

## 2025 IMAPS Device Packaging Conference

# Instrumented Getter using Additive Manufacturing

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and Seung Kim<sup>2</sup>**

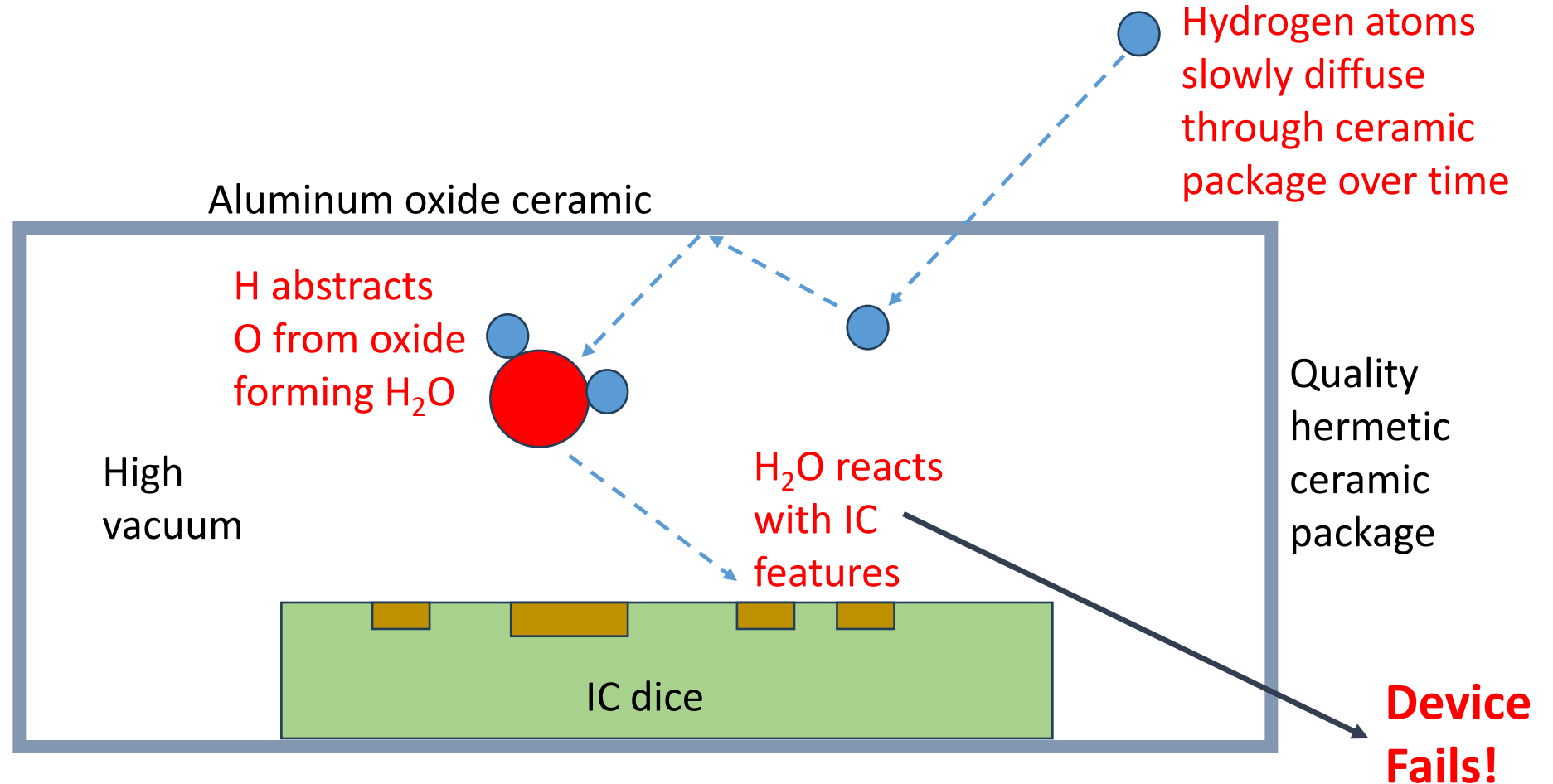
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**6 March 2025**

