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Fully printed biodegradable nanocellulose-based humidity sensor for SMART LABEL applications

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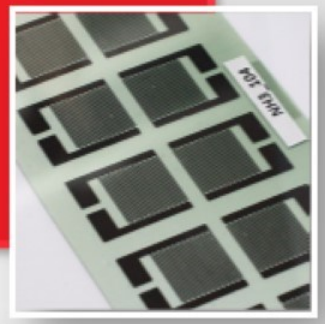
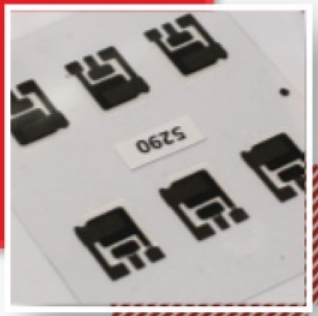
Outline

- Motivation
- MFC/NFC films fabrication
- Experimental
- Physical characteristics of NFC/MFC films
- Sensing characteristics
- Mechanical deformation within RH cycling
- Conclusion and future work





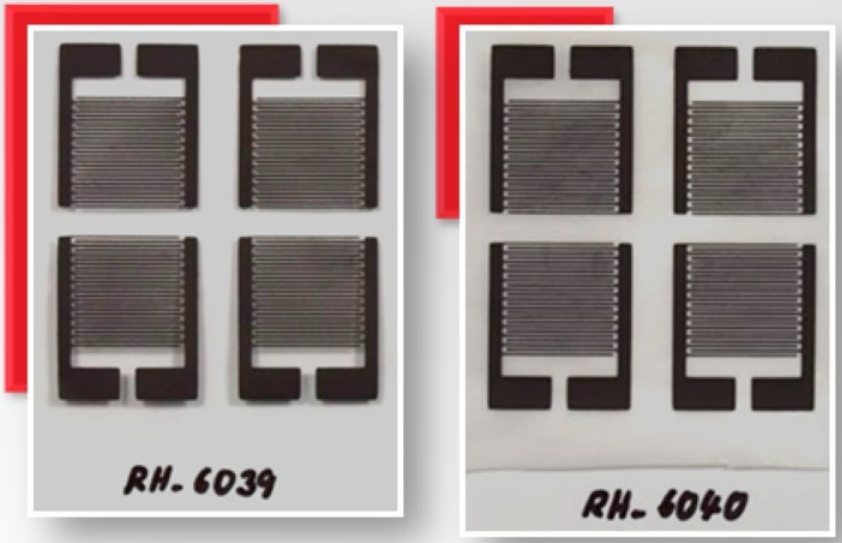
Why we are developing the sensors?

- Smart Labels with sensing capabilities.
- Monitoring of climate condition or/and other parameters according customers needs.
- Fully programmable logging management over NFC with Android based devices.
- Autonomous logging, storing to clouds.
- R2R technology process.
- Actually developed sensors
  - Temperature – NTC/PTC
  - Relative humidity
  - Ammonia
  - NO_2
  - Gas flow (coop. with external partner)
  - Acceleration (coop. with external partner)
  - Tactile sensor
  - Visible light, UV radiation (coop.), etc.

Relative humidity – NFC/MFC based

- Sorption sensors

- Composition of the sensor
  - NFC or MFC substrate as a sensitive layer
  - Carbon based printed IDE

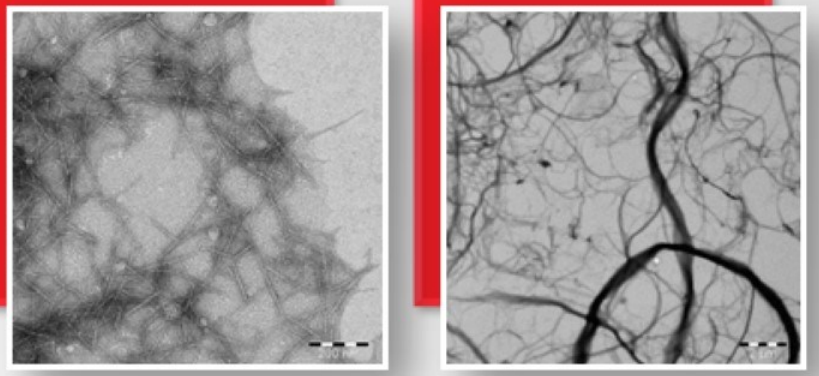


NFC- (RH_6039) and MFC- (RH_6040) based RH sensors.

