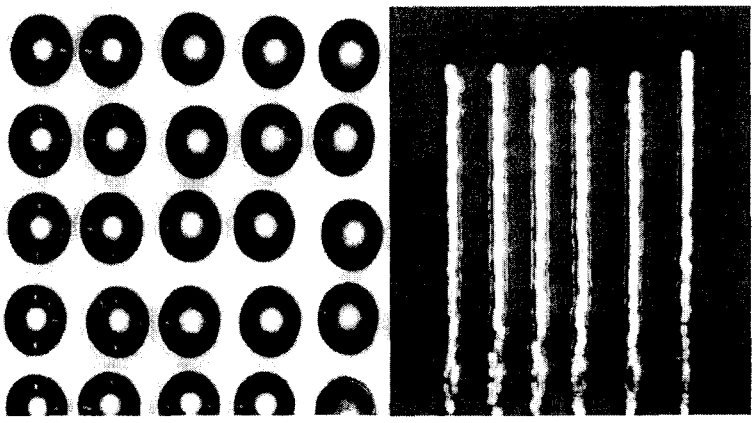


Microprocessor test vehicle (60um; 1440 sites)

Solder Jet™
Small Droplet and Tower Printing

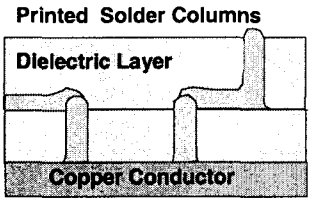
24μm bumps **on** 35μm centers

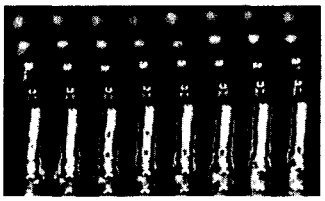
24μm towers



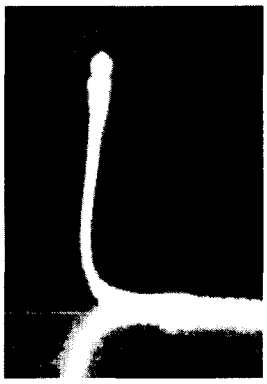
Printed Solder Interconnects

MEMS & CSP Applications





60μm towers



3-D structure,
60μm feature size

24μm towers

Conclusions

- **Successful demonstration of printing and trimming of embedded resistors using conductive polymers**
- **Ink jet trimming of embedded resistors a reliable and repeatable process. High speed and environmental test results excellent.**
- **Ink jet printing of capacitors and inductors feasible with availability of suitable materials for conductors and dielectric.**
- **Suited for industrial production as well as prototyping.**
- **Seeking partners to take this technology to the next step.**