CENIMAT-i3N

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Paper and Printed Electronics

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Abstract

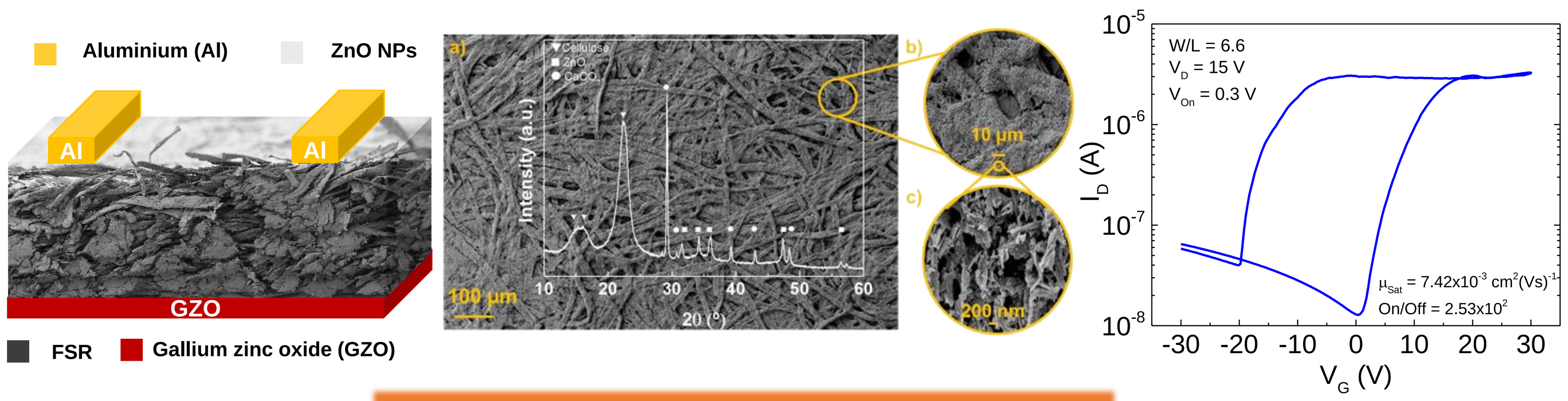
This is a glance of the paper-based electronics concepts developed at CENIMAT/I3N targeting low-cost, flexible, environmentally friendly and sustainable electronic devices. Part of the work being developed aims the exploration of paper and cellulose-based materials (vegetable and bacterial sources) as dielectric material in transistors, memories or inverters, based on oxide semiconductors. The other part aims the functionalization of cellulose fibbers with nanoparticles and the use of cellulose based substrates in processing different integrated electronic devices employing simple and low cost techniques such as printing or even pen-writing The result are printed/written transistors, memories, sensing elements or simple circuits, either by using paper as a substrate or by functionalizing it with conductor/semiconductor nanomaterials.

The ultimate goal is to support the creation of broad range of eco-sustainable electronic commodities such as smart labels, intelligent packaging, or even foldable displays to serve the next generation of creative and smart industry.

