ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

EnerHarv 2024

Challenges in Eco-friendly Sensor Integration in EH

Giovanni Landi*

*Department of Energy Efficiency Unit
Portici Research Center, ENEA, Italy

Landi Giovanni, PhD – DUEE-SPS-SEI

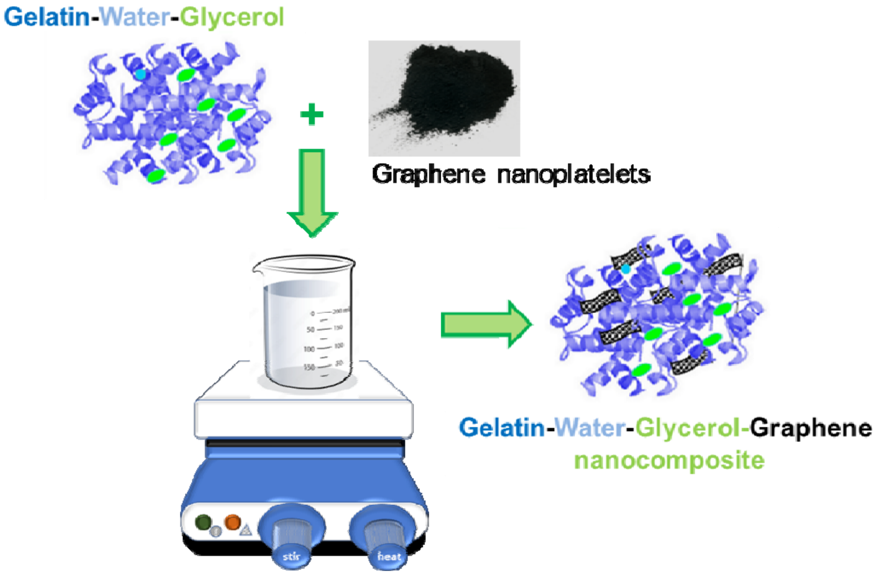
26-28 June 2024 Perugia, Italy

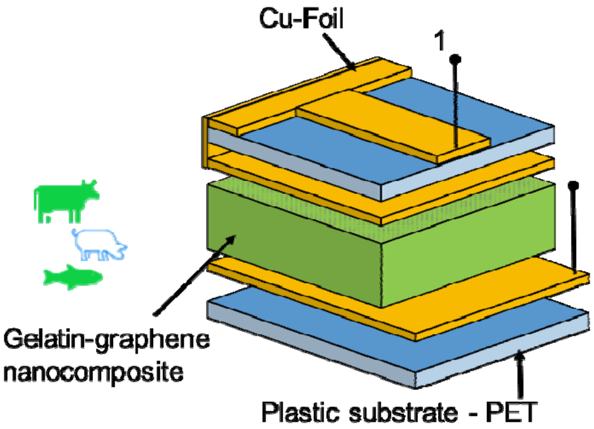
Challenges

- **Fabrication of an environmentally friendly and low-power temperature sensor** using a low-cost water-processable hydrogel based on gelatin and graphene
- **Performance evaluation and optimization** (e.g., sensitivity, response time, linearity, and power consumption) **with a driving circuit**
- **Long-term stability and regeneration** of the temperature sensor based on hydrogel nanocomposite
- **Conclusions**

Fabrication of low-cost and environmentally-friendly device

The **gelatin** was dissolved in an **80°C mixture of water and glycerol** at a concentration of 10 wt.%, and **graphene** was subsequently added to form mixtures with 0.25 wt.% of filler content. These mixtures were mechanically **stirred for approximately 30 minutes** at the same temperature.



