STUDY OF OLED END OF LIFE TREATMENTS

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Abstract

Organic Light Emitting Diodes (OLED) are rapidly evolving and enabling the generation of new Intelligent lighting applications, delivering flexible, thin, lightweight and power-efficient light sources that can transform the illumination market. In response to this, and within 7th Framework Programme on Research, Technological Development and Demonstration, Fast2light Project is working on developing novel, cost-effective, high-throughput, roll-to-roll, large area deposition processes for fabricating flexible OLED foils for intelligent lighting applications. Even more, in order to overcome potential environmental impacts already in the technology development and design phase, Fast2light project has also investigated the relevant sustainability aspects arising through the whole life cycle of these products, including their end of life. Considering the growing recycling and valorization targets for electric and electronic waste, and the absence of suitable routes for flexible OLEDs in the actual schemes, the project has carried out specific research in developing, adapting and testing technologies for recovering high added value materials. The research has been focused on mechanical and chemical recycling alternatives, like delamination, glycolysis and pirolysis. The use of LCA for evaluating also the different end of life options enables a global perspective, avoiding potential shift of burdens among i.e. different regions, time-frames and impact categories.

Keywords: *OLED, LCA, recycling, de-lamination, glycolysis*

1. Introduction

Fast2light project is focused on developing optimized deposition processes for fabricating light-emitting polymer-OLED foils for intelligent lighting applications. The research covers all the layers that are part of an OLED lighting foil, starting by the substrate choice, and introducing high-throughput deposition and patterning methods for all of the necessary materials [1]. Keeping this global vision, the project also assesses the environmental impacts from a life cycle perspective, evaluating the production, the use and end of life stages. In fact, recycling and valorization options for OLED lighting are key aspects, considering the expected growth of this emerging waste. Calculations based on market research [2] estimate 10.000 t of waste flexible OLED to be generated in 2022.

Life Cycle Assessment (LCA) methodology has been used to evaluate environmental impacts of OLEDs. LCA enables quantifying impacts associated with the use of different raw materials and energy sources, as well as with the emission of contaminants in each life cycle phase of the product.

This paper presents the results obtained in the evaluation of different recycling options for OLEDs and their environmental implications, according to LCA methodology.

2. Materials and Methods

The recyclability assessment is based on the evaluation of OLED samples developed within Fast2light project (Figure 1). The characterization of the samples, together with information about production process and product architecture, has been used to identify the polymeric nature of the substrates, their thermal stability, degradation during use, Higher Heating Value and metal content.

Figure 1. OLED sample developed in the project

Different recycling possibilities have been evaluated:

2.1. De-lamination and de-coating process

Previous experience with complex multilayer/coated wastes recommends the use of chemicals for metal mobilization or plastic layer separation. Caustic soda was used for de-coating metal covers and de-laminating organics, to recover substrate foils. The effect of concentration, temperature and process time has been studied.

2.2. Feedstock recycling: Depolimerization

Given that the OLED substrate materials (PET or PEN) are condensation polymers, chemical depolymerization by glycolysis appears as a feasible option for recovery of the starting monomers. Glycolysis reactions have been carried out in a glass stirred tank reactor at constant temperature and atmospheric pressure, in the presence of catalyst and excess ethylene glycol (EG) to promote the formation of bis(hydroxyethyl) terephtalate (BHET) and bis(hydroxyethyl) naphthalate (BHEN), from PET and PEN respectively.

Table 1. Summary of de-lamination and de-coating tests

C_{NaOH} (mol/l)	t (min)	T (ºC)
0.1-7.0	2-45	25-80

Table 2. Summary of glycolysis tests

Catalyst (w/w)	EG:OLED (mol:mol)	t (h)	T (ºC)
1% ZnAc	9:1	2	200

2.3. LCA of end of life processes

The environmental impact evaluation of the proposed OLED recycling scheme has been carried out using ReCiPe methodology [3] and starting from pilot tests data adapted to simulate scaled up processes. In the case of glycolysis, different operational scenarios have been studied, in order to assess the benefits from water and solvent recirculation.

3. Results and Discussion

3.1.OLED sample characterization test results

The OLED substrate assessed is based on PET or PEN, representing 50-70wt% of the total foil, depending on the design. The substrate can become an important waste flow relatively homogenous, interesting for recycling.

The potential thermal degradation of the substrate foils during use phase is an important issue for recyclability. The TGA results of samples which have been subjected to aging tests (at 80ºC for different run times) show no changes in their thermal degradation curves.

Metal content analyses confirm that tested OLEDs contain different metals (Ag, Al, Cu, etc.). Preliminary calculations suggest a metal content of about 0.07wt%, but this figure varies with the evolving OLED designs, and the content in valuable metals can go up to 3%. This variability and the low sample availability have impeded validating the technical and economic feasibility of the metal recovery.

3.2.De-lamination and de-coating test results

De-lamination and de-coating of OLEDs (NaOH 0.5M, 50ºC) has proven to be a suitable treatment for the recovery of the main polymer substrate, clean, free of metals and without changes in its chemical nature.

3.3.Glycolysis test results

Depolimerization by means of glycolysis has been demonstrated as a suitable recycling treatment for the recovery of the starting monomer of OLED substrate foil. PET as main foil leads to BHET, while PEN leads to BHEN. Further study is necessary to check how changes in OLED composition can affect glycolysis products.

3.4.Environmental profile

The LCA results of the waste OLED treatments considered, show that glycolysis accounts for the highest overall impact, associated with its high demand of water and ethylene glycol and the large volume of wastewater generated. For this reason the glycolysis scenario with water and solvent recirculation presents lower impacts (some impacts even have negative value, meaning that the benefit is higher than the environmental load), although they still exceed those generated by delamination. Delamination shows best environmental profile, with low energy and chemicals consumption, leading to the recovery of a film with high properties that can substitute high quality polymers.

Figure 2. De-lamination and de-coating effect over OLED

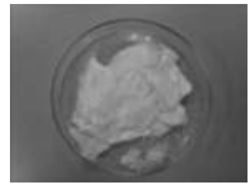

Figure 3. BHEN obtained after glycolysis runs

4. Conclusions

The main recovery target can be focused on the polymeric substrate and metals, due to the large volume (50-70% depending on OLED architecture) and homogeneity in the first case, and in the second case due to their value and the need to prevent their dissipation in the environment.

Both chemical delamination and glycolysis show good recovery results, being delamination the process with lowest environmental impact.

Glycolysis can also be considered a suitable option provided water and solvent recirculation.

Both processes are expected to enable metal recovery in a second step, which is of high importance due to the content in precious and rare metals.

However, research is still necessary in order to check the consistency of these results with different flexible OLED composition and structures (material properties may affect the processes), the full mechanical properties of reprocessed materials and the technical and economic feasibility of recovering valuable metals.

References

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