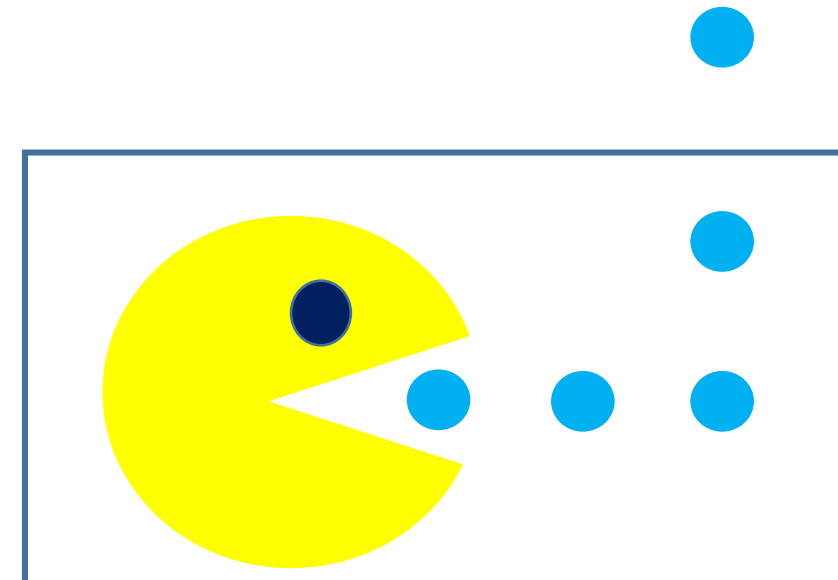
# Introducing the Problem

**High Reliability Applications:**  
heart pacemaker,  
jet engine  
controller, nuclear  
reactor sensor,  
missile guidance  
IMU, etc.



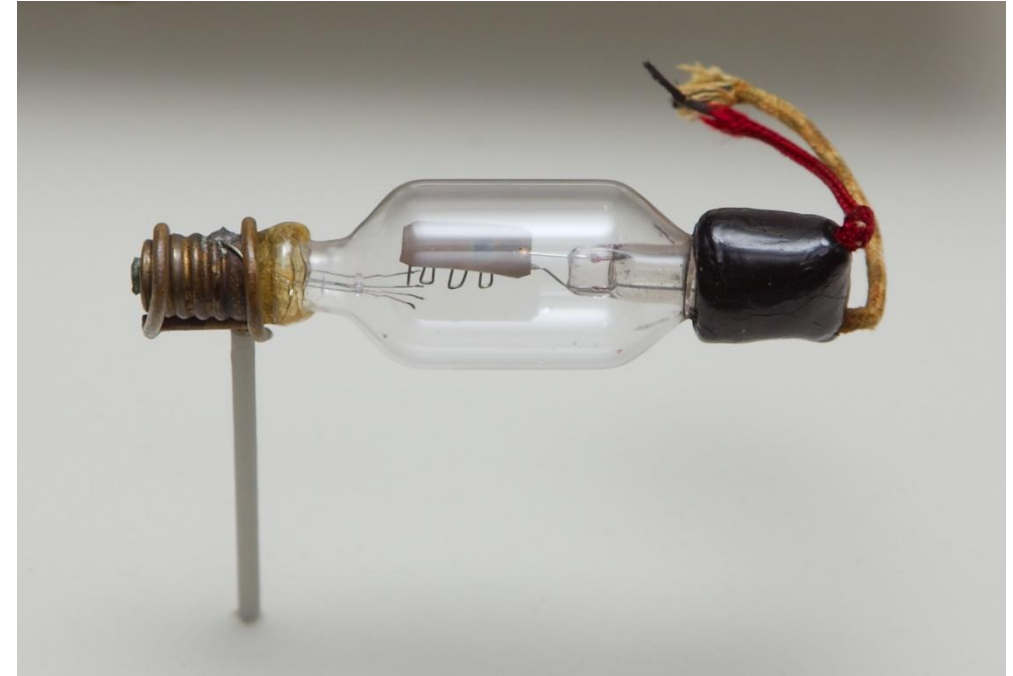
# Getters: the Traditional Solution

- Getters are used to chemically bond and trap certain gases that leak into hermetically sealed packages
  - Can extend the useful life of the packaged component
- The getter is sealed inside the package and you hope it works...
  - Open loop system
  - Catastrophic failure may be the first indication of a problem
- But what if you could instrument the getter to determine its operational status?
  - Now the getter is also a sensor



# A Brief History of Getters

- In use since the invention of the triode vacuum tube
  - Lee de Forest, 1906
- Getters are still in use today
  - CRTs / vacuum tubes
  - High vacuum systems
  - High reliability electronics
  - Optoelectronics
  - MEMS / MOEMS devices
- Getter chemistry has advanced
- But it is still an open-loop system