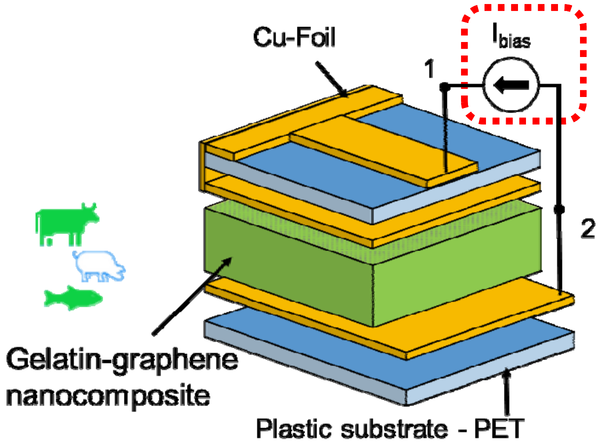


The obtained gel–nanocomposite was deposited by using a blade coating method.

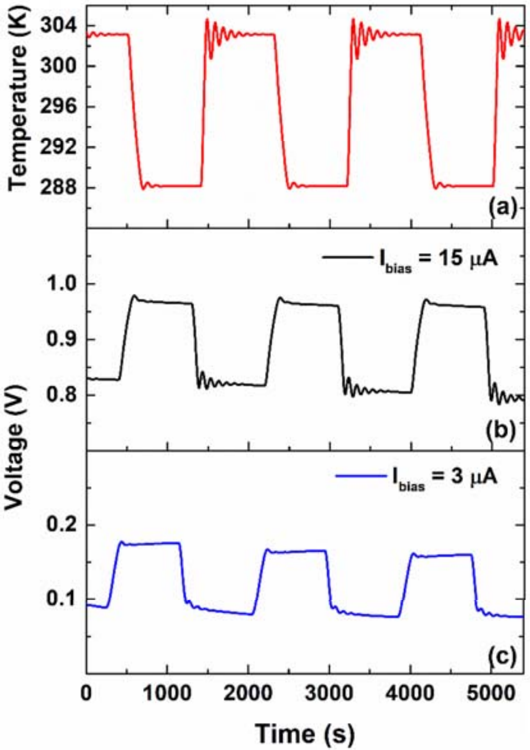
G. Landi et al., Nanomaterials 12, 2227 (2022).

Temperature dependence of electrical characteristics (1/2)

By biasing the sensor with a current (I_{bias}), it is observed that



$$m_V = \frac{\Delta V}{\Delta T} < 0$$

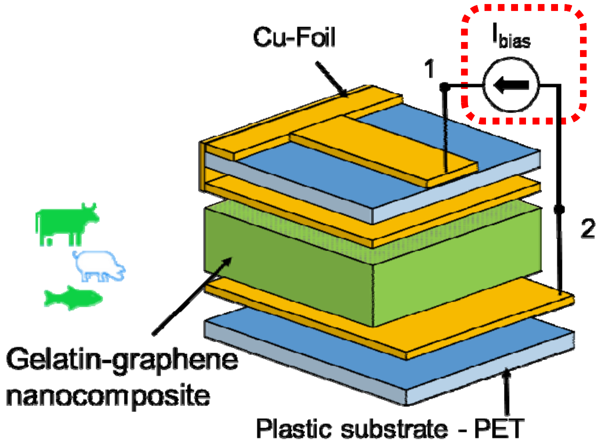


G. Landi et al., Nanomaterials 12, 2227 (2022).

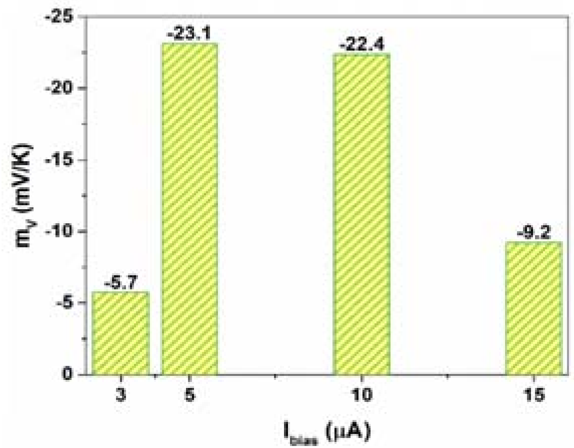
- The device follows the temperature trend.
- An increase in temperature (ΔT) leads to a decrease in the measured voltage signal (ΔV) with a negative sensitivity (m_V).