NFC/MFC free standing film preparation

MFC

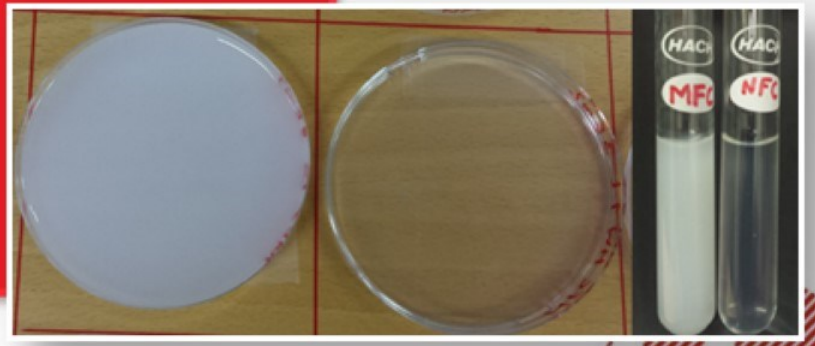
- Bleached softwood Kraft pulp was dispersed with a beater at 2.5% solids.
- The pulp was circulated through the refiner until the fines content reached over 90%.



TEM microphotograph of NFC (left) and MFC (right) suspensions

NFC

- TEMPO-mediated oxidation,
- followed by mechanical disintegration of cellulose fibers.

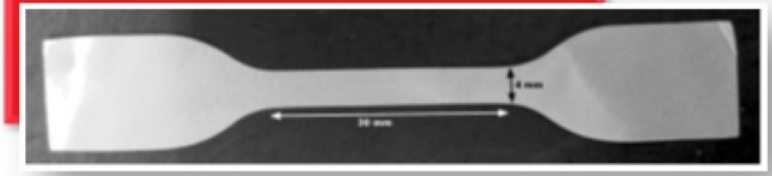


MFC (left) and NFC (right) suspensions

Physical characteristics of NFC/MFC films

- Mechanical properties of the films were characterized using an Instron 8872 equipped with a 10 kN load cell.

Sample	Tensile strength (MPa)	Elastic modulus (GPa)	Elongation at break (%)	Thickness (µm)
MFC	81 ± 3	5.5 ± 0.3	3.86 ± 0.27	25 ± 1.6
NFC	109.5 ± 10.2	7.2 ± 0.3	2.7 ± 0.7	23 ± 1.4



Dog-bone shaped specimen from MFC film for mechanical tests

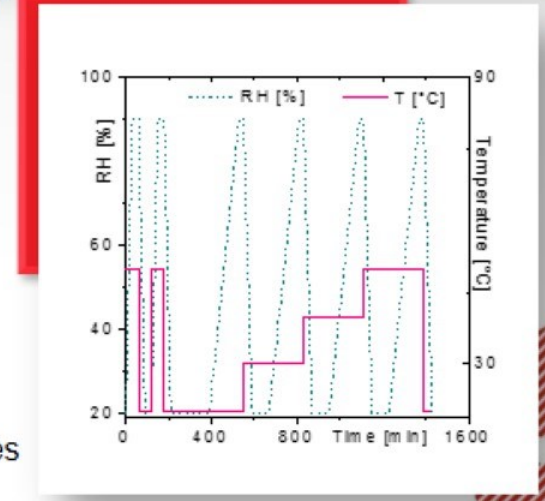
Photographs of MFC R, MFC G and different thickness NFC (HW 1H) films

