

Bio-sourced Polyester as Substrate for Sustainable Wireless Smart Tags Made by Printing

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Summary:

We report on poly(hexylene xylosediglyoxylate), a bio-derived polyester from lignocellulosic sugars, as a sustainable substrate for printed electronics. The material is compatible with the additive manufacturing of a transient zinc ink for the realization of eco-friendly sensors and wireless tags. Applying the optimized sintering parameters, different transducers, resistors, capacitors and microstrip lines were patterned to evaluate the properties of the substrate and realize sensing structures. Using the zinc and bio-polyester combination, a wireless identification tag operating at 860–930 MHz was demonstrated.

Keywords: Bio-derived polyester, printed electronics, RFID, sensors, substrate, wireless

Background, Motivation and Objective

Recent advances in bio-derived polymers have enabled the development of high-performance polyesters from lignocellulosic sugars, providing sustainable alternatives to fossil-based plastics [1]. In parallel, alternative conductive materials such as zinc have emerged as promising low-cost and less toxic substitutes for conventional silver inks in printed electronics [2]. These developments align with the growing demand for eco-responsible short life smart tags with wireless and sensing capabilities. In this context, combining bio-sourced polyesters with eco-friendly conductive inks offers a pathway toward more sustainable electronic platforms.

In this work, we are investigating poly(hexylene xylosediglyoxylate) (PHX) as a bio-sourced substrate for printed electronics. We demonstrate its compatibility with the additive manufacturing of transient conductive ink applied to wireless and environmental sensing applications.

Description of the New Method and System

PHX is a bio-based polyester produced directly from the hemicellulosic fraction of lignocellulosic biomass. It is synthesized by functionalizing this biomass with glyoxylic acid to create a rigid tricyclic monomer (DMGX), which subsequently reacts with 1,6-hexanediol to form PHX. This carbohydrate-derived polyester exhibits PET-like properties ($T_g = 72^\circ\text{C}$ and an ultimate tensile strength of 63 MPa) while allowing efficient

chemical depolymerization back to its monomers under mild conditions [1].

The PHX powder was hot pressed to form 200 μm thick substrates. The zinc ink was made of zinc microparticles mixed with polyvinylpyrrolidone as binder and using diethylene glycol monobutyl as solvent. The zinc ink was screen printed on the substrate and sintered following the hybrid chemical and photonic process described in [2]. The photonic energy was tuned for an optimal sintering of conductive ink.

The radio-frequency characteristics of the PHX substrate were characterized using a printed zinc microstrip line. The influence of ambient humidity was evaluated using a climatic chamber. Interdigitated zinc electrodes were also patterned to form a capacitive transducer, and its humidity response was evaluated. The results for both structures were compared to those obtained on a PET (Melinex ST506) substrate used in printed electronics.

Finally, an RFID UHF tag was manufactured on PHX substrate. The tag is made of a zinc antenna integrated with an RFID chip. The tag can be interfaced with zinc based capacitive and resistive transducers for humidity and temperature sensing, respectively.

For the first time, bio-sourced PHX has been applied as a printed electronic substrate showing its compatibility with conductive inks, sensing and radio-frequency applications.

Results

The transient zinc ink was successfully printed and hybrid sintered on PHX. Fig. 1 presents the resistance value as a function of sintering energy, compared to zinc printed on paper, achieving higher conductivity. The optimal parameter to achieve the highest conductivity was found to be 3.7 J/cm^2 . Above 4.4 J/cm^2 the integrity of the zinc pattern is affected, because of the PHX substrate melting locally. The thickness of the zinc layer on PHX was measured at $9.5 \pm 2 \text{ } \mu\text{m}$ and its conductivity was measured at $2.1 \times 10^6 \text{ S/m}$. These zinc resistors can be used as a temperature sensor thanks to their high temperature coefficient of resistance (TCR). Using these optimum parameters, zinc capacitive and radio-frequency structures were also printed and evaluated on PHX.