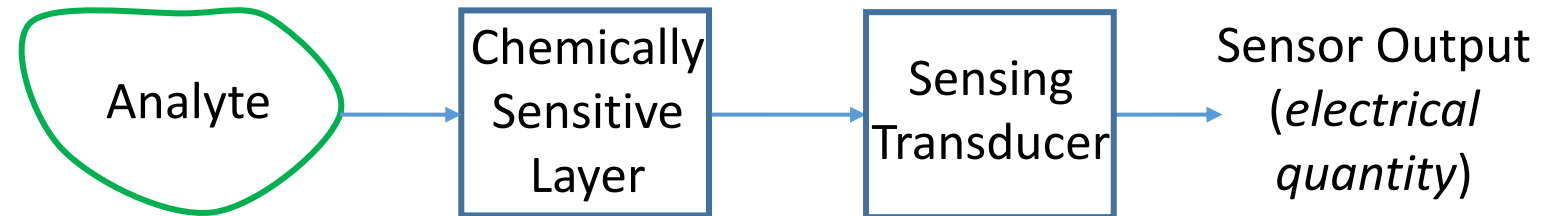
1906 Audion vacuum tube  
Curtesy Wikipedia

# More on Getters

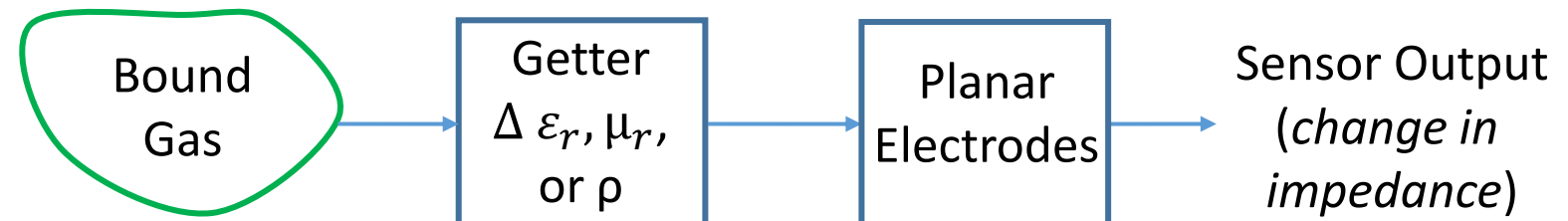
- Getters can be manufactured to bind specific gases, such as
  - Water vapor
  - Carbon dioxide
  - Hydrogen
- Some getters chemically react with the gas while others bind the gas by adsorption
- Some getters require a high temperature thermal activation step after package assembly
  - But not all getters require this step
- The size and/or thickness of some getters can be selected to bind desired quantities of gas molecules

# Viewing the Instrumented Getter as a Chemical Sensor

**Chemical Sensor:**



**Instrumented Getter:**



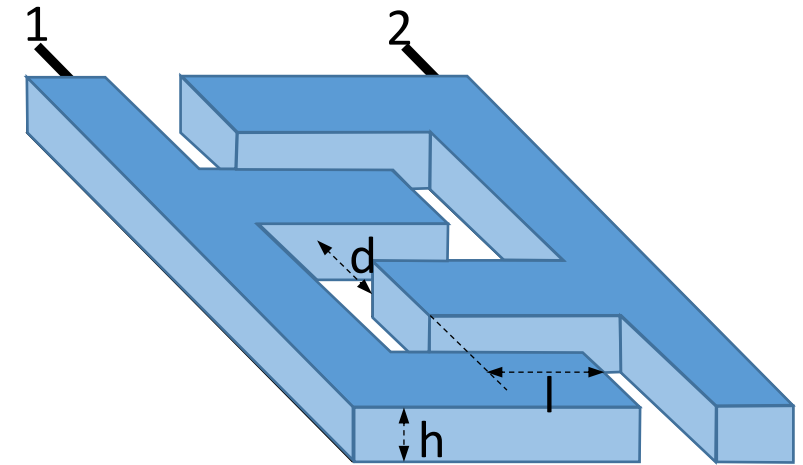
# STAYDRY<sup>®</sup> HiCap3000 Getter as the Chemically Sensitive Layer

- MacDermidAlpha Electronic Solutions high-capacity moisture getter
  - Irreversible getter material for absorbing H<sub>2</sub>O and CO<sub>2</sub>
  - HiCap3000: comes in 2.54 cm precut squares with an adhesive backing layer
  - No thermal activation
- Getter water absorption chemical reaction:
  - $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2$
- CaO: Calcium Oxide
  - $\epsilon_r = \sim 11.8$
- Ca(OH)<sub>2</sub>: Calcium Hydroxide
  - $\epsilon_r = \sim 1.8-3.5$
- Therefore, a capacitive sensor with this getter material as the dielectric should be able to instrument the getter
  - Absorbed H<sub>2</sub>O ↑ : sensor capacitance ↓

