DEVELOPMENT OF A FLEXIBLE, SUSTAINABLE, WIRELESS, CHITOSAN-BASED HUMIDITY SENSOR

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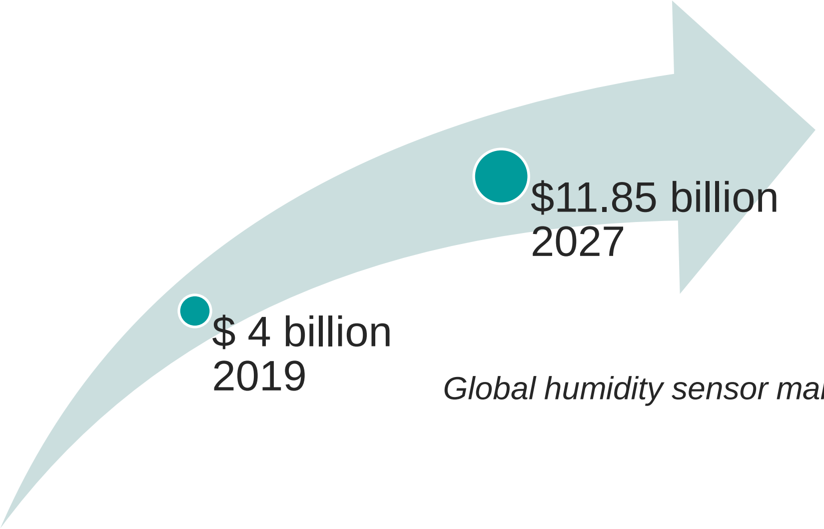
Motivation

- Humidity is one of the most relevant physical parameters to sense and control for a large variety of applications[1]
- The fastest growing waste stream worldwide is electronic waste and the number of sensors deployed increases at a high pace

→ **Urgent demand for sustainable sensor solutions!**



Global humidity sensor market[1]

Unsplash.com/John Cameron

1 Humidity Sensor Market Outlook – 2027 (Allied Market Research)

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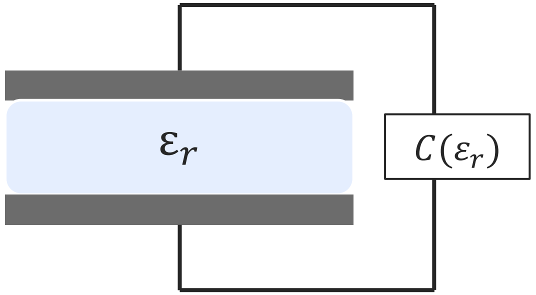
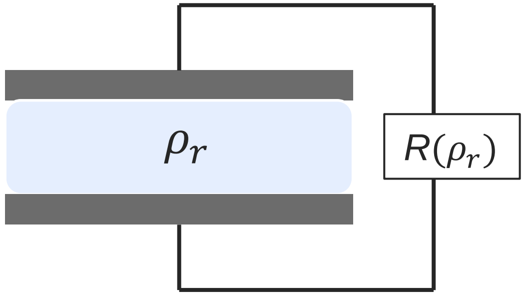
Prevalent Working Principles of Humidity Sensors

Capacitive



- ✓ most commonly employed
- ✓ stable results over long usage
- ✓ Fast response time
- χ sensitive to contamination

Resistive



- ✓ low cost
- ✓ small size
- ✓ easy read-out
- χ limited accuracy

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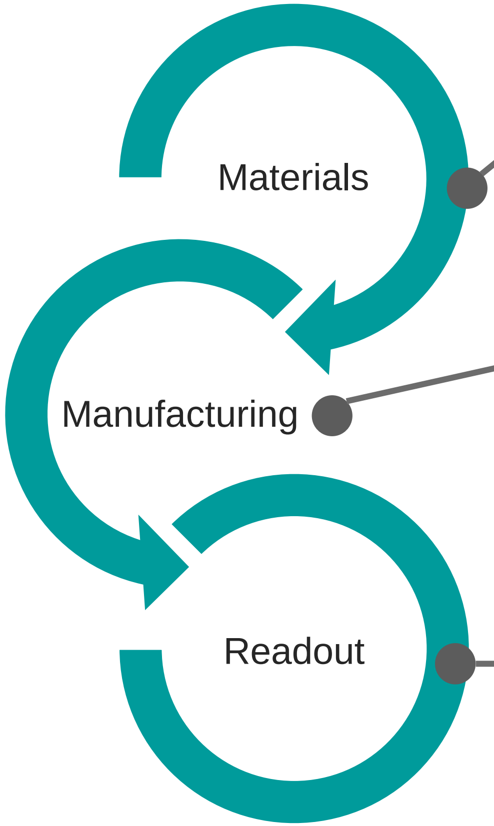