Temperature dependence of electrical characteristics (2/2)

By biasing the sensor with a current (I_{bias}), it is observed that



$$m_V = \frac{\Delta V}{\Delta T} < 0$$

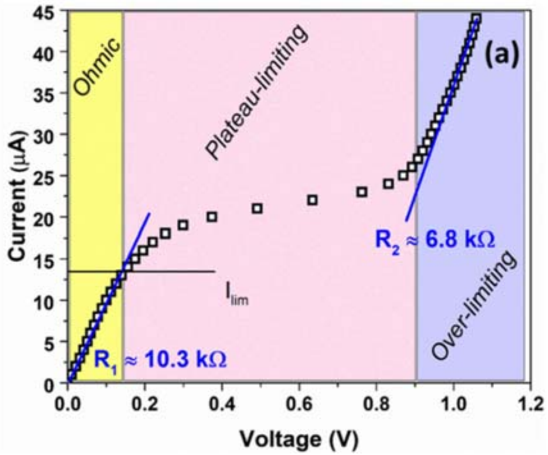


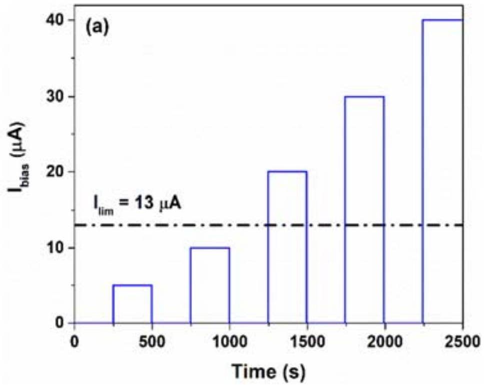
Voltage temperature sensitivity m_V is current-dependent

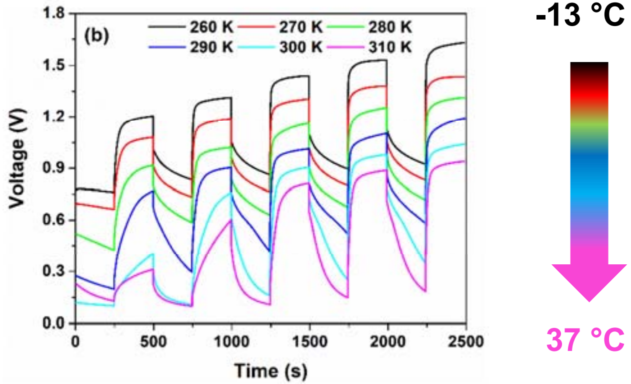
- The device follows the temperature trend.
- An increase in temperature (ΔT) leads to a decrease in the measured voltage signal (ΔV) with a negative sensitivity (m_V).

Evidence of the limiting current phenomena in the gelatin based-electrolyte

By current biasing the sensor, dissociation processes are observed in the hydrogel for $I_{bias}>I_{lim}$ generating a temperature-dependent signal.



