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Printed humidity sensors and their application

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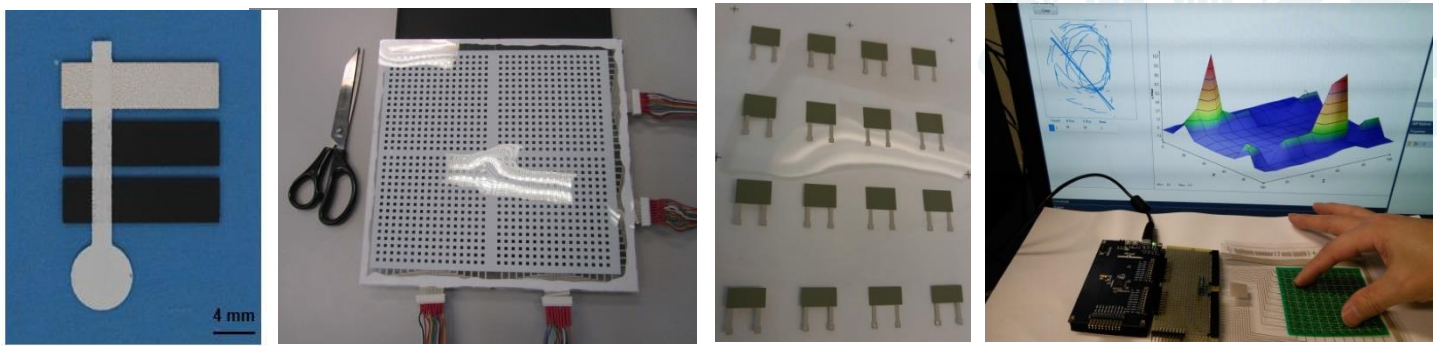
Introduction

Printable Electronics

- The combination of new solution-based functional materials and cost-effective printing processes
- Low-cost, large, flexible, lightweight, stretchable devices

Printed Sensors

- Biological and chemical sensors: glucose sensor, ...
- Physical sensors: piezoresistive-based force sensors, light sensors, temperature sensors, humidity sensors, …



Printed Humidity Sensors

- Resistive
- Capacitive

Printed Capacitive Humidity Sensors

- Polymers as sensing materials
- Co-planar interdigitated electrodes (IDEs) as dominated device structure

Progress of Existing Printed Capacitive Humidity Sensors

- Low capacitance reading (several pF) and low sensitivity (fF/%RH)
- Sensitive to environment and the need of high-cost testing equipment

Our Works:

Application need for building management

- Low-cost humidity sensors with good performance
- Low-cost detection, wireless data transmission

