Verification of Complete Circular Reuse of LCD Panel Components through Non-Destructive Disassembly

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Abstract

This study develops eco-friendly LCD panels through novel easy-to-disassemble materials and non-destructive techniques. Using a 355nm laser Lift-off method, components are reassembled, enhancing material reuse. Purified glass and liquid crystals enable smart dimming products, achieving full circular recycling and green innovation.

Keywords

Green panel non-destructive circular reuse; Innovative smart dimming products; Complete Circular Reuse of LCD Panel.

Introduction

LCD panels consist of multiple layers, including polarizers, color filters (CF), liquid crystal layers (LC), TFT substrates, and backlight modules. Their structure and optical design are highly complex. Due to the primary focus on functionality and compatibility during material selection, recycling and reuse were not considered, leading to challenges in effective disassembly and separation of end products. Most panels are either landfilled or crushed for disposal. Once the two glass substrates are sealed, even minor damage renders the entire display irreparable, resulting in waste disposal. When broken for processing, the interlayers of the panel mix together, making separation and reuse difficult.

This study aims to address these challenges by developing novel easy-to-disassemble materials and non-destructive disassembly/assembly techniques for LCD panels. By introducing easy-to-disassemble materials, eco-friendly LCD panels can be fabricated. Using a 355nm laser pulse energy Lift-off technique for non-destructive disassembly and high-selectivity green removal technology, liquid crystal materials are effectively removed. Defect-free disassembled components can then be reassembled into display products. Furthermore, layer-by-layer removal of surface coatings allows recovery of intact glass substrates, which can be recoated with ITO conductive layers. The purified and doped liquid crystal materials are utilized to produce smart dimming products, achieving full circular recycling of panel materials.

Experimental

This study is dedicated to advancing a non-destructive technology tailored for the recycling of valuable materials derived from obsolete LCD panels. In its initial phase, the research focuses on establishing a non-destructive LCD panel disassembly apparatus equipped with functions such as panel component separation, LCD material extraction, and component surface purification. This apparatus facilitates a meticulous disassembly process for panel glass components. Subsequently, the research rigorously validates the entire panel reassembly process, incorporating methodologies for purifying separated LCD materials, implementing bonding techniques for panel reassembly, and integrating advanced LCD vacuum infusion technologies. The ultimate aim is to proficiently reassemble disassembled panel components into newly regenerated LCD panels, thereby achieving the overarching goal of high-value recycling for discarded LCD panels. The study employs easy-to-disassemble panel materials and non-destructive disassembly processes developed by the research team to completely disassemble LCD panel glass components. The disassembled liquid crystal materials and glass components are tested and reused. First, optical microscopy (OM) systems are used to ensure the glass components are free from defects. If no anomalies are detected, panel assembly verification processes are conducted, including purification of removed liquid crystal materials, assembly and bonding of panels, and liquid crystal vacuum injection. Illuminance testing is performed to verify their reuse in original panel manufacturing processes.

In addition, surface material removal techniques are employed to clean residual coatings and reapply ITO conductive layers. The removed liquid crystal materials are purified, refined, and doped with dichroic dyes to meet the specifications required for smart dimming products. The final products are assembled through bonding and liquid crystal injection techniques, achieving the goal of full circular recycling and reuse of LCD panel materials. The overall panel circular recycling process is illustrated in Figure 1.

Figure 1. Non-destructive disassembly and liquid crystal removal process for green LCD panels

ISSN 0097-996X/25/5601-0186-$1.00 © 2025

Results and Discussion

Non-Destructive Disassembly Mechanism Design:

To accommodate the complete disassembly of panels of varying sizes, this study developed a stress simulation model for disassembly. Based on simulation analysis, two non-destructive disassembly mechanisms were designed using multi-point vacuum suction cups combined with jet streams.

☐ **Vertical Non-Destructive Disassembly Method:** Panels are disassembled vertically with simultaneous removal of liquid crystal materials. The disassembly time per panel is under 3 minutes, offering the advantage of a smaller equipment footprint and suitability for small- to medium-sized panels.

☐ **Horizontal Non-Destructive Disassembly Method:** Panels are horizontally transported and separated vertically in stages. Liquid crystal materials are removed in multiple steps, with a disassembly time of under 5 minutes per panel. This method minimizes the risk of panel breakage and is suitable for large panels.

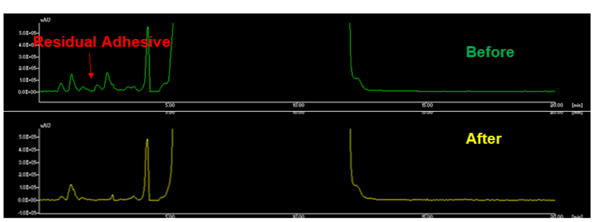
Table 1. Description and Comparison of Vertical and Horizontal Non-Destructive Disassembly Methods

