CircuHeal: An Azobenzene-Based Photochemical Switching and Conductive Filler Reinforced Dual-Layer Polymer Film for Space Electronics Repair

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Over 62 million tonnes of electronic waste are generated yearly, a figure projected to reach 74 million by 2030, with electronic circuit failure as a leading cause. Such failure is especially critical in systems where in-situ repair is inaccessible. Existing self-healing techniques rely on microcapsule rupture, Joule heating, or field-driven particle chaining. However, the use of photochemical actuation as a non-thermal, repeatable circuit-healing mechanism remains unexplored. We developed a dual-layer composite polymer film combining an azobenzene-PVA-glycerol-PEG photoresponsive layer with a conductive layer incorporating single-walled carbon nanotubes (SWCNTs), multi-walled carbon nanotubes (MWCNTs), silver nanowires (AgNW), or reduced graphene oxide (RGO). Films were fabricated via solvent casting at 37°C. Upon 365 nm UV irradiation, azobenzene undergoes reversible trans-cis isomerisation, inducing localised polymer fluidisation & macroscopic bending that mechanically reconnects fractured conductive pathways. Successful azobenzene incorporation of a photo-active functional group was confirmed by FTIR spectroscopy. Azobenzene concentration was optimised at 3 wt%, the minimum threshold achieving bending over 45°, while optimal photomechanical response occurred in the 20-40 micron thickness range. Percolation analysis showed that 3-4 wt% SWCNTs outperformed MWCNTs, RGO, & AgNW in both network formation efficiency and multi-cycle durability. The optimised composite recovered over 94% of conductivity within a single 180-second UV healing cycle & sustained above 65% across five consecutive cycles. Operating reversibly, our composite provides a fail-safe circuit-repair mechanism, improving circuit maintenance and safety in aerospace, space, & soft robotics industries.

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