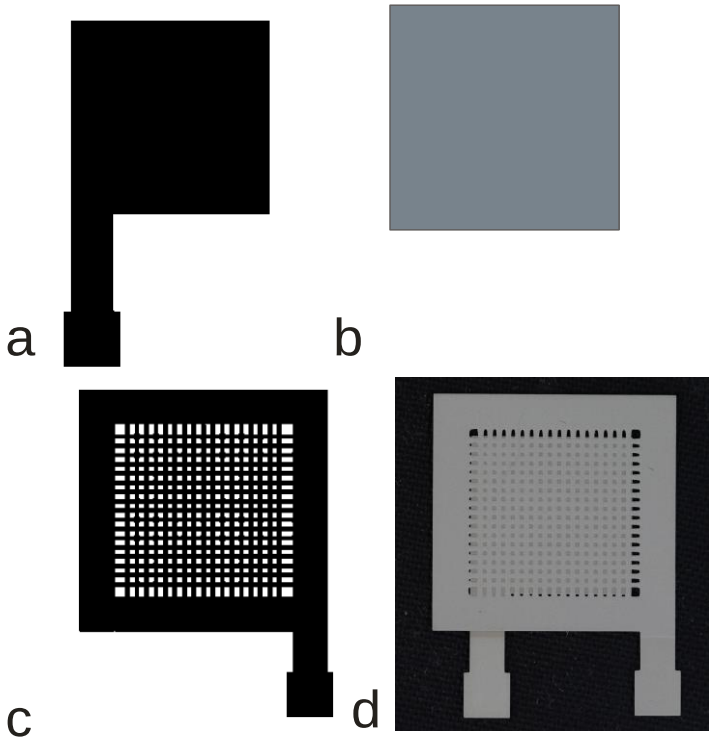
Our approach

Sensor Structure

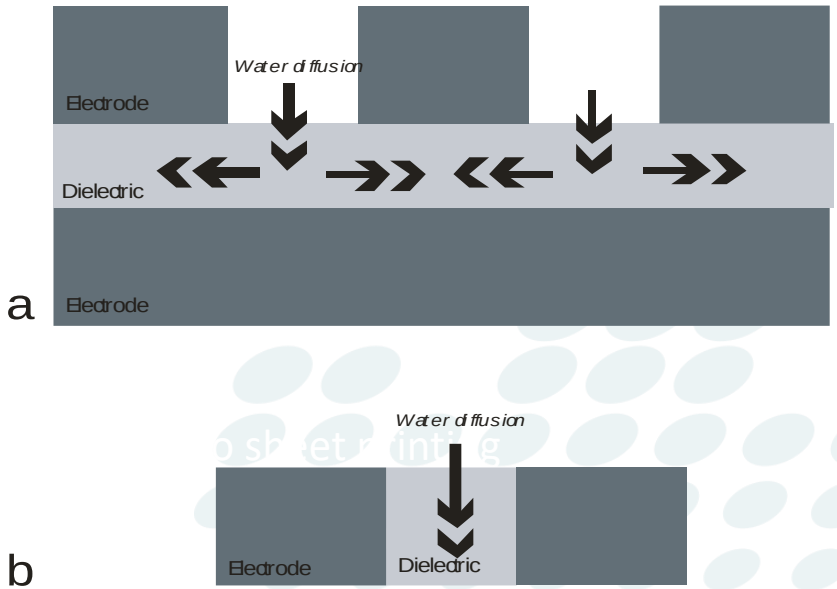
- Using a popular humidity sensing polymer: cellulose acetate butyrate (CAB)
- Use stacked parallel-plated electrodes to increase capacitance reading by over 100 times:

$$C_p = \frac{k\varepsilon_0 S}{t}$$

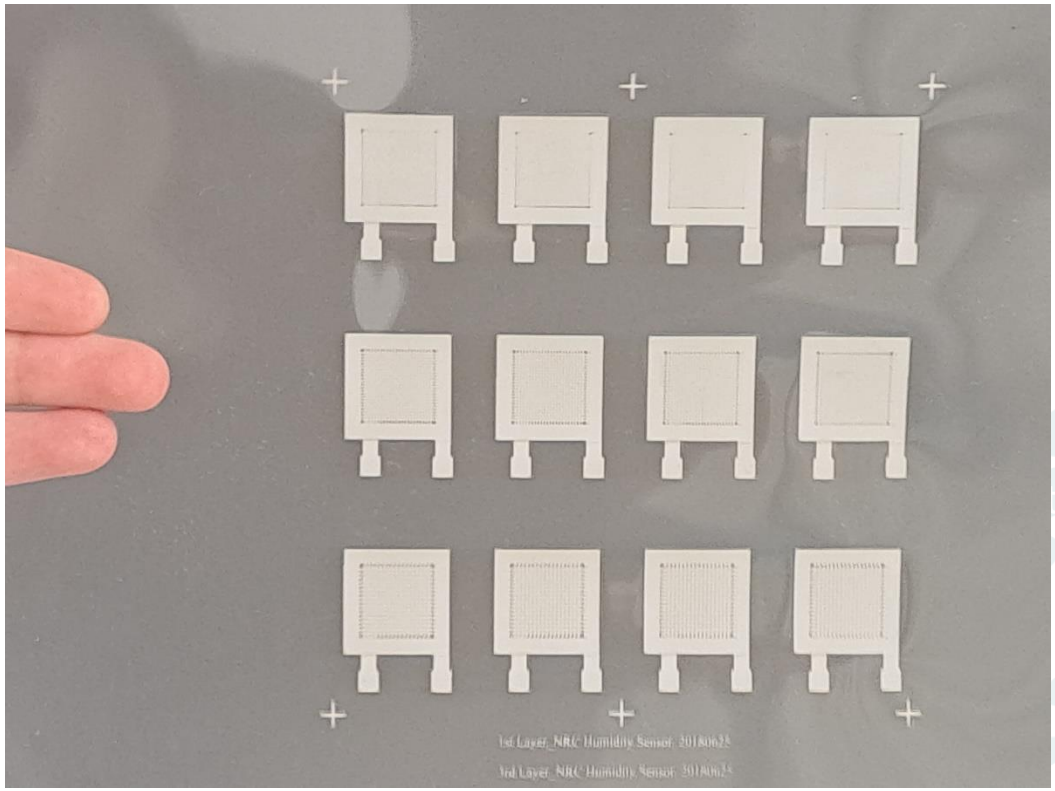
Device design and printing



Comparison with IDEs

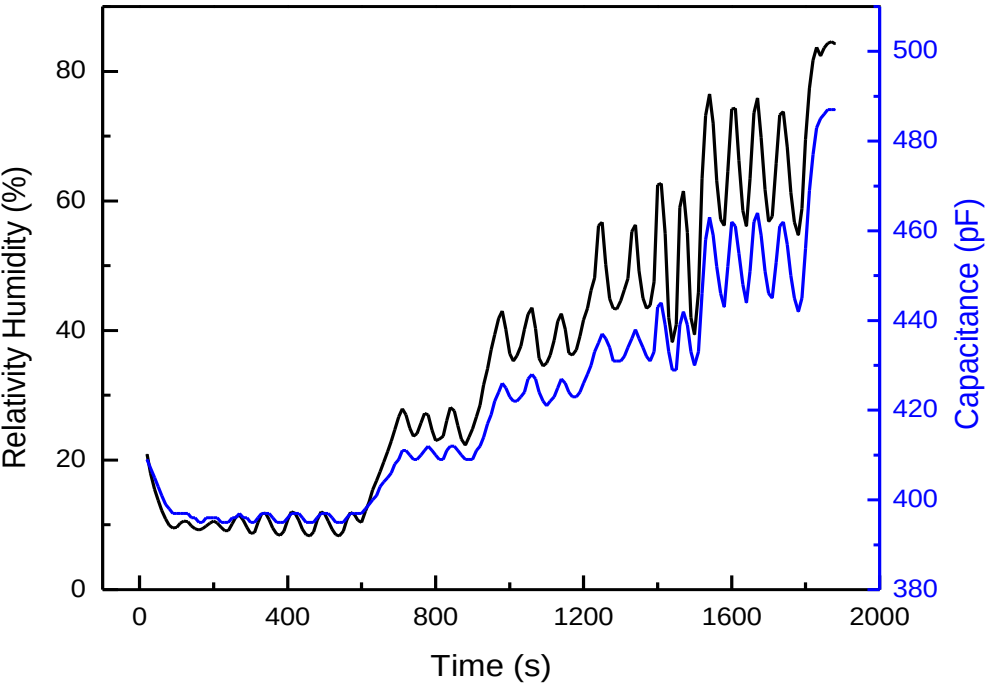


Humidity sensors printed on a PET film

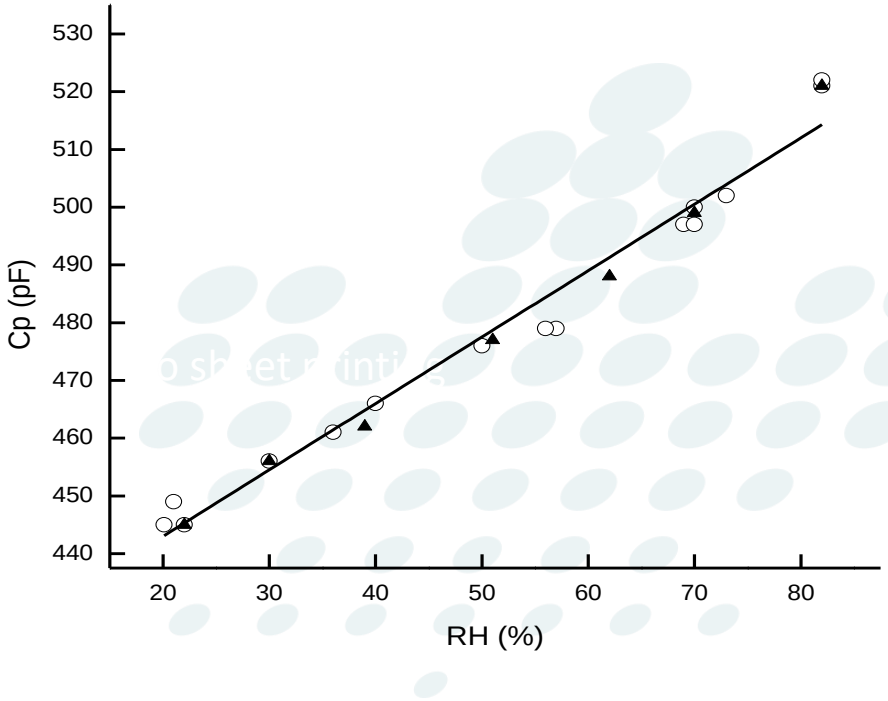


Sensor performance