Employ sustainable raw materials

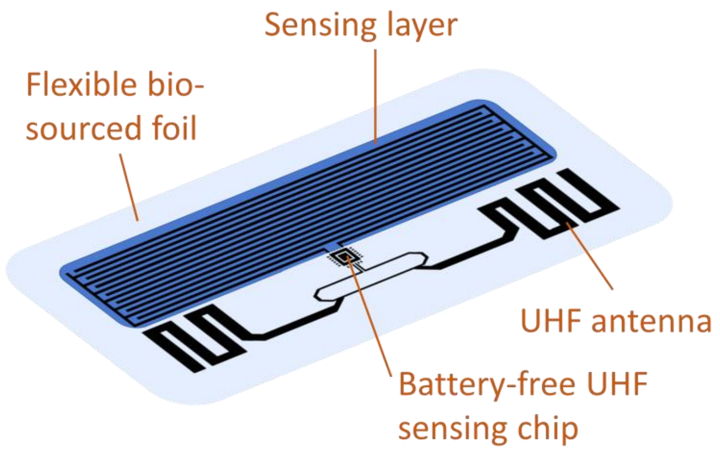
Bio-sourced polymers
Bio-degradable materials

Save energy and resources

Additive manufacturing technologies
Digital printing

Wireless readout

Passive chip solutions (no battery)
Energy harvesting from electromagnetic field



MATERIALS

Exploit Chitosan for humidity sensing

✓ Environmentally friendly, low-cost, biocompatible and biodegradable sensing material

✓ Derived from chitin, a natural polymer that is found in the exoskeletons of crustaceans

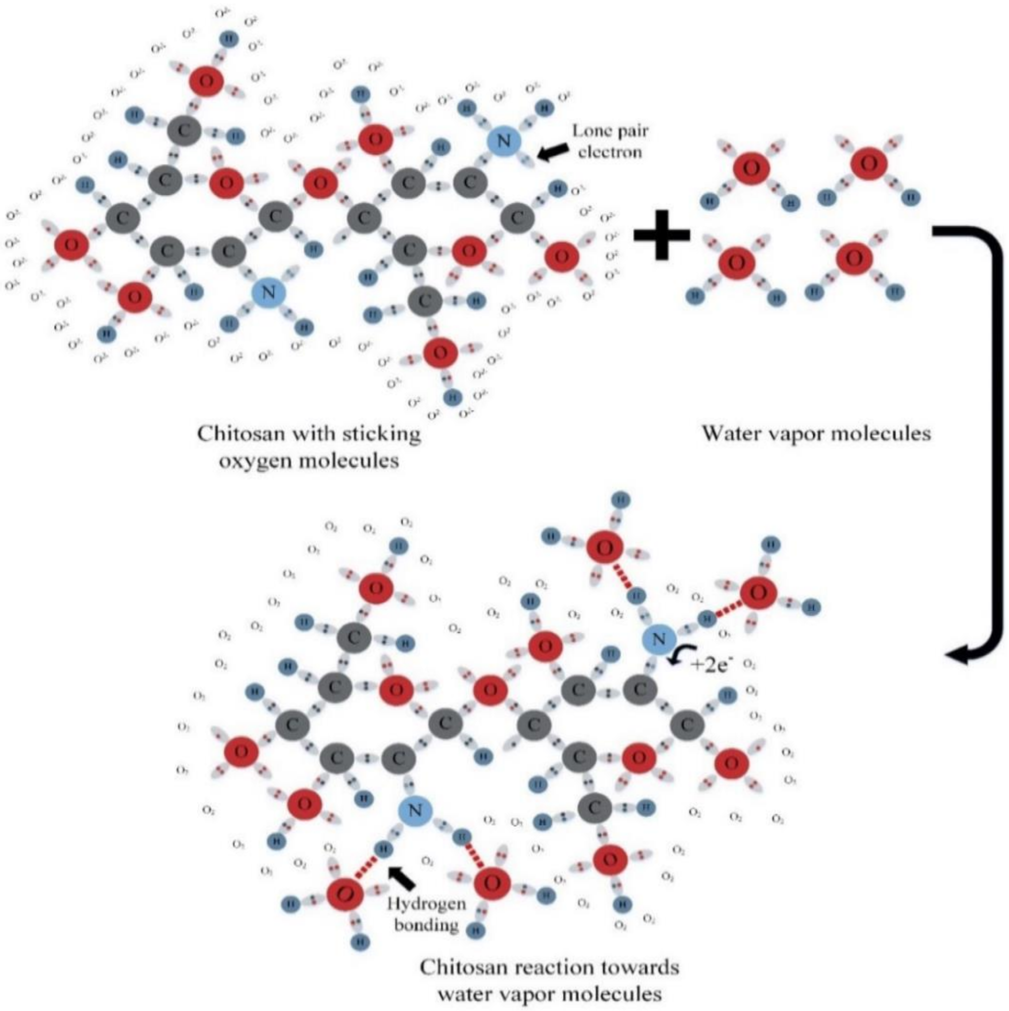
✓ Reduction of waste, as seashells are waste products from fishing/food industry