# IDE Array as the Capacitive Sensing Transducer

- Capacitive IDE sensing array
  - IDE: Interdigitated Electrode
  - Much of the capacitance is due to fringing outside the plane of the IDE
- The vertical sensing range is approximately 1.33 times the IDE tooth width
- Many possible implementations
  - MEMS
  - Printed Circuit Board (PCB)
  - Thick film (ceramic substrate)
  - Additive Manufacturing (AM)

**IDE Structure**



$$C \cong \frac{(n-1)\epsilon_0\epsilon_r\gamma hl}{d}$$

# IDE Arrays for Capacitive Detection

- IDE arrays have been used in many capacitive sensing applications
- Examples include:
  - Capacitive moisture content measurement of soil
    - R.N. Dean, A.K. Rane, M.E. Baginski, J. Richard, Z. Hartzog and D.J. Elton, "A capacitive fringing field sensor design for moisture measurement based on printed circuit board technology," IEEE Trans. on Instrumentation and Measurement, Vol. 61, No. 4, April 2012, pp. 1105-1112.
  - Capacitive moisture content measurement of grain
    - R.N. Dean, J.D. Craven II Jr., E.A. Guertal and K.A. Varnavas, "A PCB sensor for status monitoring of stored food stocks," IEEE Sensors Letters, vol. 3, no. 4, April 2019, 4pp.
  - Detection of ice
    - R.N. Dean, "A PCB sensor for detecting icing events," IEEE Sensors Letters, vol. 5, no. 1, Jan. 2021, 4pp.
  - PCB IDE sensor array for instrumenting a getter
    - R.N. Dean and M.A. Previti, "Passive wireless instrumented getter," IEEE Sensors Letters, vol. 7, no. 8, Aug. 2023, 4pp.

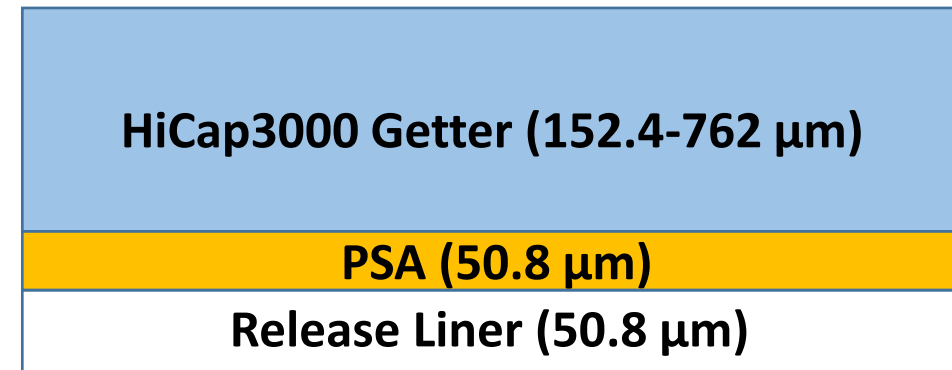
# Selected Sensor Implementation Technology

- AM print the IDE sensing array onto the ceramic lid of the package
  - Alternatively, print it on the inside of the ceramic package
- Attach the getter to the AM printed IDE sensing array
- Electrically connect the IDE to the packaged component
  - It would monitor the getter as needed
- This implementation does not add a separate sensing substrate to the package
  - MEMS → adds a Si substrate
  - PCB → adds a polyimide or FR4 substrate
  - Thick film → adds a ceramic substrate