Response to environment humidity



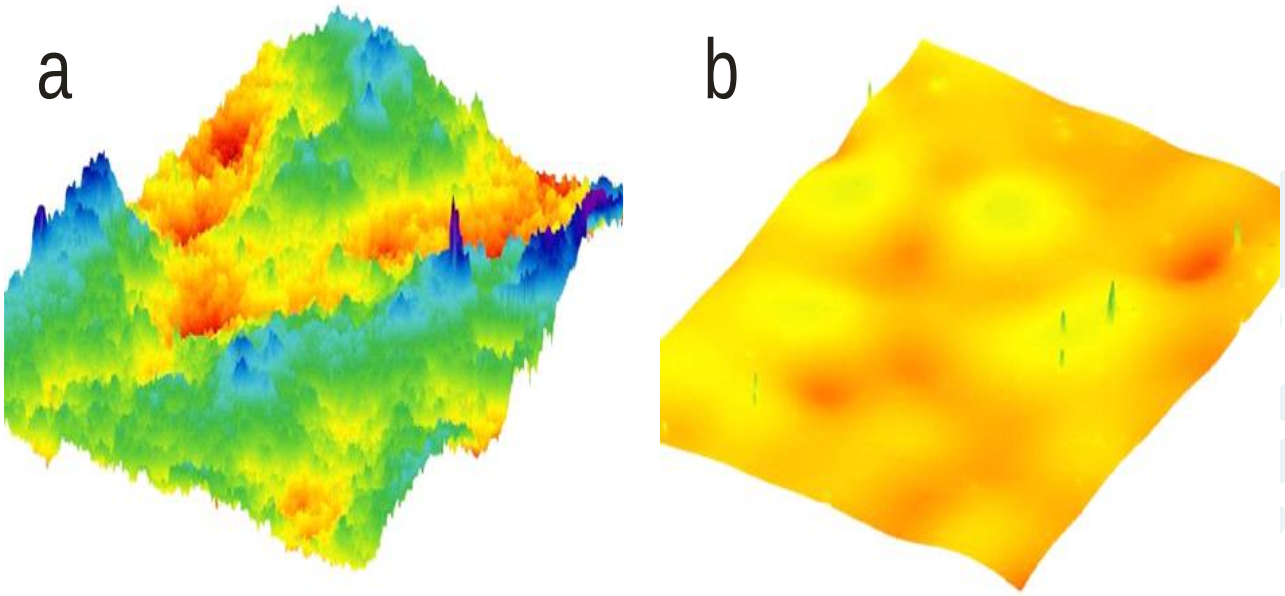
Sensor reading at various humidity



Effects of printing on sensor performance

Printing	Thickness (μm) of CAB	Capacitance (pF)	Sensitivity (pF/%RH)
Screen printing	18.3	435	1.2
Flexo printing	12.8	527	1.8
Flexo printing	24.8	266	0.9
