Additively Manufactured Flexible Hybrid Electronic Sensor for Discrete Fatigue Crack Detection

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Overview

- Introduction
- Sensor design and manufacture
  - Via generation
  - Manufacturing process sequence
- Experimental validation
  - Tear test
  - Wireless integration
- Conclusions and future work

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Introduction

- Fatigue cracking is common in aluminum aircraft structures
- Cracks must be monitored before reaching a critical size
- Printed flexible electronics offer conformable materials with sensing
- Printed flexible hybrid electronics integrate semiconductor components to allow flexible computing

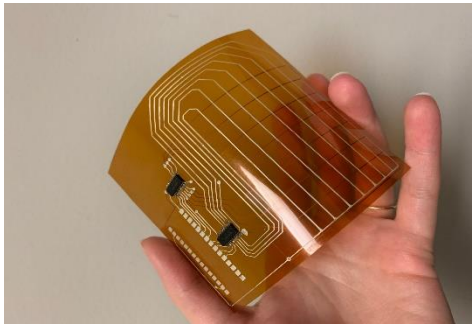

Figure 1a. Printed flexible hybrid electronic

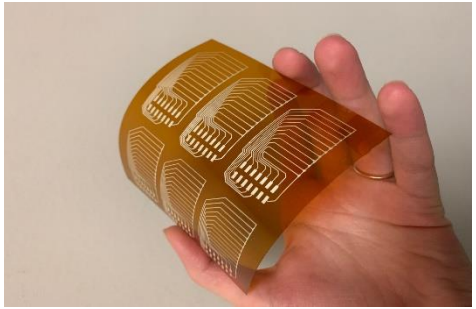

Figure 1b. Printed flexible electronic

Introduction

- Voltera is a commercial PCB printer
- Gerber files are converted to G-code
- Capabilities:
  - Silver conductive trace printing
  - Via and through-hole drilling
  - Solder paste dispensing
  - Reflow soldering
- Intended for rigid substrates

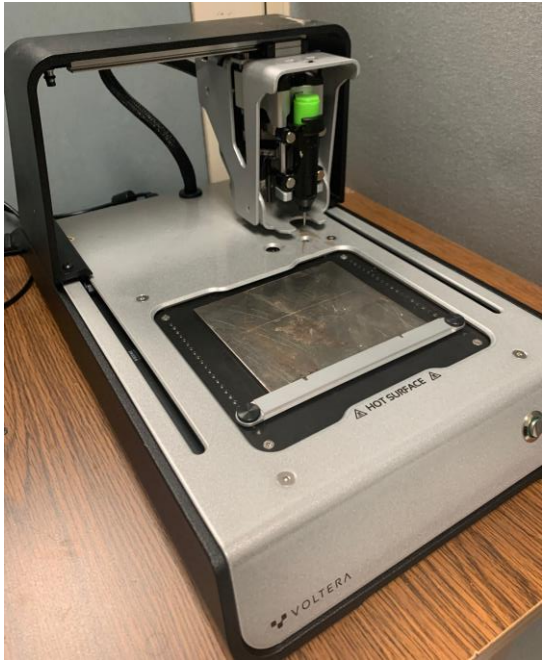

Figure 2. Voltera desktop printer with metal build plate.

Modular PFE Sensor

- Digital input array
- Crack can be monitored in the x-direction
- Array of discrete digital inputs indicate the crack's length
- Each broken trace corresponds to a distance

