Eco-friendly wireless sensing tags for smart packaging applications

James Bourely[1], Xavier Aeby[2], Jaemin Kim[3], Nicolas Fumeaux[1], Gilberto Siqueira[2], Christian Beyer[3], David Schmid[3], Gustav Nyström[2], Oleksandr Vorobyov[3] and Danick Briand[1]

[1]Soft Transducers Laboratory, EPFL, 2002 Neuchâtel, Switzerland
[2]Cellulose and Wood Materials, EMPA, 8600 Dübendorf, Switzerland
[3]Centre Suisse d'Electronique et de Microtechnique, 2000 Neuchâtel, Switzerland

As of 2022, the generation of global electronic waste has reached close to 60 million metric tons annually. Furthermore, less than 25% of the electronic devices that often rely on printed circuit boards made of toxic materials are recycled [1]. With a projected doubling of the number of Internet-of-things products by 2030, developing environmentally friendly and non-toxic sensing alternatives would be an impactful solution to the growing electronic waste issue. In the field of perishable goods, monitoring of temperature and relative humidity is of high interest. This sensing is either based on colorimetric indicators that are subjective to the lighting and camera colour perception or on more complex systems such as bulky data loggers for traceability [2]. Therefore, stable, low-cost, environmentally-friendly sensing and identification wireless tags that do not require a free line of sight are promising for a new generation of chipless smart packaging [3].

Within this scope, the GREENsPACK "Green Smart Packaging" project, a collaboration between EPFL, EMPA, and CSEM in Switzerland, aims to develop printable radio-frequency identification and sensing tags made of degradable and renewable materials.

In particular, the tags are made of compostable bio-polymers and recyclable paper substrates. Employing additive manufacturing such as screen-printing, conductive zinc traces are patterned and sintered using a hybrid chemical and photonic method to achieve high electrical conductivity and enhanced stability [4]. Eco-friendly encapsulation and sensing layers are implemented on the tag.

Two types of resonating tags have been produced operating in frequencies ranging from 1 GHz to 10 GHz for the monitoring of environmental parameters relevant to perishable goods.

Firstly, a degradable microstrip line for punctual monitoring of temperature and relative humidity was designed and fabricated. The temperature is assessed using the changes in the electrical properties of the metallisation layer whereas humidity variations are detected with specific biodegradable coatings. Secondly, a near-field communication compostable tag was produced for temperature-threshold detection based on the phase-changing properties of fatty acids.

These technologies pave the way toward the future development of cost-effective printed sensors and inlays that operate on chipless tag designs and utilize wireless communication, enabling their more environmentally respectful end-of-life disposal for smart packaging applications.

[1] C. P. Baldé, E. D'Angelo, V. Luda, O. Deubzer, and R. Kuehr, "Global Transboundary E-waste Flows Monitor - 2022," *U. N. Univ. UNU Int. Telecommun. Union ITU Int. Solid Waste Assoc. ISWA BonnGenevaRotterdam*, 2022.

[2] Rodrigues, C.; Souza, V.G.L.; Coelhoso, I.; Fernando, A.L. Bio-Based Sensors for Smart Food Packaging—Current Applications and Future Trends. *Sensors* **2021**, *21*, 2148. https://doi.org/10.3390/s21062148

[3] P. Fathi, N. C. Karmakar, M. Bhattacharya and S. Bhattacharya, "Potential Chipless RFID Sensors for Food Packaging Applications: A Review," in *IEEE Sensors Journal*, vol. 20, no. 17, pp. 9618-9636, 1 Sept.1, 2020. https://doi.org/10.1109/JSEN.2020.2991751

[4] Fumeaux, N., Briand, D. Zinc hybrid sintering for printed transient sensors and wireless electronics. *npj Flex Electron* **7**, 14 (2023). https://doi.org/10.1038/s41528-023-00249-0