Cellulose-based substrates as dielectric

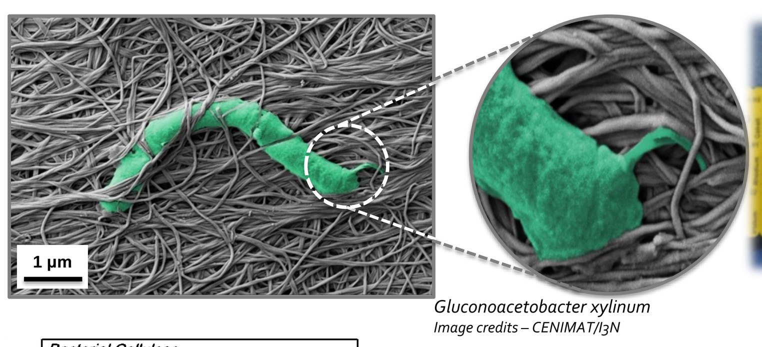
Paper Functionalized FETs

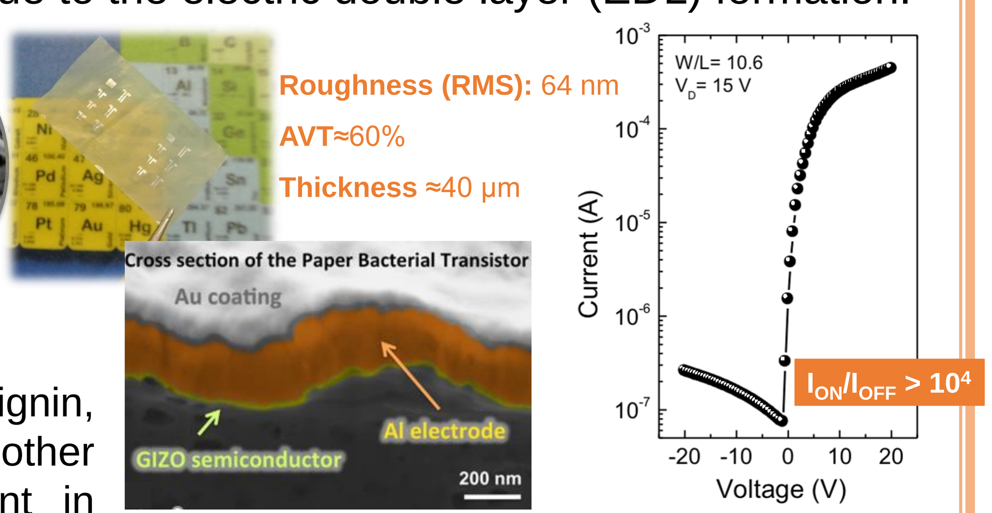
- Paper (FSR) top surface was functionalized with ZnO via wet chemical precipitation based on $ZnC_4H_6O_4{\cdot}2H_2O$ and NaOH, at room temperature.
- After functionalization paper can act as semiconductor, substrate and dielectric.

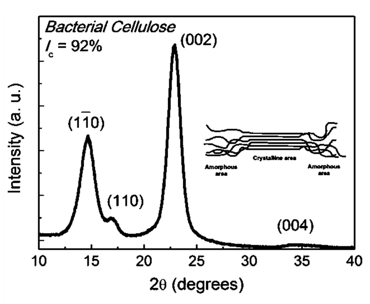


Bacterial Cellulose

- Highly pure and crystalline bacteria-produced biopolymer composed of ultrafine nanofibers (< 100 nm wide).
- Acts as substrate and dielectric due to the electric double layer (EDL) formation.







Cellulose I, free of lignin, hemicellulose and other components present in the vegetable cellulose