Inkjet printing	-	2730	11.4

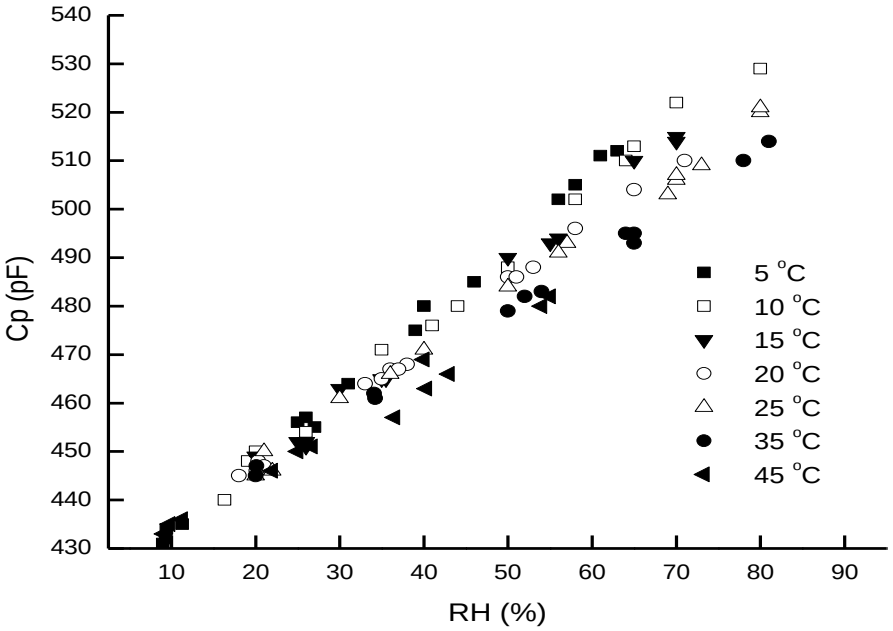
Effects of surface roughness of the printed CAB



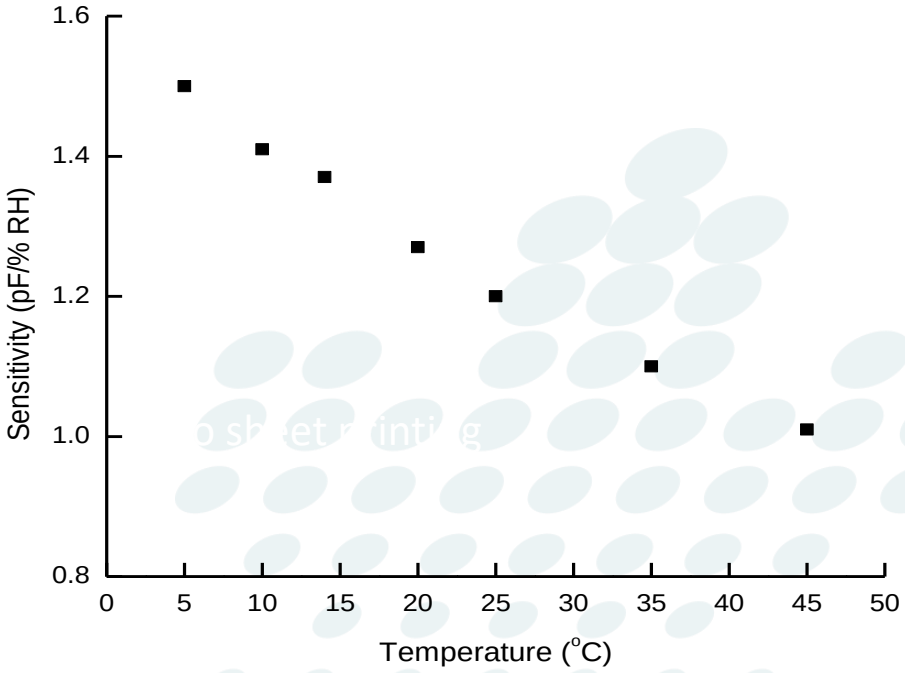
Scanning white light interferometer images of the sensing material printed by (a) screening printing and (b) flexo printing