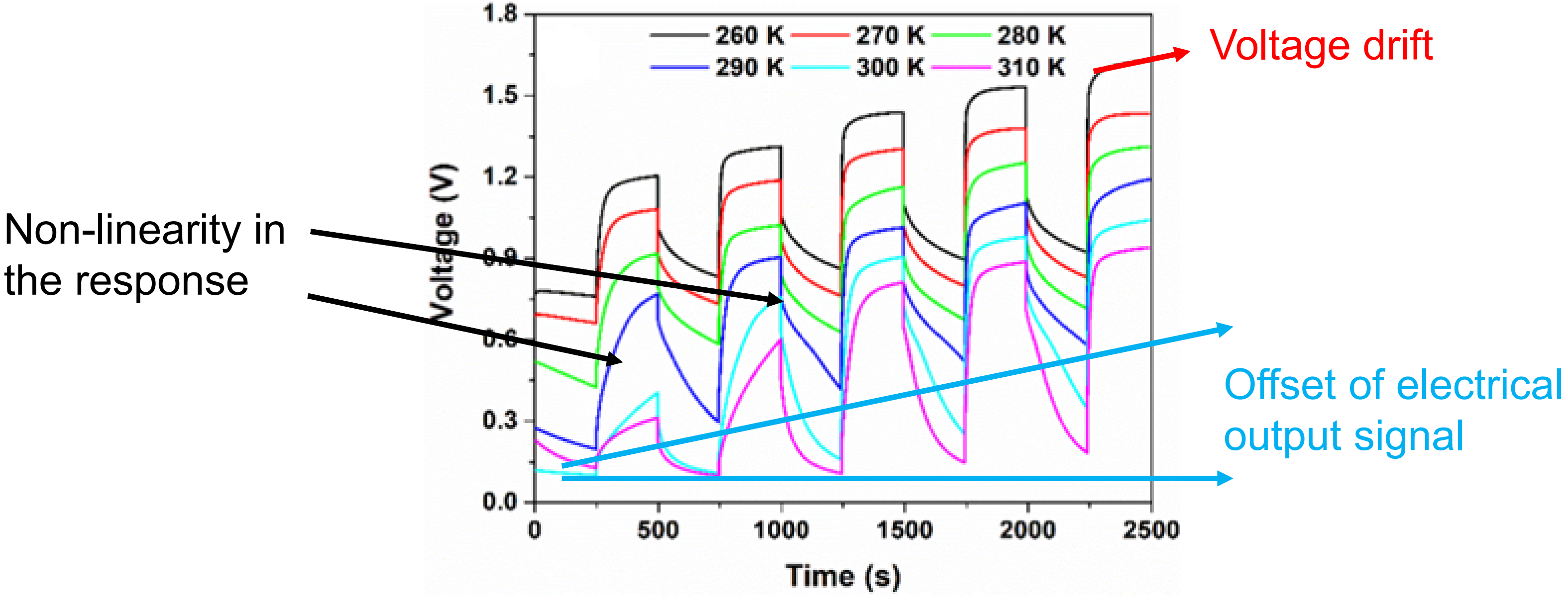




G. Landi et al., Nanomaterials 12, 2227 (2022).

Driving circuit for reducing the voltage drift and offset of the temperature sensor (1/2)

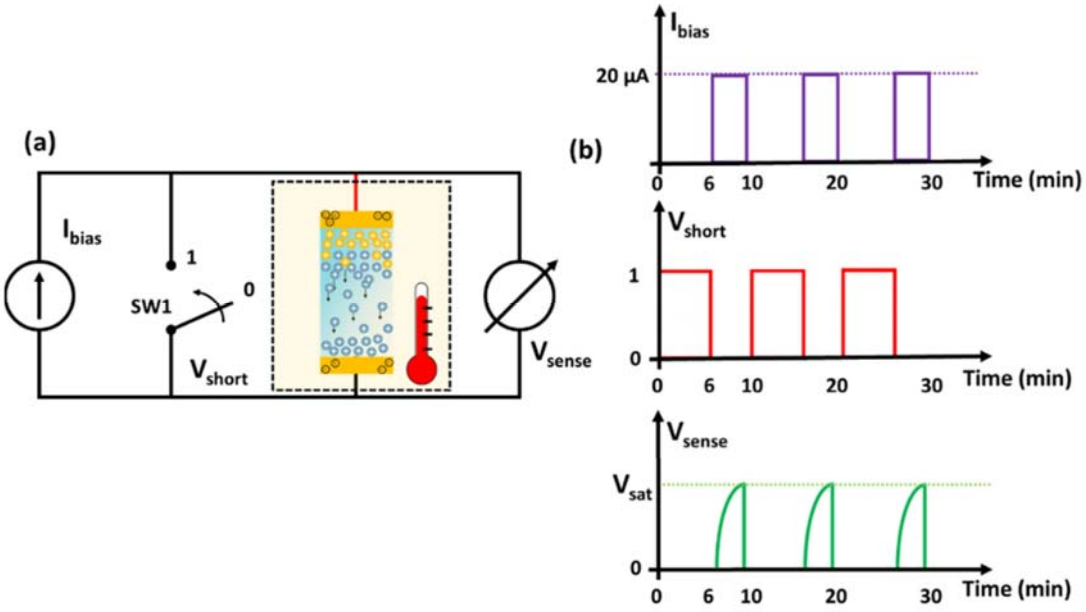
A DC current drive circuit has been designed to increase cycling stability and reduce voltage drift and offset of the temperature sensor electrical output signal.