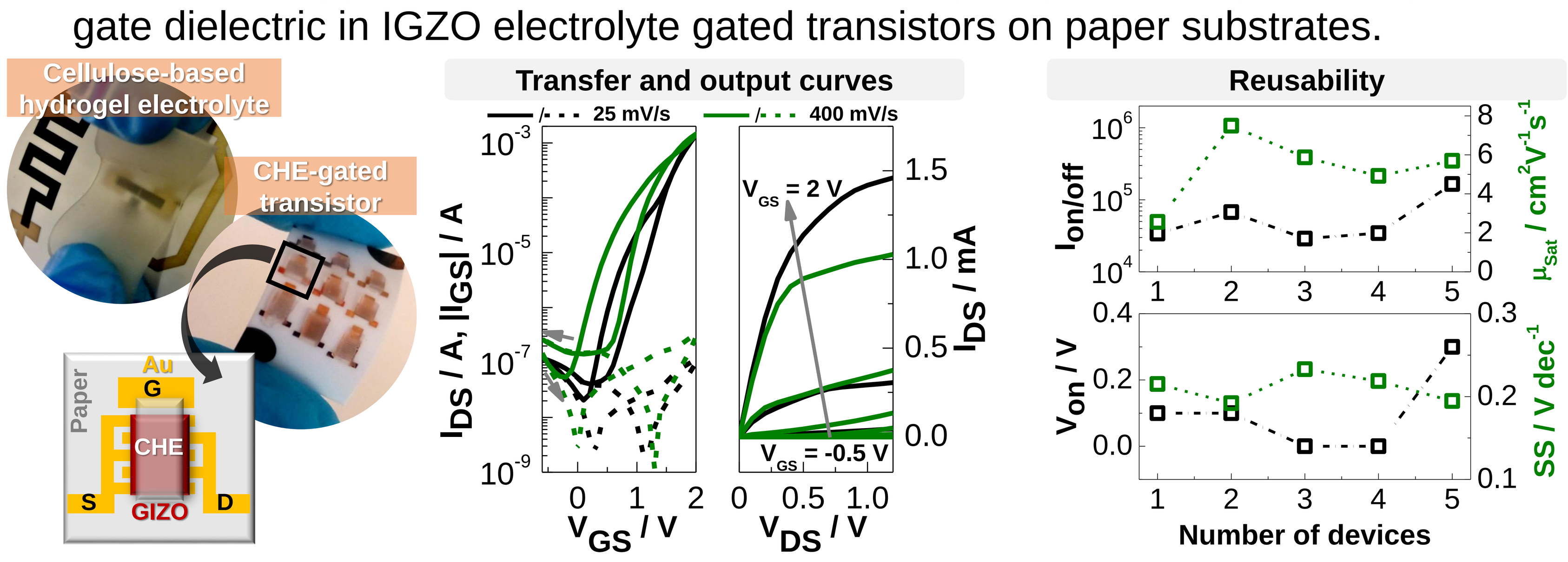
Capacitance (F/cm²)	μ_{sat} (cm²/Vs)	V_{ON} (V)	I_{ON}/I_{OFF}	S (V/dec)
6.12x10^{-8}	17.4	-3	6×10^4	1.20

"Optoelectronic Devices from Bacterial NanoCellulose" from the book "Bacterial Nanocellulose - From Biotechnology to Bio-Economy". Elsevier (2016) edit by M. Gama; F. Dourado; S. Bielecki

Cellulose-based composites for electronics

Cellulose-based hydrogel sticker as the gate dielectric

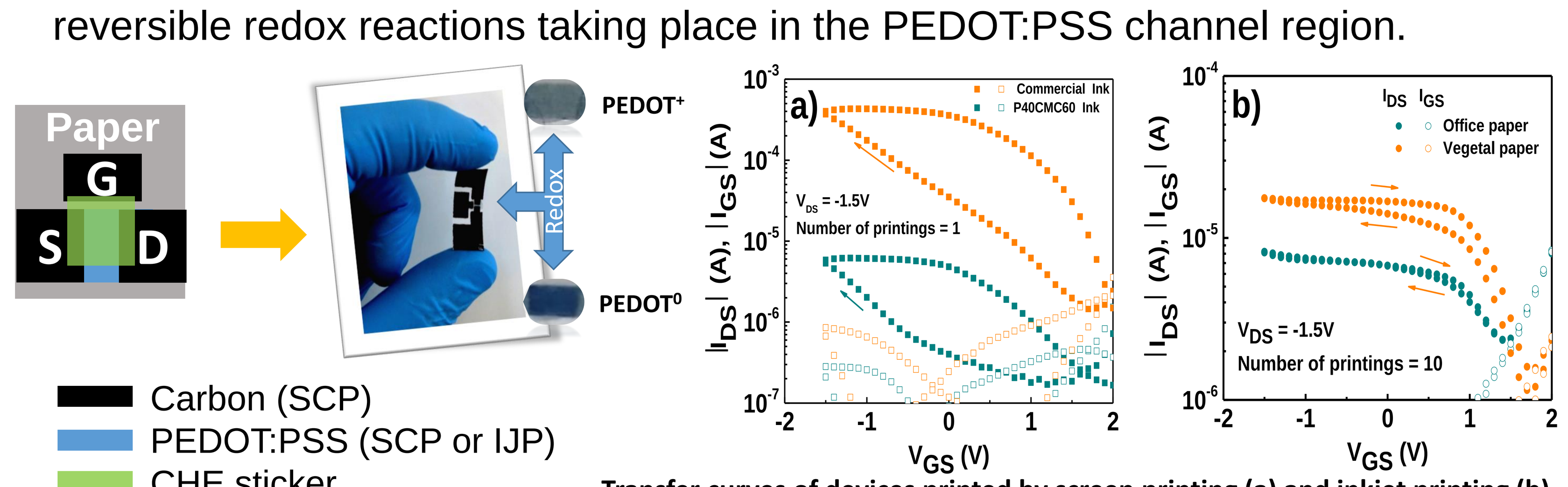
- Development of a new category recyclable and reusable hydrogel electrolyte stickers based on cellulose using a green and economic process.
- Promising properties for application in paper electronics: transparency, flexibility, transferability, and high specific capacitance (5 μF.cm^{-2}).
- Successful application of the cellulose-based hydrogel electrolyte (CHE) as the gate dielectric in IGZO electrolyte gated transistors on paper substrates.