Temperature effects on sensor performance

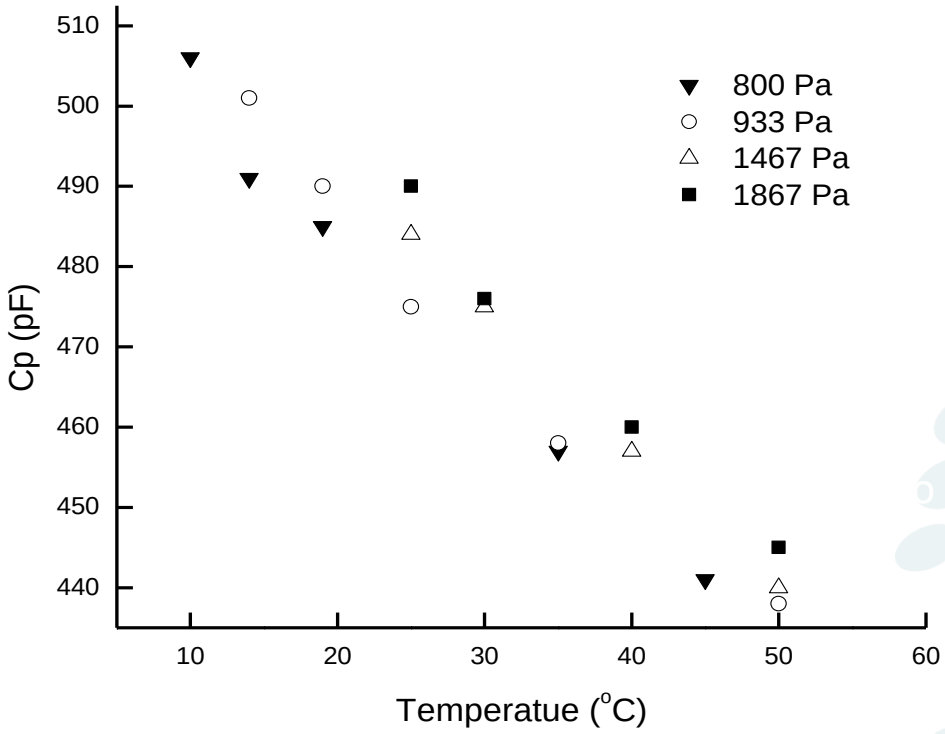
Sensor reading at various temperatures



Sensitivity at various temperatures

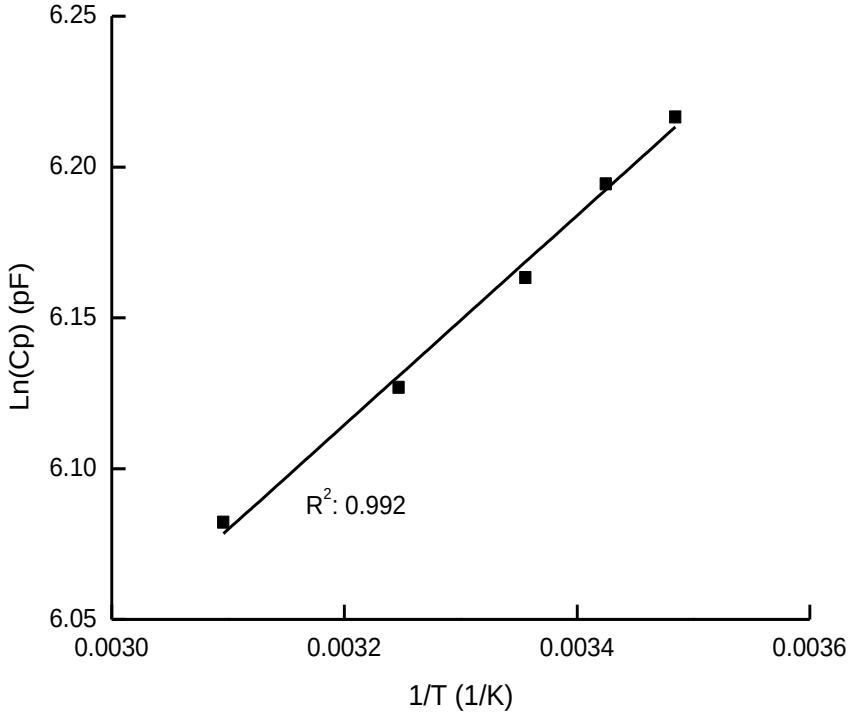


Sensor reading at various water vapor pressure

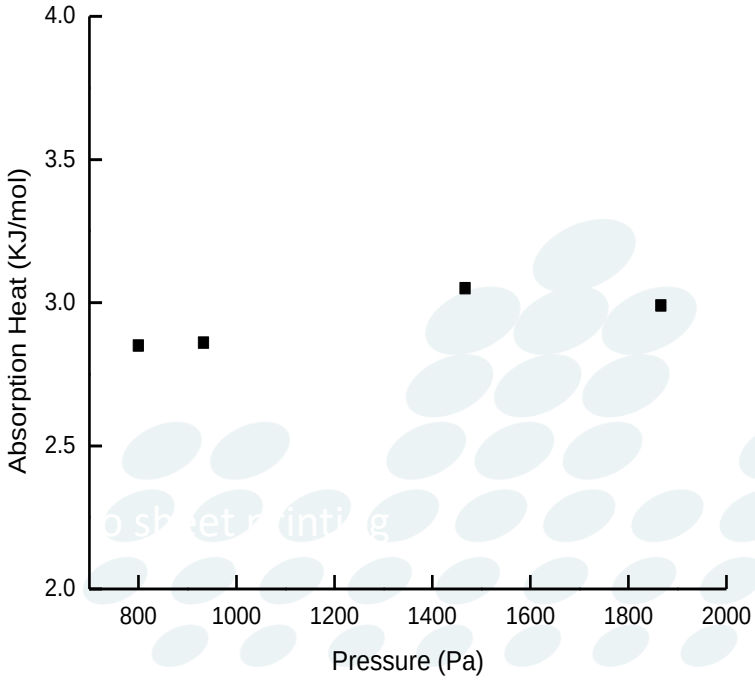


RH= Vapor pressure at T/Saturation vapor pressure at T

Sensor reading at various water vapor pressure



Heat of water absorption in CAB

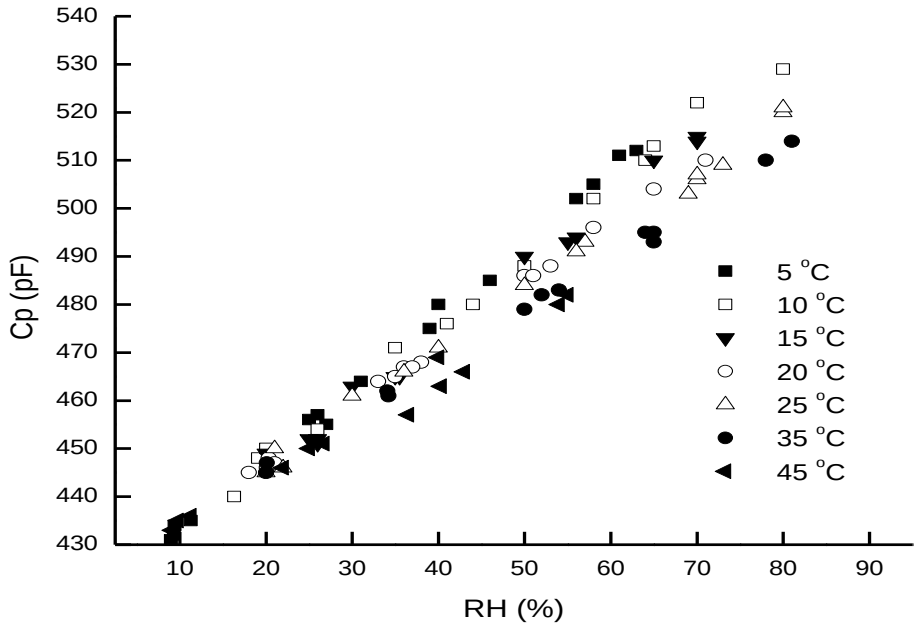


Following van's Hoff expression

$$Sol = Sol_0 \exp(-H_s/RT)$$