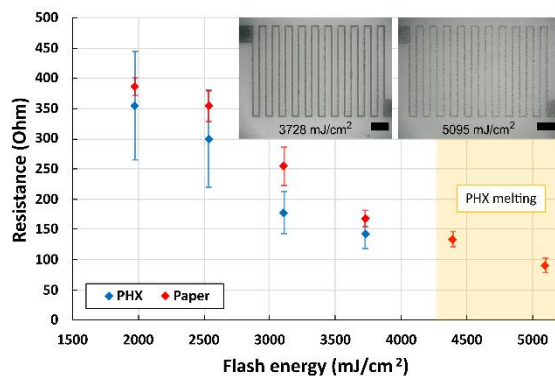


Fig. 1. Resistance of the zinc track vs flash lamp energy for PHX and paper substrates. Scale bar = 2 mm.

Fig. 2 shows the interdigitated electrodes capacitor and its capacitance evolution when exposed to dry air and air at 80% RH, both on PHX and PET substrates. PHX substrate is slightly more sensitive to humidity than PET, with its capacitance increasing by 5% in comparison to 1.5% for PET, when increasing the humidity from 0 to 80% RH. However, its recovery to 0% RH is much faster, leading to less hysteresis when cycling it up again to 80% RH, making the structure of interest as humidity sensor.

A microstrip line resonating at 1 GHz was also printed on PHX and PET and tested. Fig. 3 shows the S_{12} response of the resonator on PET and PHX where a change in resonance frequency of less than 5 MHz is observed when exposing the resonator to 0% and 80% RH. At 1 GHz, PHX exhibits a similar behavior as PET showing its suitability for high-frequency applications.

Finally, we manufactured a UHF (870-930 MHz) RFID tag with a zinc antenna, as seen in Fig. 4. The eco-friendly RFID tag was able to be detected at a distance up to 9.6 m using a commercial reader emitting at 0.5 W. The RFID chip having sensors' inputs, the tag can integrate a zinc

RTD sensor and/or an IDE humidity transducer printed on PHX substrate at the same time as the antenna.

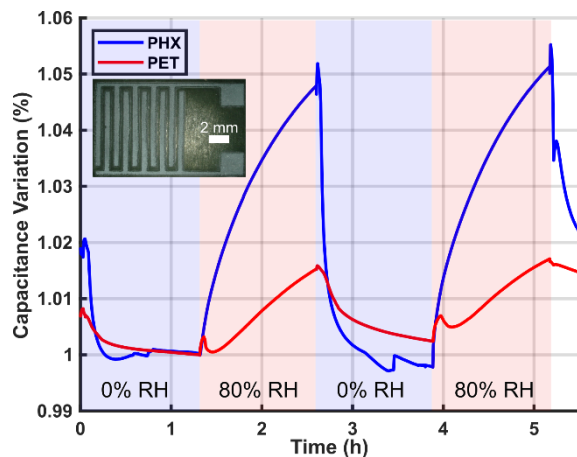


Fig. 2. Capacitance variation over time for zinc on PHX and on PET when cycling from 20% to 80% relative humidity at 20 °C.

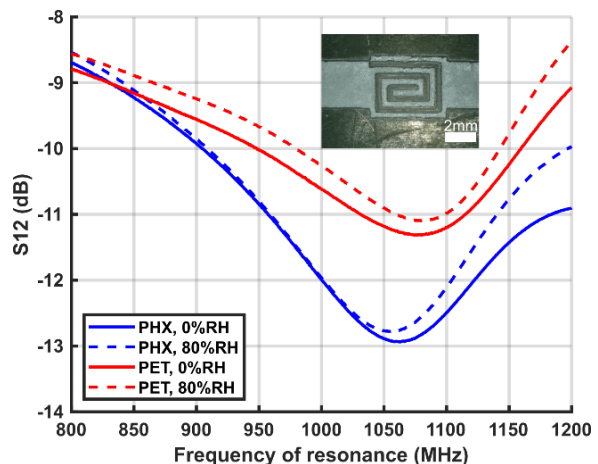


Fig. 3. S_{12} response vs frequency for the zinc strip line on PHX and PET substrates when exposed to 0 and 80% RH at 20 °C.



Fig. 4. Optical image of the zinc antenna printed on PHX and assembled to an UHF RFID chip.

This work shows the suitability of PHX as a bio-sourced substrate alternative to PET/PEN for printed electronics and wireless devices.

References

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