I. Cunha, et al. Adv. Funct. Mater. 2017-02, 0, 1–11 (doi: 10.1002/adfm.201606755)

Printed PEDOT:PSS OECTs on paper-based substrates

- PEDOT:PSS organic electrochemical transistors (OECTs) were fabricated on vegetal paper and office paper, using printing techniques, such as screen printing (SCP) and inkjet printing (IJP).
- The devices exhibit modulation of both optical and electrical properties, due to reversible redox reactions taking place in the PEDOT:PSS channel region.

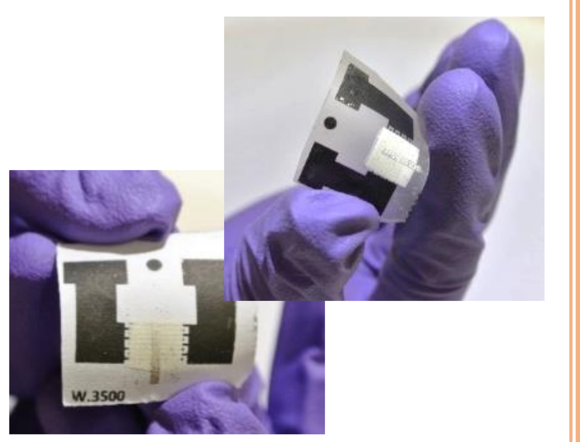


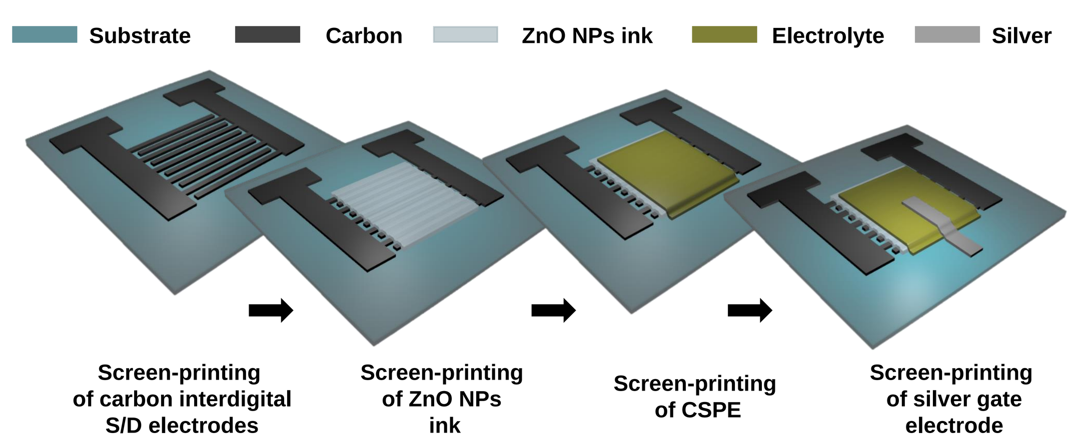
Transfer curves of devices printed by screen printing (a) and inkjet printing (b).

