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# Solid-State Humidity Sensing Element

## Introduction

Due to past and recent battery failures, researchers at NASA's Marshall Space Flight Center began research and development on energy storage systems that did not utilize liquids or gels as the electrolyte. During measurement of one of the manufactured devices, the device exhibited large swings in capacitance when near or in contact with the testing technician. Temperature sensitivity was evaluated and it was found that temperature was not the cause of the swings. The sample was then tested in a humidity chamber. The device showed a six order of magnitude change in capacitance just by breathing on it. The material was immediately recognized as a solid-state humidity-sensing material that offered ultra-high sensitivity across a wide range of humidity levels. The material was granted patent in 2018. The sensor material has passed a range of testing including temperature cycling, humidity cycling, and corrosive environments.

## The Technology

The sensing material is based on a novel ceramic dielectric material. The raw dielectric powder is processed via a sintering method of raw oxide nanopowders at temperatures over 1000°C. The sintered powdered is then suspended in an ink for printing that is processed above 800°C. MSFC typically builds the device on alumina substrate material. There are no polymers in the matrix and high temperature environments do not adversely affect the mechanical integrity of the sensor. The dielectric sensing element layer can be shaped via a range of printing methods although currently MSFC utilizes the screen printing method. This method is very easy and is an inexpensive way to mass-produce these sensors. In this method, a commercial electrode ink is printed and cured. The MSFC developed material is then screen printed on top of the electrode and sintered. Finally, a top electrode (again using a commercial ink) is printed on top to complete the circuit. For the low-cost devices, MSFC uses a AgPd material however if a more robust material is needed MSFC has used AuPt. Other electrode shapes have also been designed and tested successfully. For example, interdigitated electrode fingers with dielectric on top has been produced and shown to work just as effectively as the "plate capacitor" design. MSFC has recently developed a lower temperature ink so the dielectric ink is processed at 130°C. The material still exhibits excellent sensitivity. This ink was developed to 3D print the dielectric along with an antenna for wireless humidity sensing. The device has been successfully demonstrated and is currently the project for a Master's degree student in Electrical Engineering.

MSFC has conducted several tests to ascertain the robustness of the material. In one test, a device was exposed to N-methyl 2-pyrrolidinone for a week. The sensor was still sensitive with no discernible drift. Devices have been exposed to methanol, isopropyl alcohol, 3% hydrogen

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peroxide, and other chemicals without impact. Due to how the material is doped and processed, the most likely Achilles heel is exposure at high temperatures (>400°C) in oxygen rich environments. MSFC currently has one device that has been monitoring humidity for over 2 years and is still in operation.

**Conclusion**

The ceramic sensing element is robust and can be formed using a dielectric ink or paste formulation, also developed by NASA, via traditional screen printing or advanced ink-jet, aerosol or 3D printing methods. The printed sensor element can be very thin, microns in thickness, with a small footprint, one square centimeter or less. The devices exhibit fast response and recovery speeds with large capacitance response/change per relative humidity unit change across a wide range of humidity levels in a log-linear response. Preliminary test data conducted in a humidity test chamber shows a log-linear measured response in capacitance although impedance can be monitored.

**Benefits**

- Very high sensitivity to small changes in relative humidity.
- Fast response and recovery speeds.
- Robust solid-state design with no polymers.
- Operates at low voltages and power.
- Small sensing element form factor enables miniaturized sensor design.
- Ceramic sensing element offers higher temperature sensing capabilities.
- Flexibility in dielectric ceramic powder formulations enables use of a variety of thick and thin film printing methods.