G. Landi et al., Nanomaterials 12, 2227 (2022).

Driving circuit for reducing the voltage drift and offset of the temperature sensor (2/2)

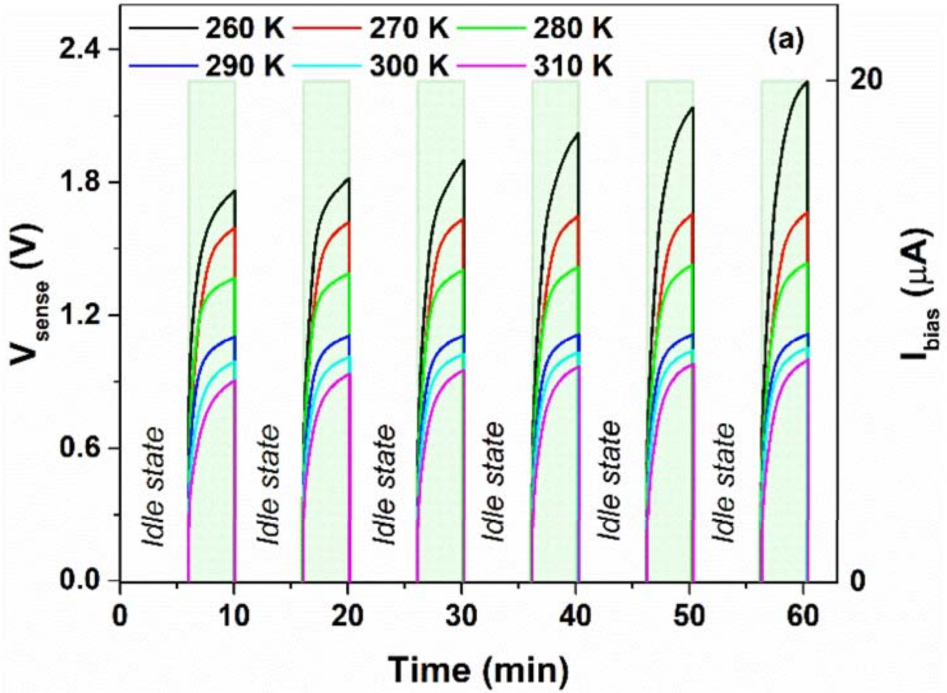
A DC current drive circuit has been designed to increase cycling stability and reduce voltage drift and offset of the temperature sensor electrical output signal.

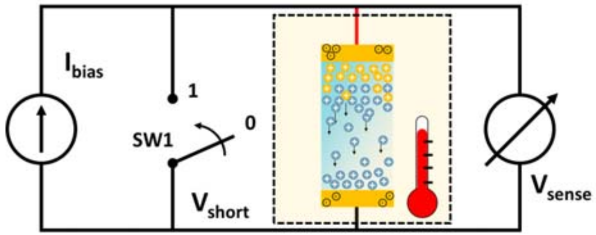


The drive circuit performs a measurement cycle every 10 min with an idle time of 6 min and a sense period of 4 min.