# Capacitive Interrogation of the HiCap3000 Getter Material

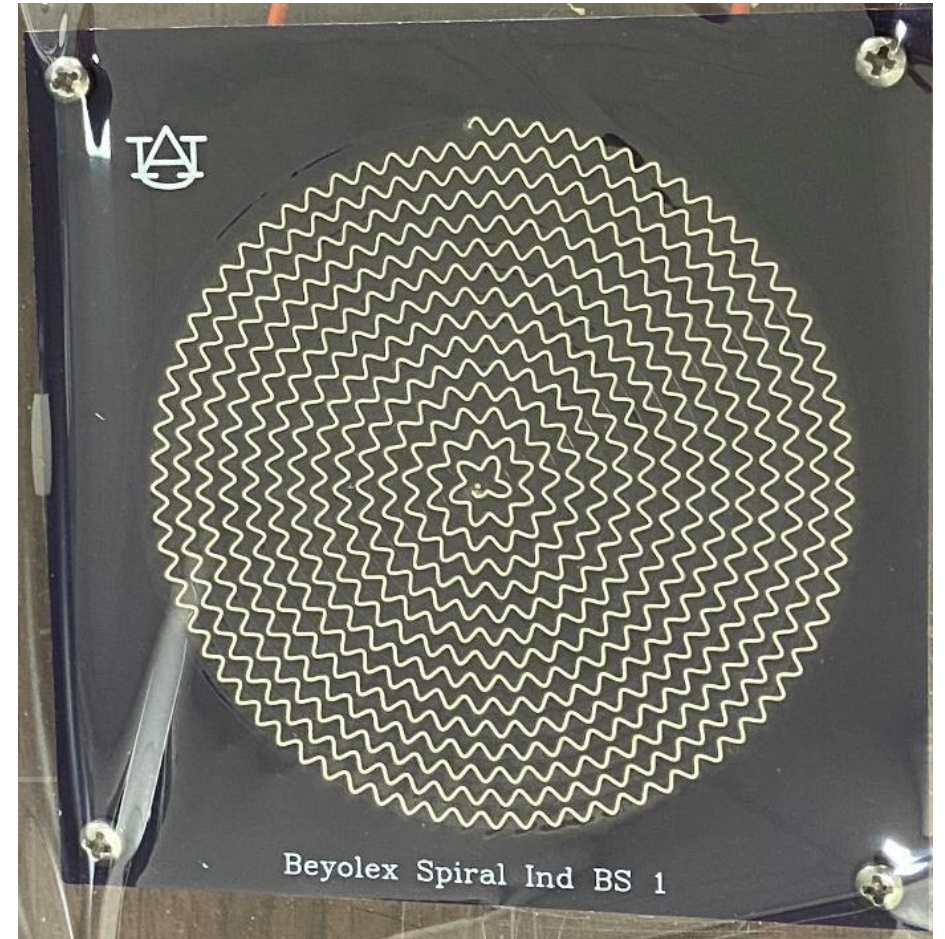
- To capacitively interrogate the getter material:
  - Sensing detection range must exceed  $51\ \mu\text{m}$
  - The further into the getter material the better
- IDE trace/space width of 16 mils ( $\sim 407\ \mu\text{m}$ )
  - Set by AM printer limitations
  - Detection range of  $\sim 540\ \mu\text{m}$
  - Sufficient to interrogate well into the getter material

## HiCap3000 structure



# Additive Manufacturing of Electronics and Electronic Assemblies

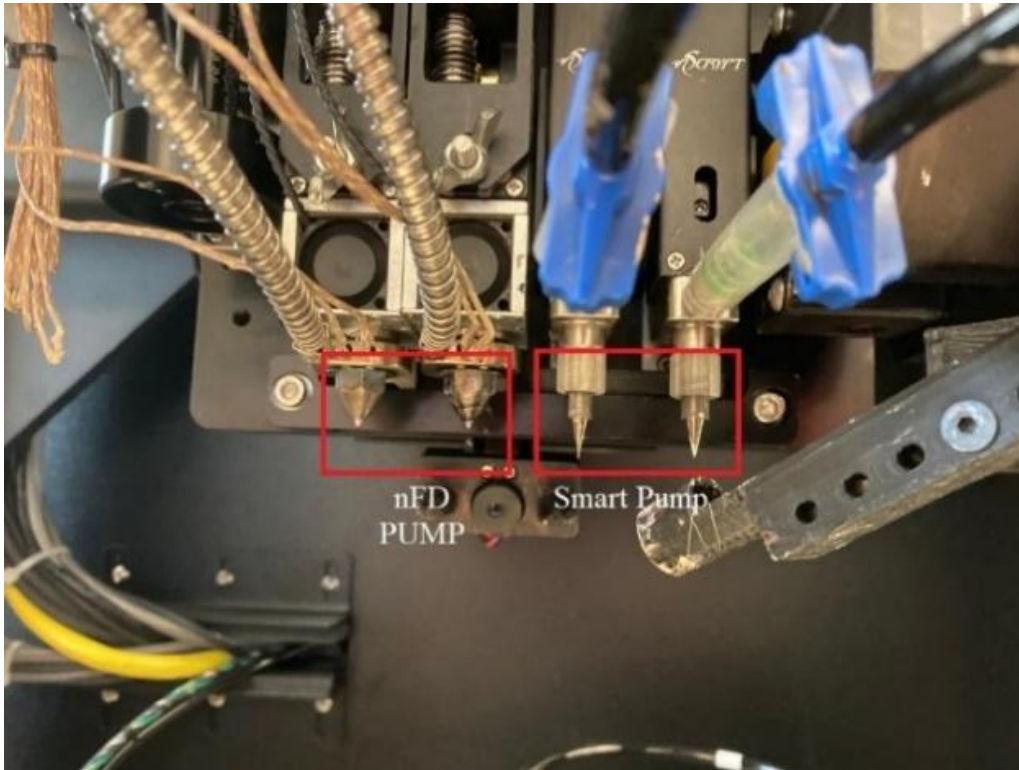
- AM consists of realizing 3D objects one layer at a time
  - Usually by precisely printing 2D patterns of a material one drop at a time
- AM is being used to realize electronic devices and assemblies by printing
  - Structural materials
  - Dielectric materials
  - Conductive materials
  - Semiconductor materials
- Advantages include
  - Less waste material
  - New types of devices
  - Printing circuits on unusual materials and surfaces