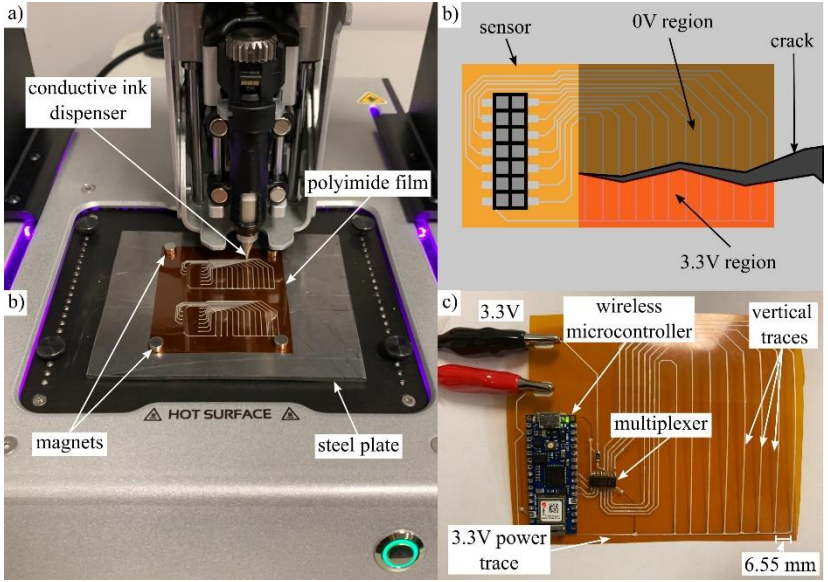

Figure 3. Voltera manufacturing and sensing principle for digital input array.

One-dimensional PFHE Sensor

- Uses the same sensing principle
- Multiplexer and wireless microcontroller integrated
- More complex manufacturing processes:
  - Double-sided printing
  - Via generation
  - Soldering

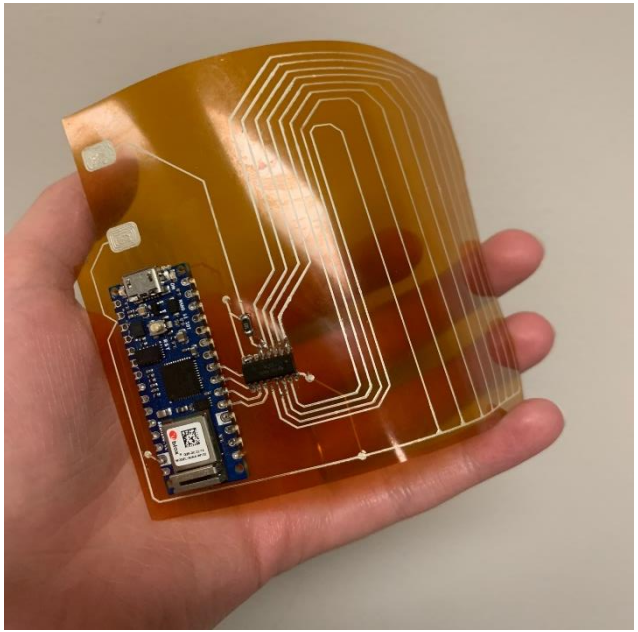

Figure 4. PFHE sensor with digital input array integrated with wireless microcontroller.

Via Generation

- Different techniques on polyimide using Voltera
- Lowest resistance: 61.10 mΩ

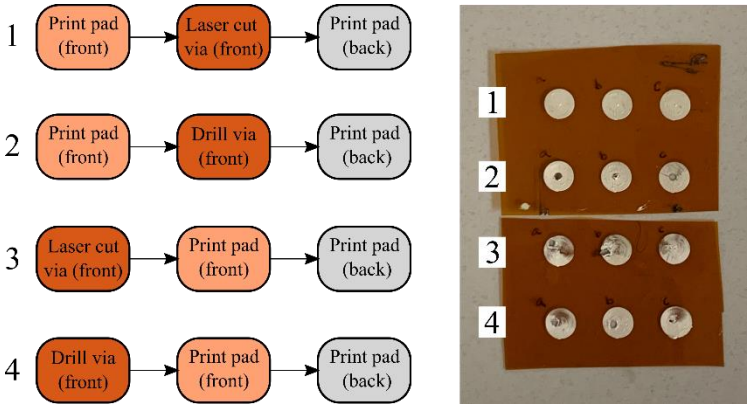

Figure 5. Different manufacturing processes for vias.