✓ Vegan alternative: Chitosan can also be synthesized from fungi

MATERIALS

The humidity sensing principle of Chitosan

- The sensor resistance is very much influenced by the chemisorption of Oxygen species on the sensor surface.
- As soon as a constant voltage is applied, electrons are transferred from the valence band to the conduction band forming ionic species (O_2^-, O^-) and reducing the number of free electrons
- In the presence of water, O_2 is formed, and electrons are released again, which decreases the resistance again



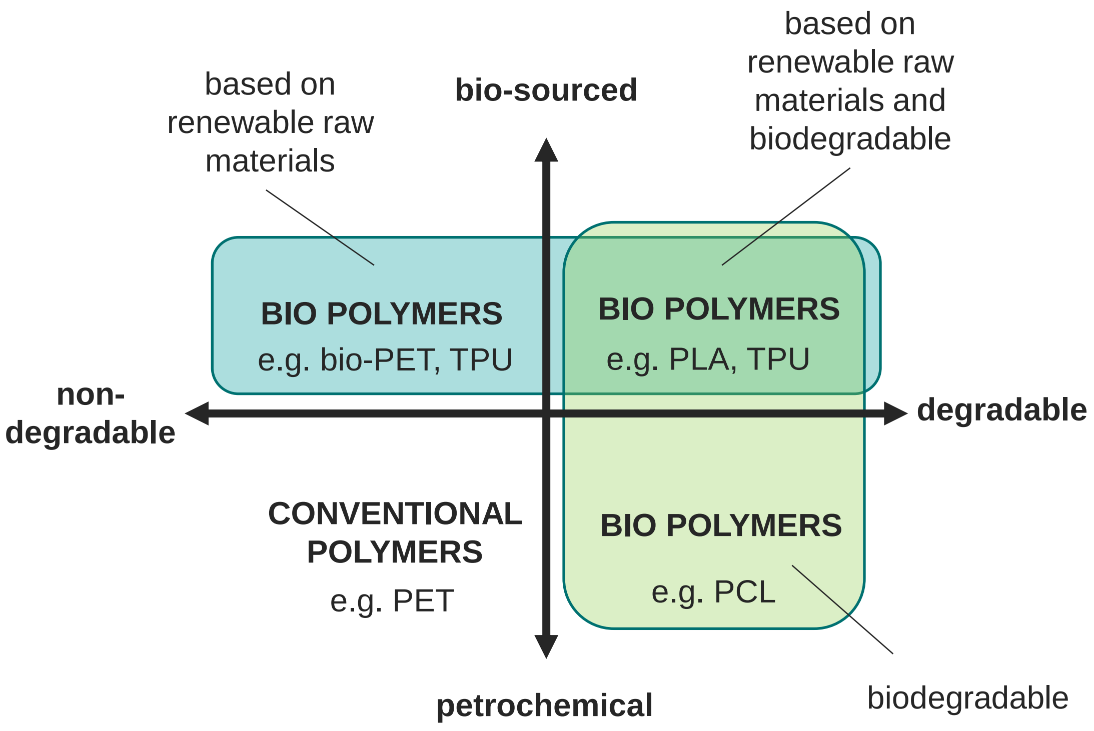
Illustrations of the sensing mechanism of chitosan film sensor.[1]

1 Balyan, M., et al.. (2019). Energy harvesting properties of chitosan film in harvesting water vapour into electrical energy. *Journal of Materials Science: Materials in Electronics*, *30*, 16275-16286.