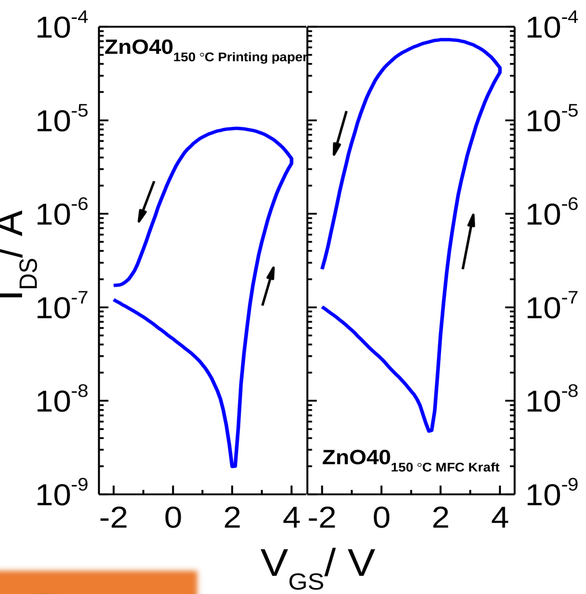
Printed Electronics

Fully Printed ZnO NPs EGTs on Paper Substrates

- The semiconductor ink, ZnO40, was developed by blending 40 wt% of commercial ZnO NPs in a vehicle, i.e. 5 wt% of Ethyl Cellulose dissolved in 80:20 %v/v of toluene/ethanol solution.
- Processing temperatures less than 150 °C allows the development of fully screen-printed EGTs on paper substrates, namely on printing paper (PP) and MFC Kraft (MK).