**AM stretchable LC sensor**

# AM Printing the IDE Transducer


## Four printing heads on the nScript system

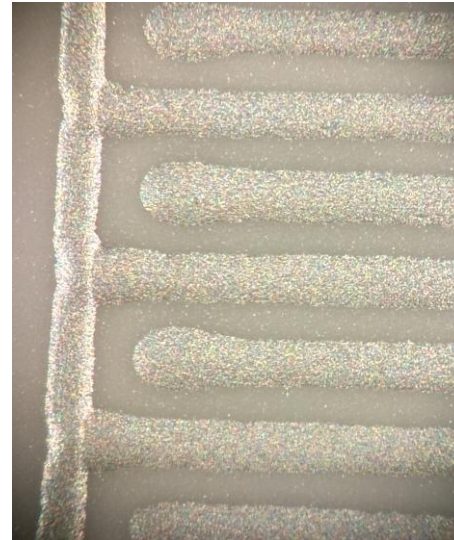


- Printed on an alumina substrate
  - CoorsTek ADS-96R material
  - 1 mm thick
  - Polished surface
  - Emulated a ceramic package lid
- AM printing
  - 4-head nScript printer
  - 108  $\mu\text{m}$  ID Luer adapter nozzle
  - Metalon<sup>®</sup> HPS-021LV ink
    - Water-based Ag nano-particle electrically conductive ink
    - Cured at 120°C for 20 min

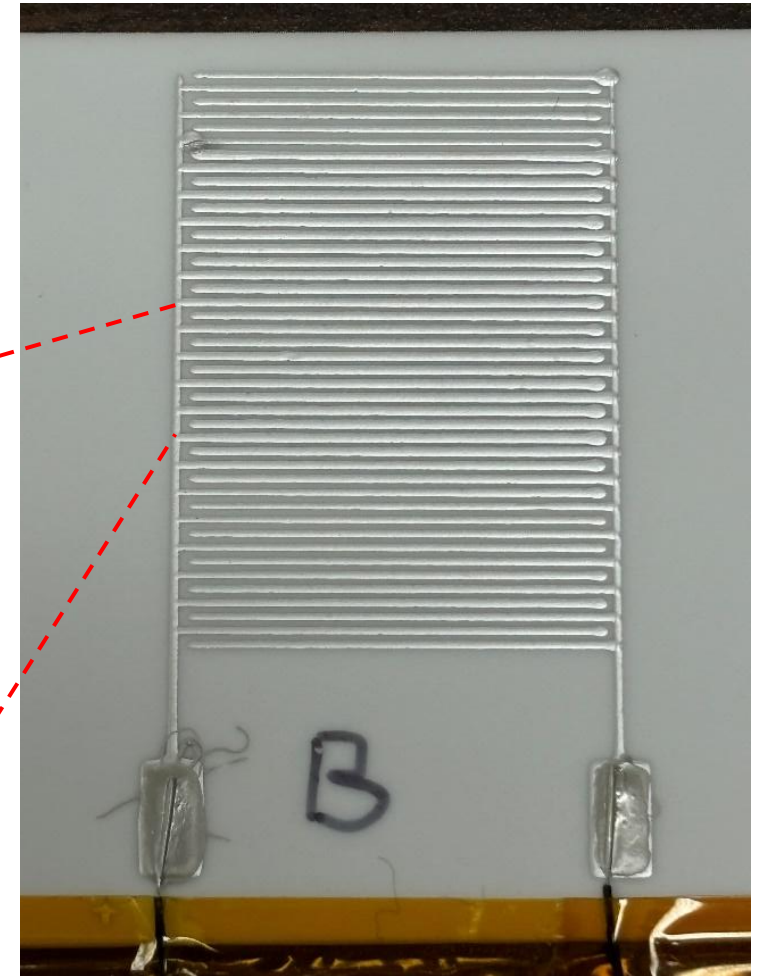
# AM Printed IDE Transducer

- IDE design
  - 43 IDE fingers
  - Each finger was 25.5 mm long
  - 16 mil ( $\sim 407 \mu\text{m}$ ) trace and space width
    - At the limit of printer resolution
  - Oversized IDE to facilitate manual placement of getter square on it