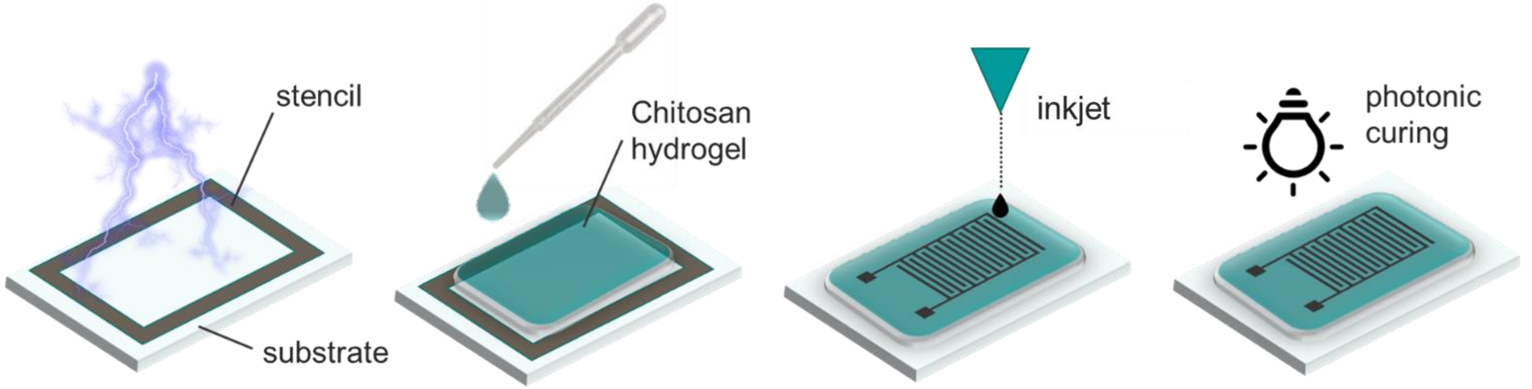
MATERIALS

Bio-sourced thermoplastic polyurethane (TPU) as substrate material

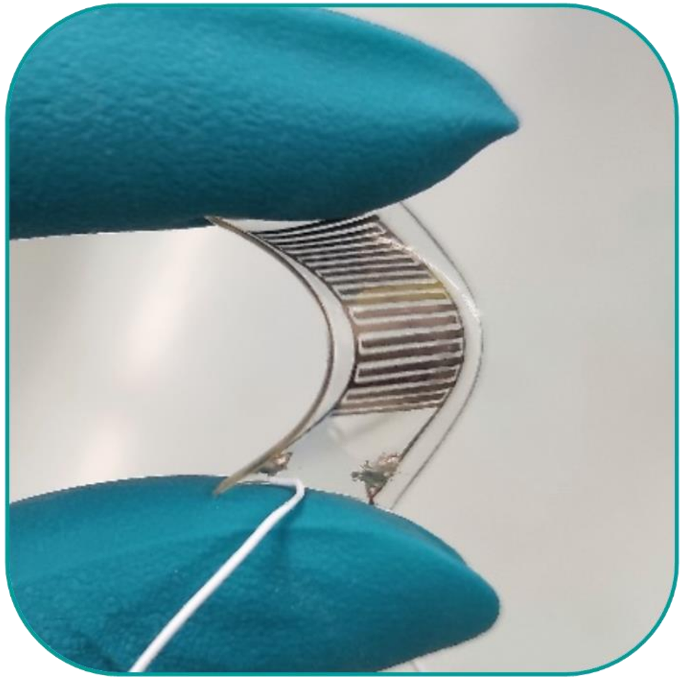
- ✓ Durability and resistance against oils and chemicals
- ✓ Non-toxic → ideal for usage in biomedical applications
- ✓ Bio-based TPU is fabricated from plant oils (e.g. castor oil)
- ✓ Bio-degradable TPU variations are being developed