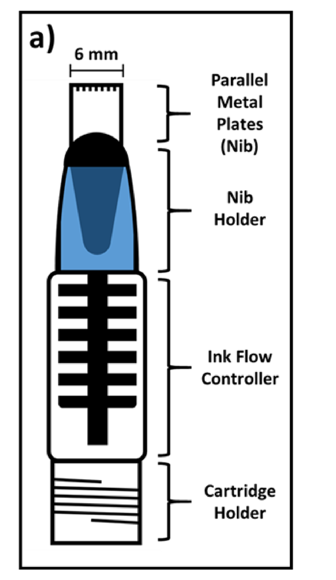




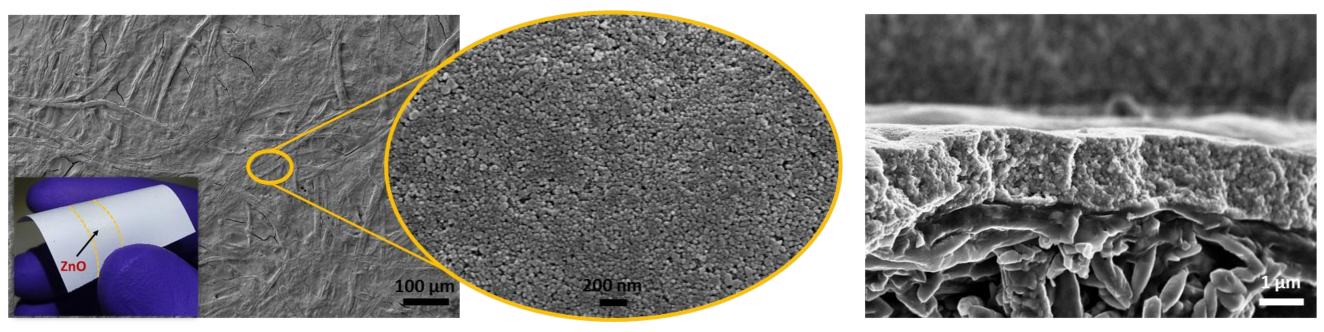


Hand-Written ZnO NPs EGTs on Paper

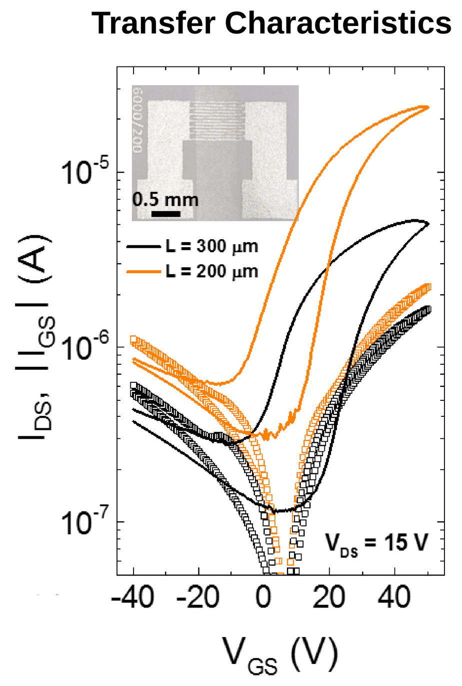
- A calligraphic pen was used to deposit wide lines of ZnO on conventional printing paper from a 50 wt% ZnO aqueous ink.
- The obtained ZnO films show a dense packed NP matrix with sufficient interparticle connectivity to be used as hybrid hand-drawn/printed UV-sensors, transistor devices and logic gates.