Experimental setup

- **Sensor fabrication**
  - Graphite based ink formulation
  - The width of electrode "fingers" and the gaps between them were 200 μm.
  - Printing substrates: NFC, MFC, PET
- **Measurements apparatus**
  - Climatic chamber Votch VC7018
  - AC RLC bridge Agilent E4980A equipped with 10 channel multiplexer
  - Fully automatically in the range from 20 % to 90 % RH for temperatures from 20 °C to 50 °C.
  - 0.5 % RH/min

S 200 HF

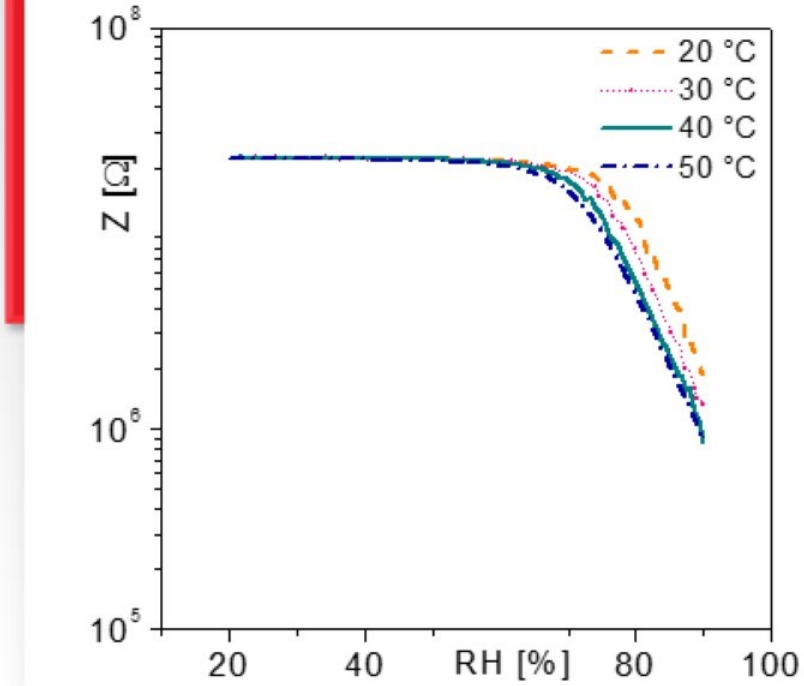
Votch VC7018



RH cycles

Sensing characteristics of carbon IDE

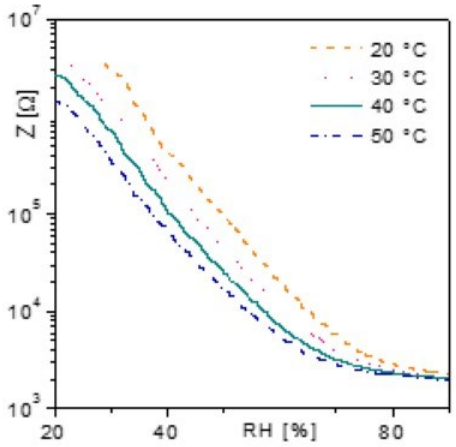
- RH cycles, the impedance characteristics at 1 kHz frequency were measured.
- PET substrate - sensitivity of carbon based ID structure itself to the moisture
- Sensing properties of carbon IDE dependant on humidity from 70% RH and higher



Dependence of impedance on RH and temperature for carbon based ID on PET

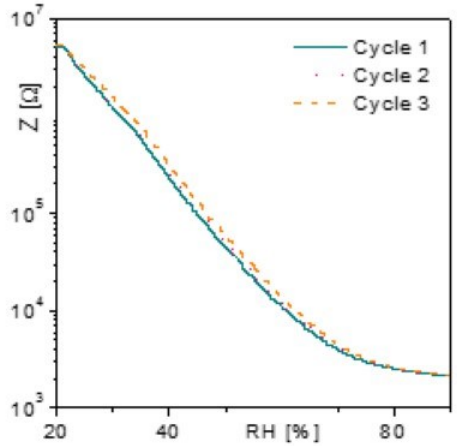
Sensing characteristics of NFC based sensor

- High impedance changes at low humidity levels.
- The saturation of impedance was observed at higher RH values.
- Three orders of magnitude change in layer impedance.
- The maximal impedance is below 10 MΩ.