G. Landi et al., Nanomaterials 12, 2227 (2022).

Advantages of the bias circuit (1/2)



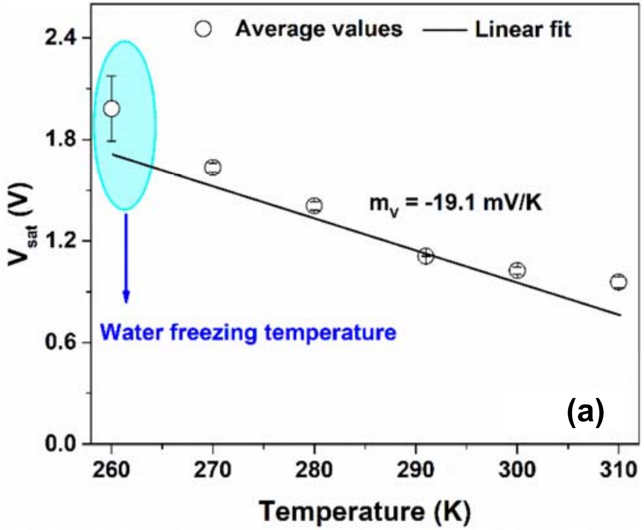


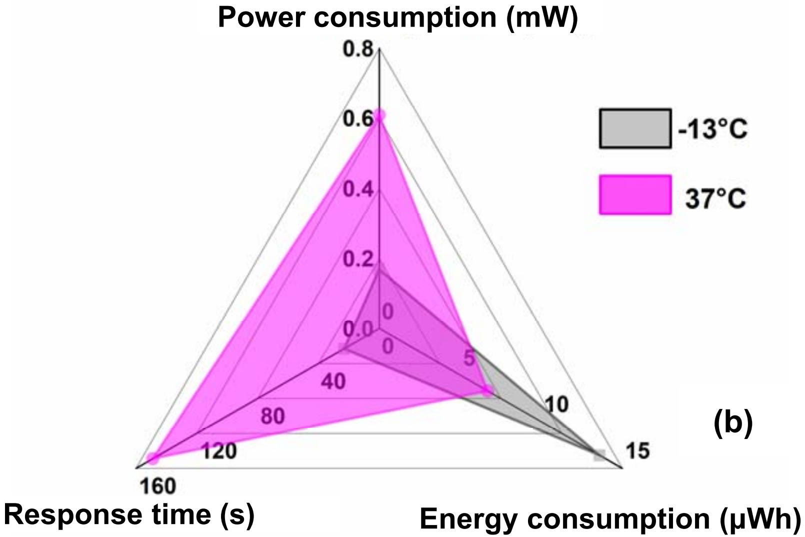
- Linearity of response;
- Long-term stability;
- Offset and drift reduction of the output signal;
- Detection of ice formation;

G. Landi et al., Nanomaterials 12, 2227 (2022).

Advantages of the bias circuit (2/2)