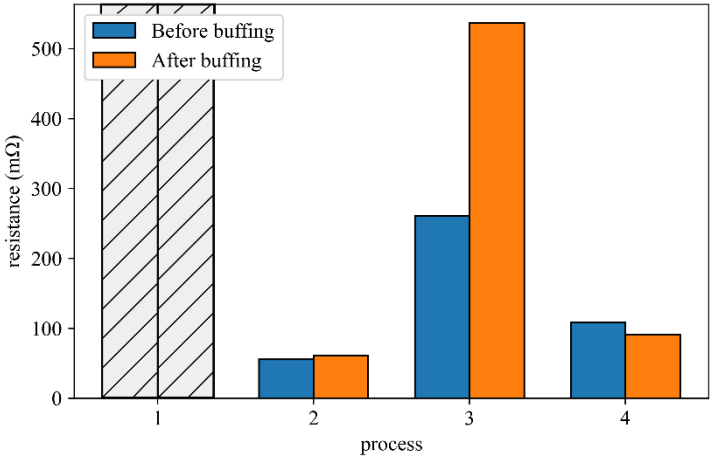

Figure 6. Resistance of vias from each process

Manufacturing Process

- Manufacturing process:
  a) substrate plate adherence
  b) front layer print
  c) front layer thermal sintering
  d) front layer via generation
  e) back layer print
  f) back layer thermal sintering
  g) buffing
  h) solder paste application
  i) solder reflow

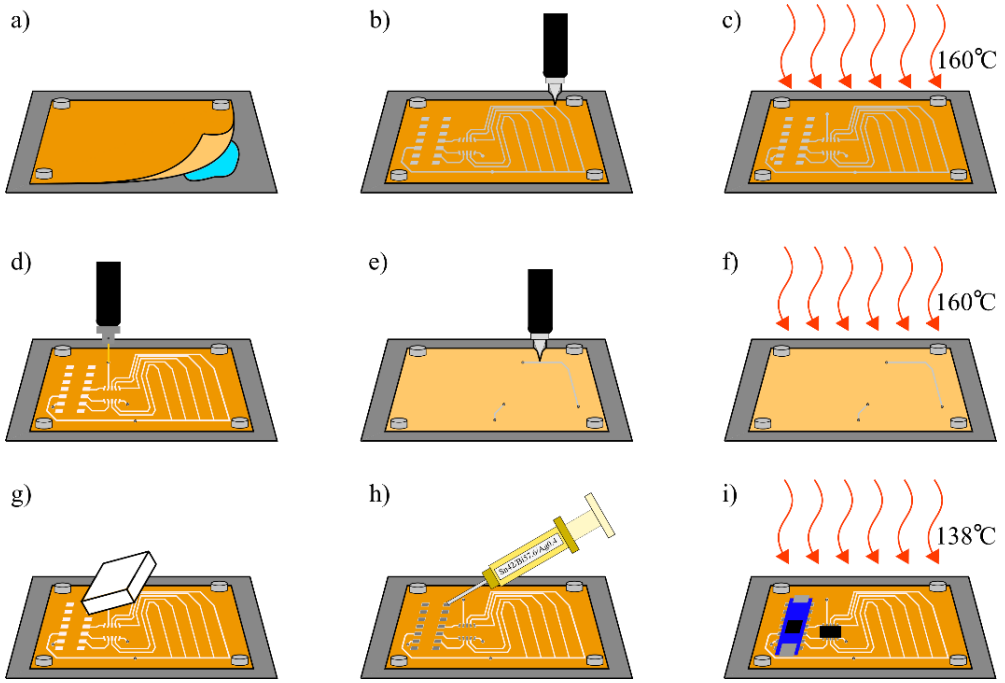

Figure 7. Manufacturing process for one-dimensional PFHE

Tear Testing

- Validate the sensor's ability to detect crack progression
- Sensor was adhered to an aluminum sample with a starting crack and pulled apart
- Arduino Mega is the external processor