Method	Vertical non-fragmentation disassembly method	Horizontal non-fragmentation disassembly
Equipment appearance		
Applicable	Small and medium size panels (under 30 inches)	Large panel (30~50 inches)
Disassembly time	3 min	5 min
Illustrate	➢ Vertical transfer of panel ➢ Vertical disassembly of panel ➢ Simultaneous stripping of LCD	➢ Panel horizontal transfer ➢ Vertical separation of upper and lower panels ➢ Peeling off the upper and lower LCD panels in stages
Advantage	The equipment occupies a small area	Low risk of panel breakage

Component Cleaning and Liquid Crystal Purification:

Both disassembly methods successfully recover intact panel components and liquid crystal materials. Glass components are confirmed to be free of surface defects and residual adhesives using optical microscopy. Liquid crystal materials undergo inorganic material filtration and polar impurity adsorption techniques, effectively removing residues without altering the original physical or optical properties. Purified liquid crystal materials meet quality standards required for panel reassembly, as shown in Figure 3.

a)



b)

Test Item	SPEC. of Commercial LC	Purified Recycle LC
Float Viscosity(η,cps)	16.0±1.0	16.0
Clearing point(Tc,℃)	74.7±1.0	75.0
Birefringence (Δn)	0.097±0.001	0.097
Dielectric Anisotropy(Δε)	-2.8±3.0	-2.8
Resistivity(Ω-cm)	>1×10^{13}	2×10^{14}
Moisture Content (ppm)	<100	65

Figure 3. Physicochemical properties of purified recycled liquid crystals (a) Residue analysis (HPLC); (b) Physical properties

Innovative Circular Reuse of LCD Materials:

Once the functionality of the disassembled glass components and the quality of the liquid crystal materials meet original commercial specifications, adhesive materials are introduced, and precise alignment of TFT and CF components is performed. Vacuum suction injects purified liquid crystal materials, resulting in the successful reassembly of regenerated LCD panels.
To ensure that panels made with recycled liquid crystals exhibit optical and electrical properties consistent with panels made from commercially available materials, V-T curve (voltage-transmittance) comparison tests were conducted. Results, shown in Figure 4, confirm identical performance, demonstrating the stability and feasibility of regenerated LCD panels.

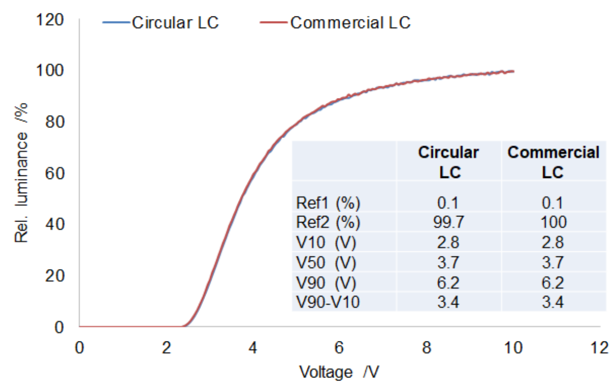


Figure 4. V-T curve comparison between recycled and commercial liquid crystal materials

Additionally, this study developed a layer-by-layer coating removal technique to recover intact glass substrates. The substrates were recoated with ITO conductive layers, and liquid crystal materials were refined and doped with dichroic dyes. Smart dimming products were assembled using bonding and liquid crystal injection techniques. Performance tests showed that smart dimming products achieved less than 40% transmittance in the dark state (0V) and over 70% in the bright state (10V), meeting industry specifications (Figure 5).

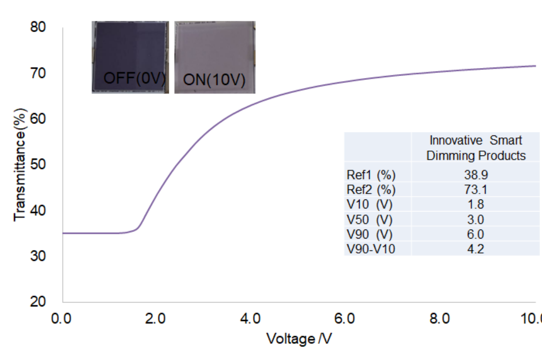


Figure 5. V-T curve of smart dimming products using recycled materials

Conclusion

This study successfully developed a non-destructive disassembly and full circular reuse technique for LCD panels. By introducing easy-to-disassemble materials, eco-friendly LCD panels were fabricated. Using laser Lift-off technology, panels were disassembled without damage, enabling the recovery of intact components and liquid crystal materials for reassembly into high-quality display products. Through layer-by-layer coating removal and reapplication of ITO, combined with dichroic dye doping, smart dimming products were also fabricated.

The proposed technology achieved over 80% material recovery and reuse from discarded LCD panels, significantly enhancing the overall value of recycled materials. Moreover, it established an innovative fully circular LCD panel recycling solution, offering a sustainable approach for future green recycling and reuse of LCD panels.

Acknowledgements

This research was financially supported by the Ministry of Economic Affairs, Taiwan under grants 112-EC-17-A-24-1717.

References

1. Chien-Wei Lu, Hung, Huan Yi , “Recycling technology of liquid crystal in waste LCD panels”, Materialsnet, 342, p128-p134(2015)
2. Taiwan Patent I796842
3. Taiwan Patent I471159
4. Taiwan Patent I809528