Printing resolution  
not ideal 



**Fabricated IDE**



# Device Assembly

- Release liner removed from 2.54 cm square getter pad
  - Exposed the PSA layer
- Getter adhered to alumina substrate over IDE array
  - With the PSA layer
- Electrical connection wires attached to pads on the alumina substrate
  - With conductive epoxy
  - Electrical junctions protected with polyimide tape

## Assembled Device



# Test Plan

- Measure the device's capacitance before and after 6-day humidity soak
  - At ambient lab conditions
- Capacitance measured with Agilent 4192A impedance analyzer
  - At 200 kHz
- Humidity chamber
  - Approx. 61% RH
  - Approx. 20.8°C

## Expected Getter Response from Datasheet

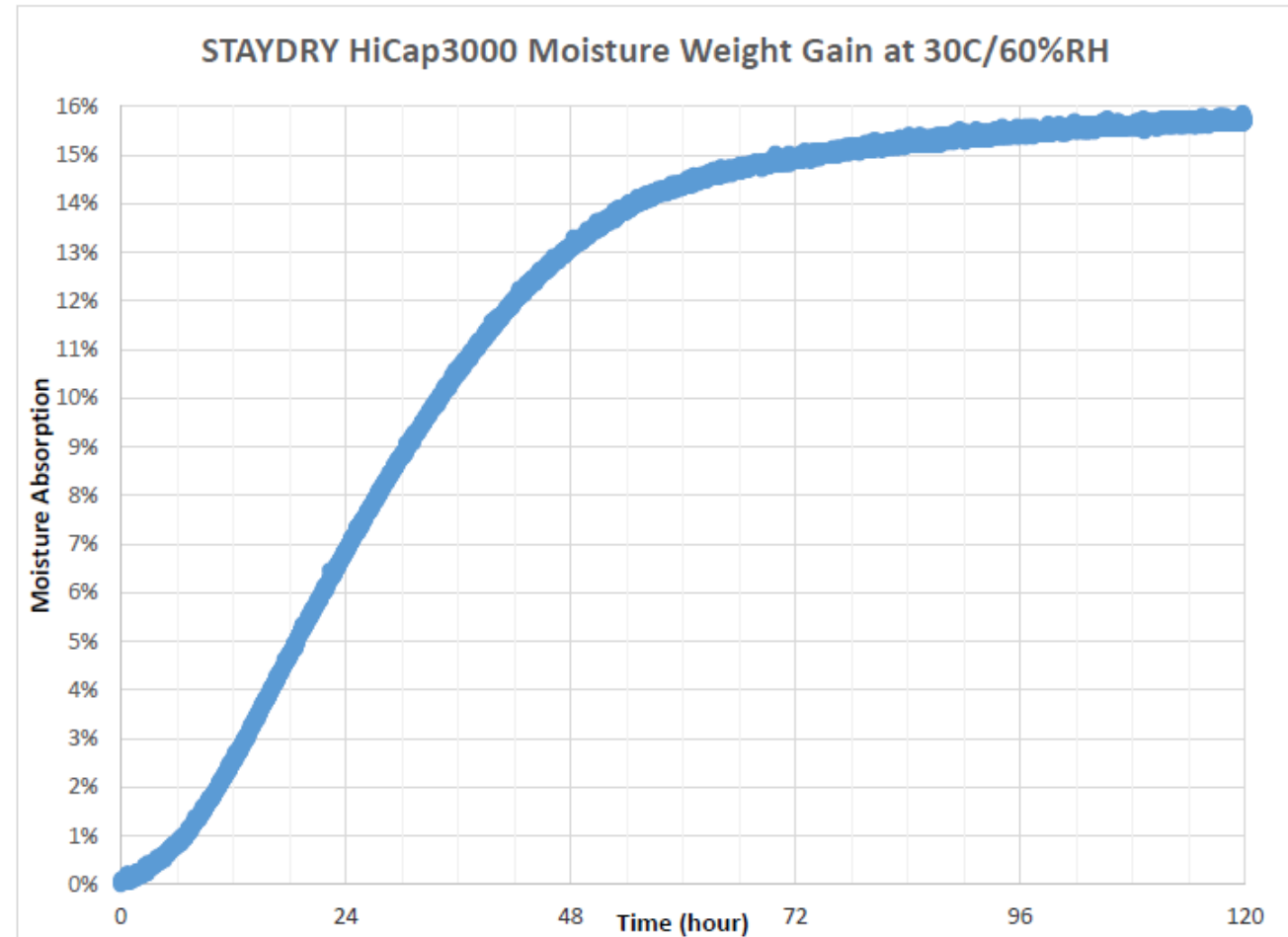


Figure 2 – Overall moisture gain at 30C/60%RH

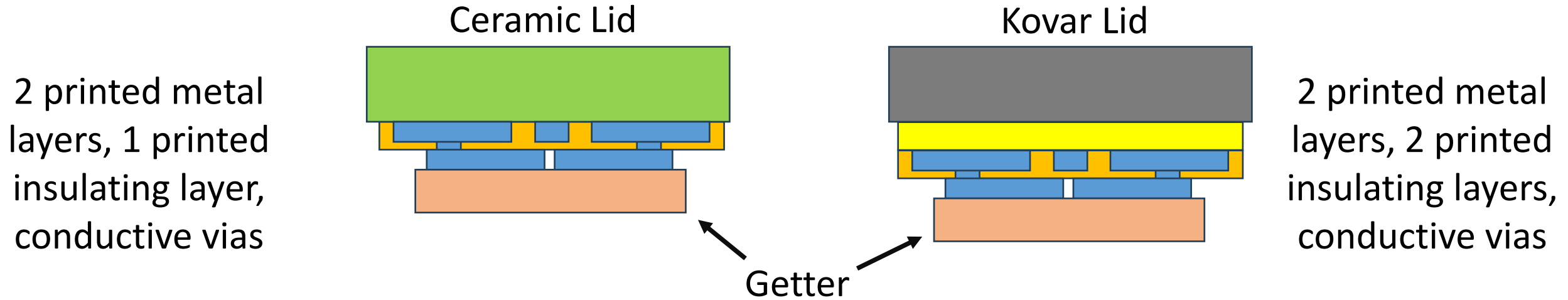
# Results from 6-Day Humidity Soak

- Sensor capacitance changed with moisture absorption
  - The device experienced a 2.4% decrease in sensor capacitance
    - 64.1 pF before the humidity soak
    - 62.56 pF after the humidity soak
  - This compares well with the same getter material used on a reference polyimide PCB IDE design from an earlier project
    - A 2.53% decrease in sensor capacitance was observed
    - R.N. Dean and M.A. Previti, “Passive wireless instrumented getter,” IEEE Sensors Letters, vol. 7, no. 8, Aug. 2023, 4pp.
- Getter swelling and potato chipping
  - Much less getter swelling and potato chipping was observed compared to previous work with the HiCap2019 getter