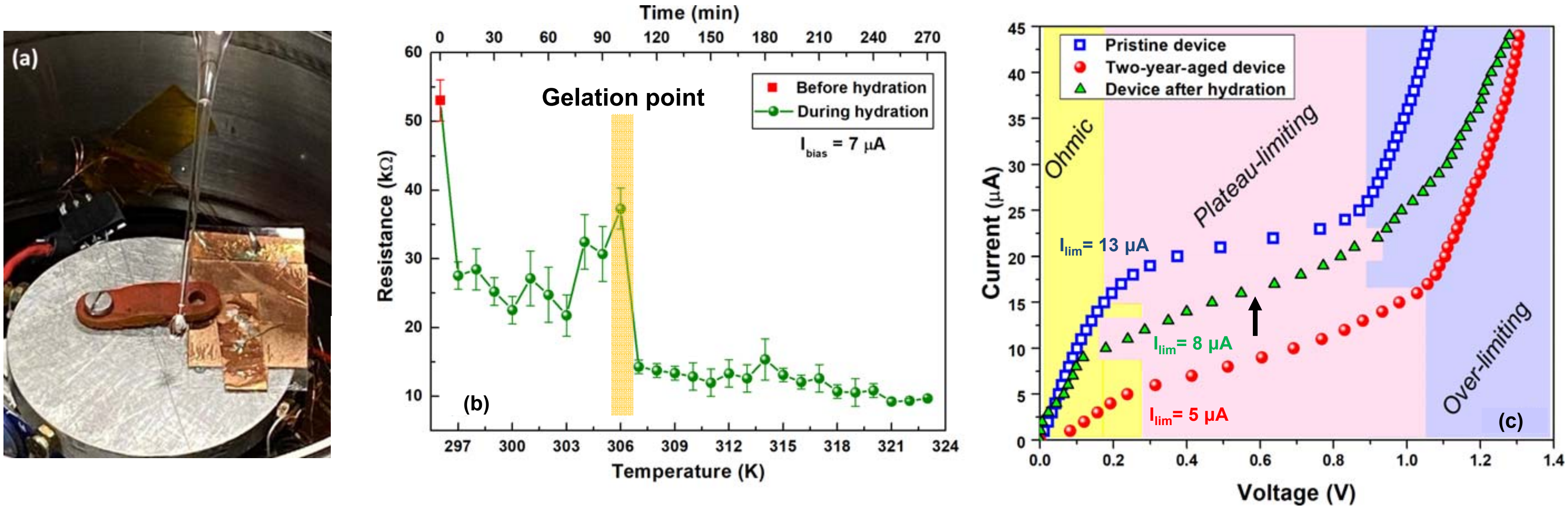
- Temperature sensitivity increases to **-19.1 mV/K**;
- Fast electrochemical sensor response 30 s - 150 s;
- Low energy consumption **<15 µWh** (suitable for environmental monitoring for indoor applications).





G. Landi et al., Nanomaterials 12, 2227 (2022).

Regeneration process of the aged device through water uptake: thermal stability and real-time monitoring



The regeneration process initiates at the gelation point (~306 K), resulting in a more conductive nanocomposite.

The regenerated sensor displays a significant shift in the current-voltage characteristic towards a higher current range, aligned with an observed **increase in the limiting current value.**

G. Landi et al., Nanomaterials 14, 283 (2024).

Conclusions

- **Fabrication of an environmentally friendly, low-power temperature sensor** using a low-cost, water-processable hydrogel based on gelatin and graphene.

- The environmentally friendly sensor exhibits temperature **sensitivity of about -19 mV/K, fast response and low energy consumption (<15 µWh)** suitable for environmental monitoring in indoor applications.

- **Experimental evidences of long-term stability** of the temperature sensor **after two years**.

- The **effective regeneration of aged sensors**, by adding a few drops of water at a temperature above the gelation point of the hydrogel nanocomposite, **contributes significantly to its sustainability and reusability**.

Thanks for your attention

This research was funded in the Program Agreement between the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the Ministry of Environment and Energy Safety for Electric System Research, in the framework of its Implementation Plan for 2022-2024. In particular, the activity is included in Project 1.5 “High-efficiency buildings for the energy transition”, Work Package 3 “Innovative technologies and components for increasing the energy performance of buildings.

Giovanni Landi, PhD
Email: giovanni.landi@enea.it

Contacts:

Giovanni Landi, PhD
C. R. ENEA Portici (Naples) – DUEE-SPS-SEI
Department of Energy Efficiency Unit
http://www.enea.it
http://www.agenziaefficienzaenergetica.it