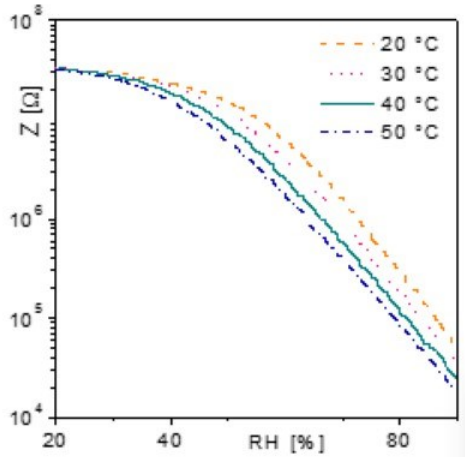
Dependence of impedance on RH and temperature for NFC-based sensors

Stability of sensor response in repeated cycles



Sensing characteristics of MFC based sensor

- In contrast to the NFC sensors, sensitivity at high humidity levels.
- Sensitivity to humidity from 40% RH without any saturation at high humidity values.
- Three orders of magnitude change in layer impedance.
- The maximal impedance is below 20 MΩ.



Dependence of impedance on RH and temperature for NFC-based sensors

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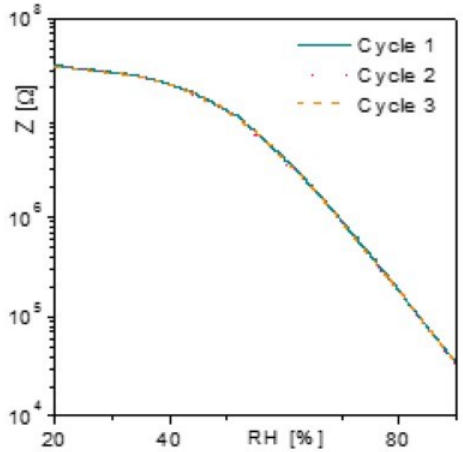
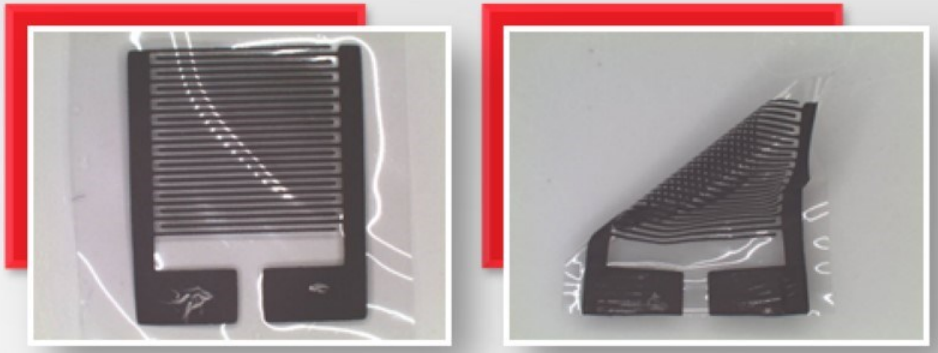


Mechanical deformation of MFC/NFC films within the humidity cycles

- MFC sensors exhibit lower mechanical deformation, and better reproducibility of sensing characteristics
- This can be contributed to the higher deformation (swelling) of the NFC substrate at high RH.



NFC based sensor before/after cycling in humidity chamber

NFC based sensor before/after cycling in humidity chamber

Conclusion and future work

- The MFC and NFC substrates represent very promising sensing layers for humidity sensing applications.
- The nature of their sensing behavior is dissimilar and is controlled by the differences surface chemistry and nanoscale fibrillar structure of the cellulosic materials
- Each type of sensing material is limited to sensing at a specific range of RH.
- Future work will investigate use of combinations of NFC and MFC to widen the measurable RH range
- It will be tested coating of optimized NFC/MFC mixture to a carrier substrate such as paper to improve the mechanical and sensing stability
- Testing under DC.

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Thank you for your attention

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