MANUFACTURING



1. Plasma surface activation
2. Drop casting
3. Printing of electrodes
4. Curing of electrodes

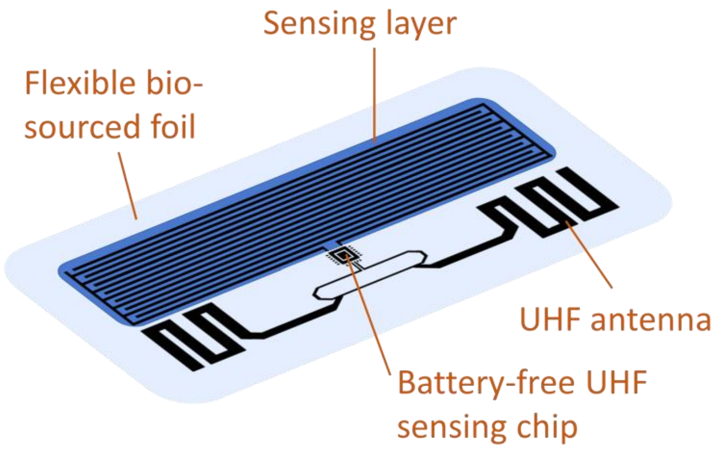


1 Zikulnig, et al. "Sustainable Printed Chitosan-Based Humidity Sensor on Flexible Biocompatible Polymer Substrate." IEEE Sensors Letters 6.12 (2022): 1-4.

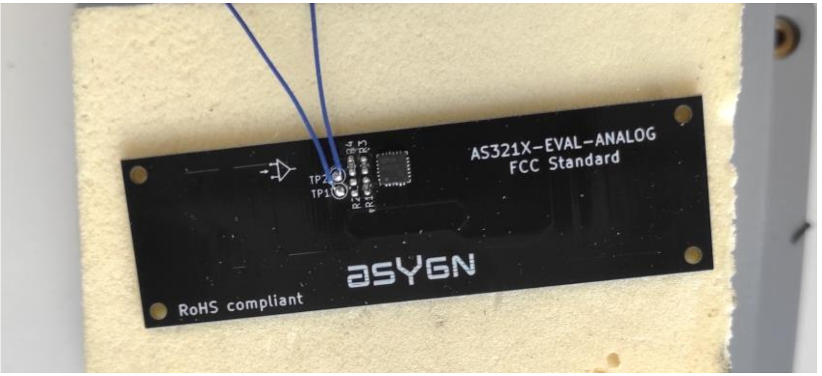
READOUT

Wireless readout concept

- Commercial passive sensing chip harvests energy from electromagnetic field → no batteries required!
- UHF frequency range: 865 - 915 MHz
- Reading and writing distance of several meters (4-5m)



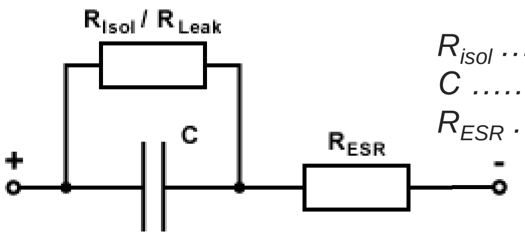
Concept of wireless Chitosan-based humidity sensor



Setup for readout using rigid PCB antenna (functional demonstrator)

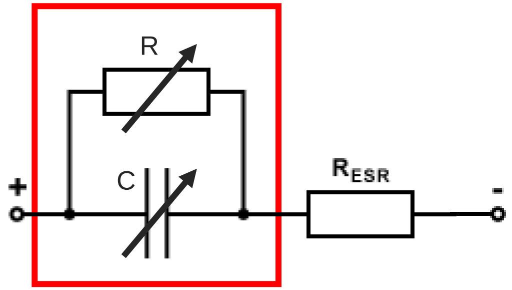
CONCEPT

Equivalent circuit of sensor:



R_{isol} …. parallel resistance
C ……. capacitance
R_{ESR} … lead resistance

Sensor element



- **2 measurement principles in one single device:**
  - Generation of free electrons in Chitosan layer due to rising humidity levels → **Decreasing resistance with increasing humidity!**
  - Hydrophilic nature of Chitosan facilitates adsorption of Water-Molecules → **Increasing capacitance with increasing humidity!**