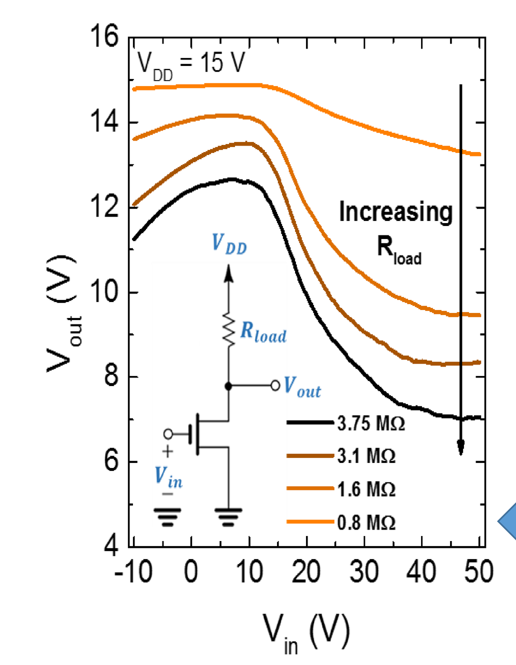
Schematic of the used Metal Plate Pen

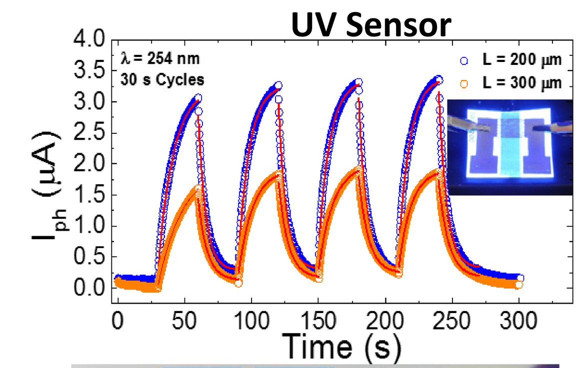


Cross-Section of Paper + ZnO

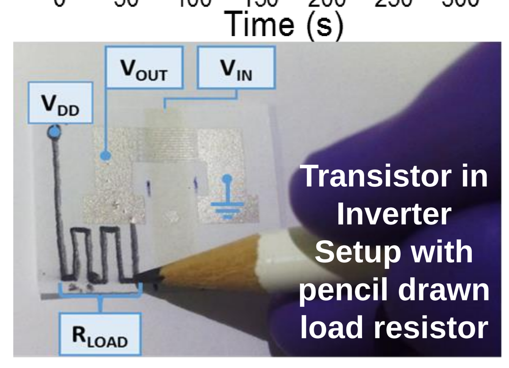


Transfer Characteristics



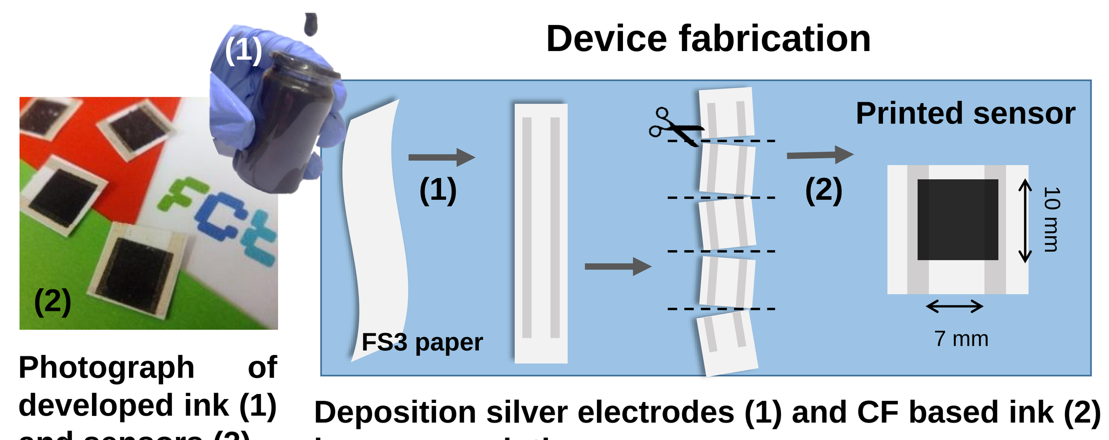


UV Sensor



P. Grey et al., 2017, accepted for publication in Advanced Materials Technology

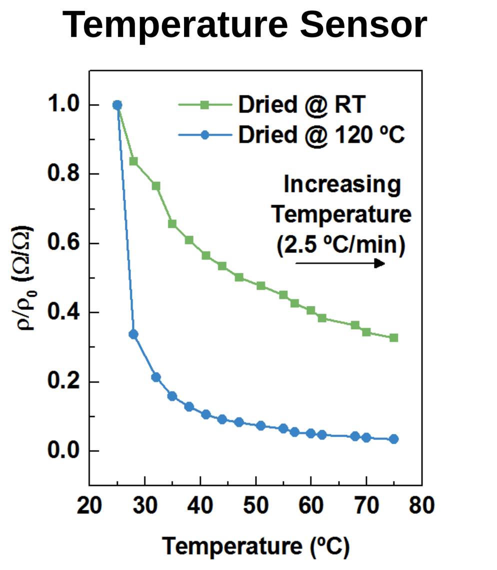
Carbon fiber-based films as sensing elements



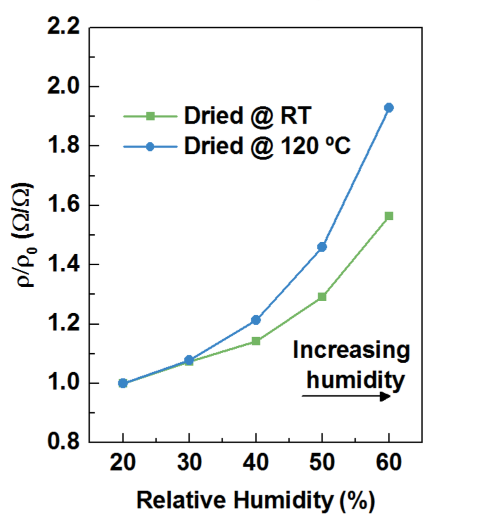
Photograph of developed ink (1) and sensors (2)

Deposition silver electrodes (1) and CF based ink (2) by screen-printing

Temperature Sensor



Relative Humidity Sensor



- Development of an environment-friendly cellulose-based conductive ink for screen-printing.
- Ink formulation consists on blending carbon fibers and an aqueous solution of carboxymethyl cellulose.
- Resistivity of 1.03 Ωcm after 10 printing passes for films dried at RT.
- Films are sensible to temperature and relative humidity variations.

Barras et al. 2017, Flexible Printed Electronics (doi: 10.1088/2058-8585/aa5ef9)

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