Temperature effects on sensor reading:

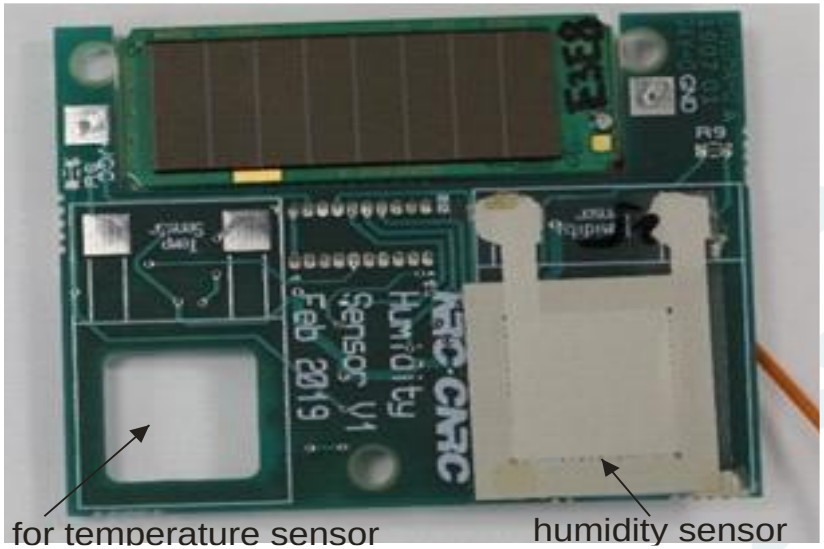
- Caused by the temperature effect of water absorption in CAB, a thermodynamic nature
- The effect needs to be calibrated for high precision measurement in a broad temperature and humidity range,



Sensor Application in building management

Sensors with capacitance reading over 400 pF, sensitivity over 1 pF/%RH => low-cost DC circuit

A packaged humidity sensor with self-powering and wireless communication capabilities



Multiple packaged sensors were deployed in various areas of a office building for building management

Conclusion

- **Flexible capacitive humidity sensors with parallel-plate electrodes were designed and printed.**
- **The sensors were tested to have a capacitance over 400 pF and sensitivity over 1 pF/%RH, and the performance can be substantially improved through printing.**
- **The temperature effects of the sensing performance was studied.**
- **Humidity sensors with self-powering and wireless communication capabilities were packaged and applied in building management.**