CHARACTERIZATION RESULTS

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Resistive Measurement:

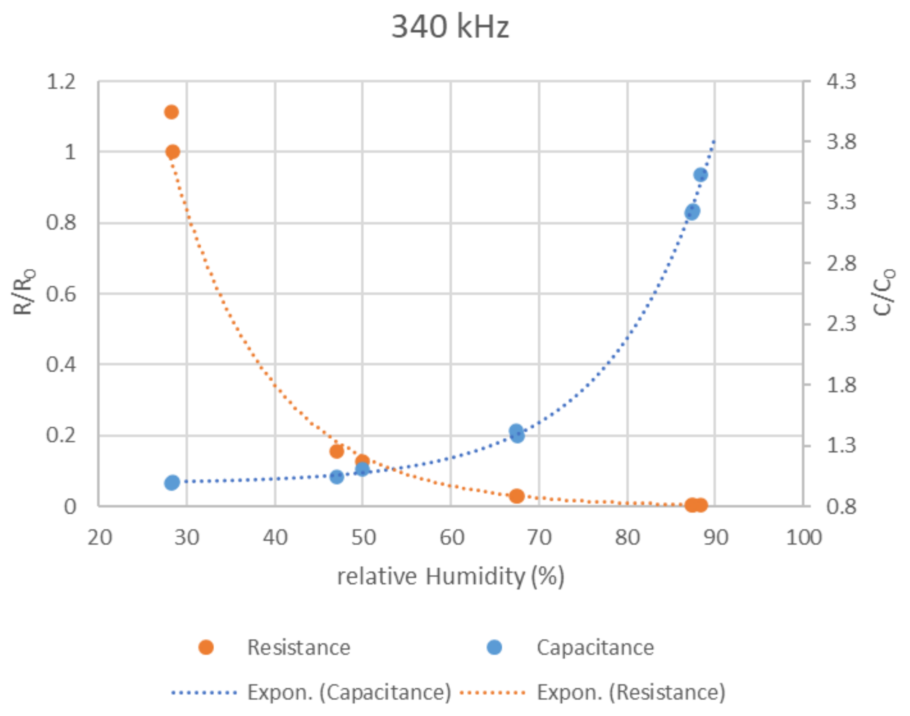
$$\frac{R(H)}{R_0} = a \cdot e^{-\lambda_R \cdot H}$$

- $R^2 = 0.9961$
- **Highly sensitive in the low-humidity range (<50%rH)**

Capacitive Measurement:

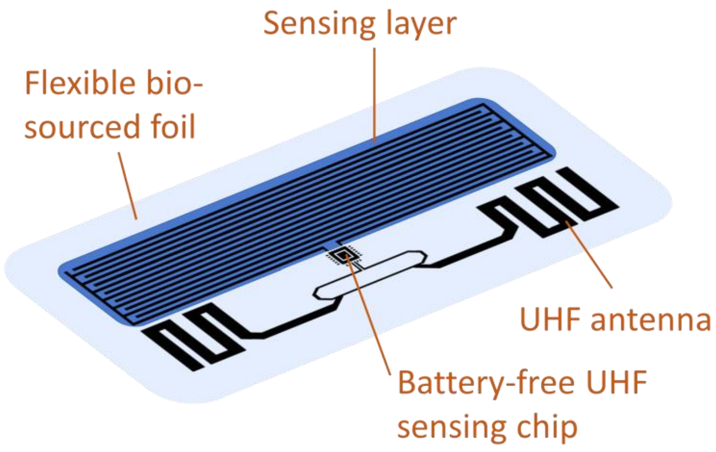
$$\frac{C(H)}{C_0} = b + c \cdot e^{\lambda_C \cdot H}$$