# Issues Moving Forward

- Additively manufactured electronics lacks maturity at this time
  - Need higher manufacturing yield and smaller feature sizes
  - Long term outgassing needs to be investigated
  - Long term reliability needs to be investigated
  - Possible electromigration issues with AM printed Ag nano-particle conductors exposed to moisture
  - A lot of research funding is being applied to maturing AM electronics
- This approach puts the burden of monitoring the getter onto the electronics inside the package
  - Not suitable for all applications

# Future Work: Multi-layer AM Instrumented Getter



- Planar Inductor - IDE sense capacitor LC tank circuit
  - AM printed conductive layers
- Getter status measured wirelessly using inductive coupling to the LC tank circuit as with the polyimide PCB version
  - R.N. Dean and M.A. Previti, "Passive wireless instrumented getter," IEEE Sensors Letters, vol. 7, no. 8, Aug. 2023, 4pp.
- No added complexity to the packaged electronics

# Conclusions

- Traditional getter usage is open loop
  - A problem is often first observed by failure of the packaged device
- Some getters experience a change in electrical properties as a gas is bound
  - HiCap3000 Getter: Absorbed  $\text{H}_2\text{O}$   $\uparrow$  : relative permittivity  $\downarrow$
- The getter was instrumented using an IDE array
- IDE was AM printed onto an alumina substrate
  - Emulated a ceramic package lid
- A 6-day humidity soak resulted in a 2.4% change in measured capacitance as the getter bound moisture
  - Demonstrated the viability of this approach

Thank You  
Questions?