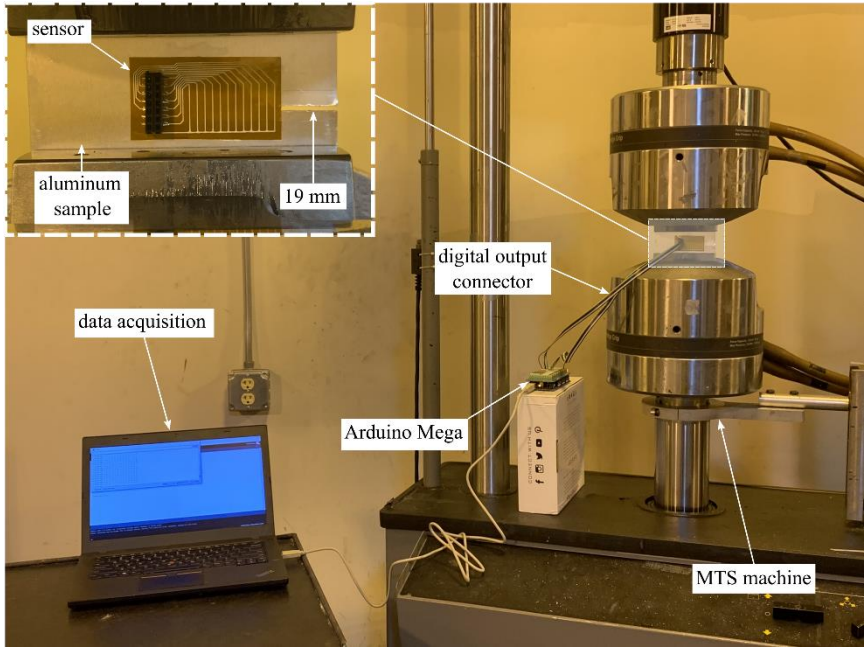

Figure 8. Tear test setup for prototype sensor.

Tear Testing (cont.)

- Traces 12 and 11 broke rapidly
- Trace 10 took longer
- Signal settled at zero
- Digital input signal corresponded to crack length

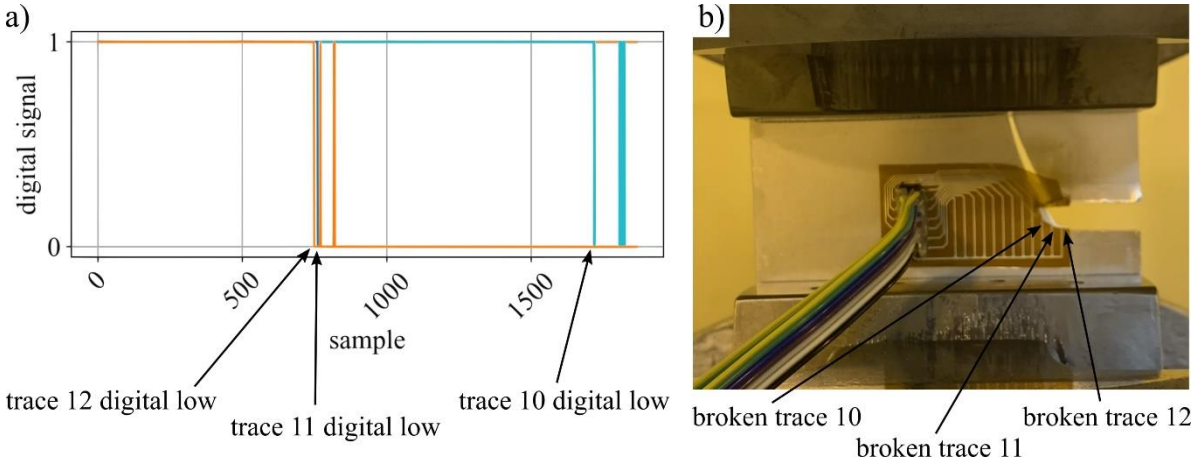

Figure 9. Aftermath of tear testing shows a) change in digital input for each trace over time and b) cracked specimen with torn sensor.