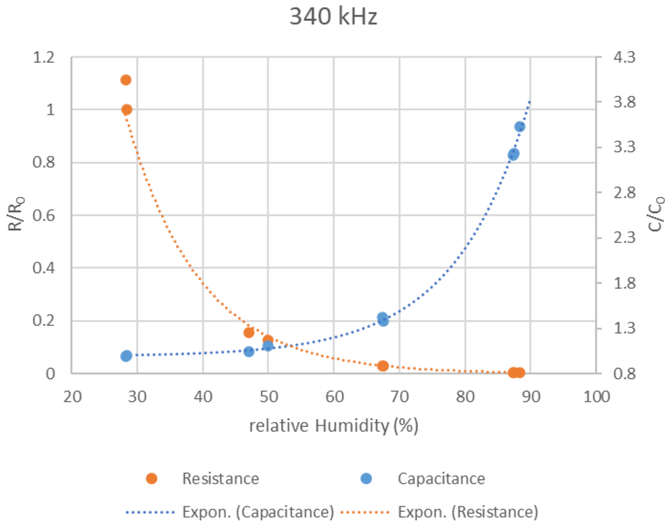
- $R^2 = 0.9989$
- **Highly sensitive in the high-humidity range (≥50%rH)**



CONCLUSION

- Realization of capacitive and resistive highly sensitive humidity sensor in one single device
- Additive manufacturing and utilization of sustainable materials
- Single-chip solution, battery-free readout





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- SAL project FLEXS: https://silicon-austria-labs.com/forschung/projekte/details/flexs
- Zikulnig, J., Lengger, S., Rauter, L., Neumaier, L., Carrara, S., & Kosel, J. (2022). Sustainable Printed Chitosan-Based Humidity Sensor on Flexible Biocompatible Polymer Substrate. *IEEE Sensors Letters*, *6*(12), 1-4.
- Contact: Johanna.zikulnig@silicon-Austria.com
- Visit us at ICM Foyer.17

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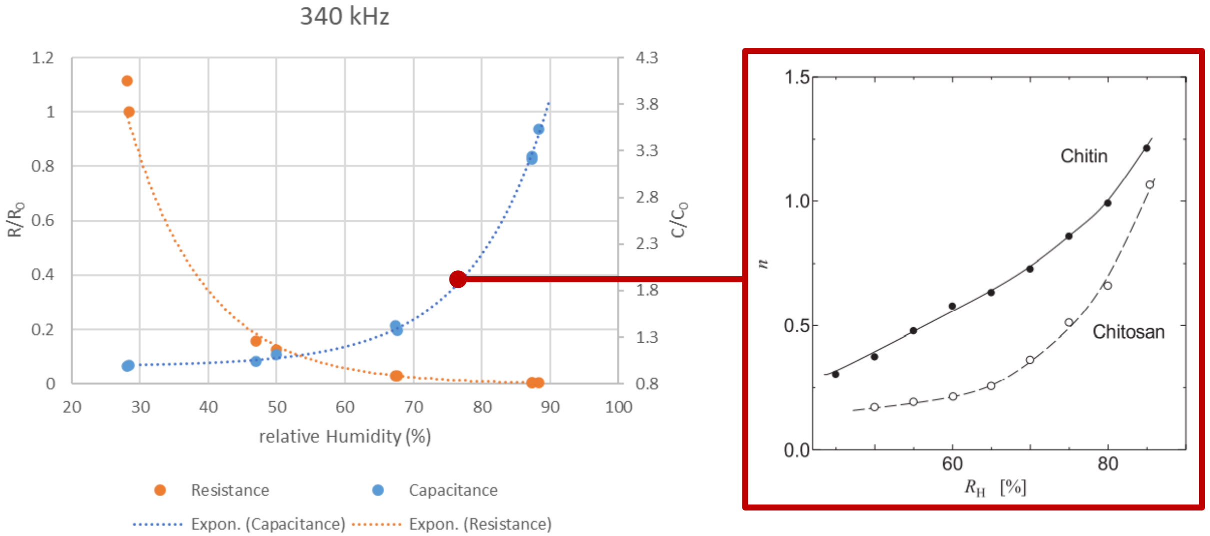
CHARACTERIZATION RESULTS

- Changes in capacitance due to relative humidity match the humidity uptake of Chitosan (Fig. 1 (b))[1]



(a) (b)

Fig. 1: (a) humidity response of Chitosan sensor; (b) humidity absorption depending on relative ambient humidity [1]

1 Kawabata, T., & Matsuo, Y. (2019). Role of acetyl group on proton conductivity in chitin system. *Journal of Materiomics*, 5(2), 258-263.