Wireless Testing

- Wireless microcontroller sends data to GUI
- Data is received with no delay
- Material draws more power
  - Polyimide: 231 mW
  - Traditional: 116 mW

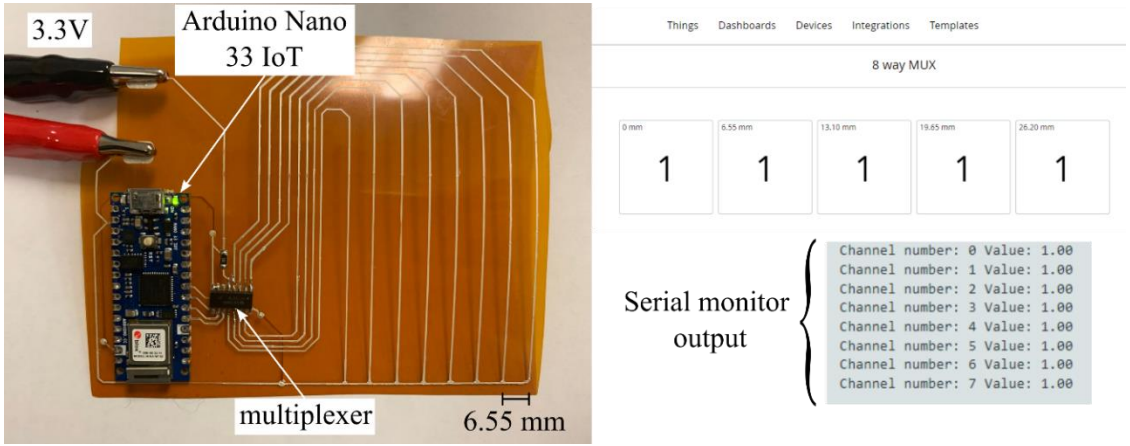

Figure 10. Wireless data transfer test using PFHE sensor will all digital inputs intact.

Conclusion

- Via generation and PFHE manufacturing technique can create effective crack monitoring sensors
- Facilitates:
  - Double sided printing
  - Semiconductor integration
- Future work:
  - Sensing in two directions
  - Power supply issues
  - Improved sensor resolution

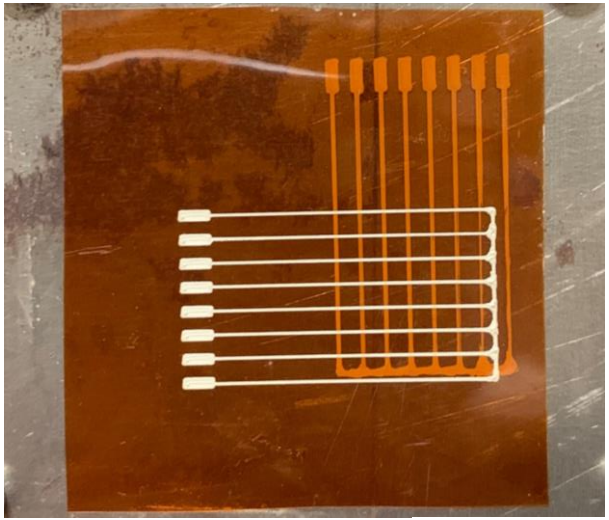

Figure 11. Proposed 2D sensing grid.

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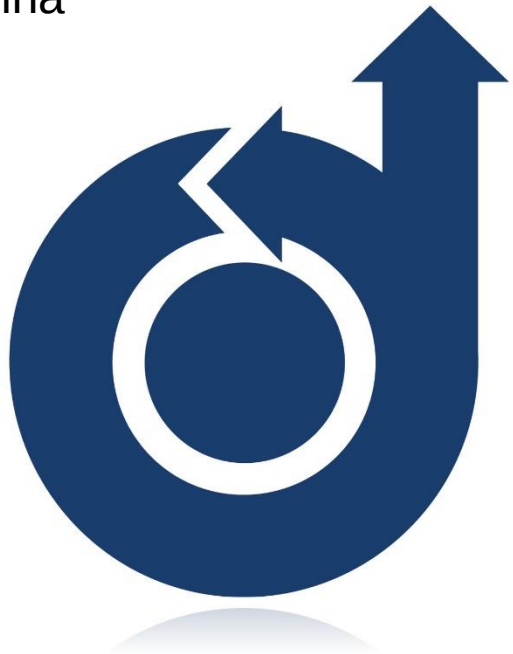

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