Abstract

Due to the rapid development in electronic industries and high consumer demand for upgrades in functionality and design, electrical and electronic equipment have a shorter lifetime in developed and developing countries markets, leading to tonnes of electronic waste. According to global transboundary e-waste flows monitor 2022, the worldwide generation of waste electrical and electronic equipment (WEEE) reached 41.8 million tonnes (Mt) in 2014, which increased to 44.7 Mt in 2016 and 53.6 Mt in 2019, and is expected to reach 74.7 Mt by 2030 and 110 Mt by 2050. Researchers have found that only 20% of the e-waste produced is being recycled every year and 80% is informally recycled, dumped, or incinerated, causing loss of valuable resources and environmental hazards. Printed circuit boards (PCBs), a valuable part of any e-gadget, contain up to 60 different elements and a significant metal content (40 wt%), should be viewed as valuable secondary resources. Their treatment not only reduces environmental impact compared to mining but also offers economic opportunities and promotes circular economies. Recycling with the only objective of waste management is not a striking scenario in emergent nations where economic interests oust environmental liabilities. Hence, it is essential to consider remanufacturing products in the process of WPCB recycling to re-utilize the recovered metals as starting material for production of commercially valuable products, e.g. nanomaterials. This would help acquire the goal of circular economy by closing the materials loop, decreasing inputs, reusing, minimizing waste, and efficiently recycling huge quantity of scrap electronics, creating wealth and reducing pollution. In this direction, nanotechnology has also been recently used to recover base metals, toxic metals, and precious metals in different sizes and morphologies. Oxides of transition metals, such as CuO, ZnO, NiO exhibit typical photocatalytic and catalytic attributes. Monoclinic cupric oxide, Cu(II)O, a p-type semiconductor, has a bandgap range of 1.2–1.8 eV. CuO offers diverse potential applications in fields of catalysis due to its thermal stability, superconductivity, and photocatalytic behaviour.

In view of this, we present an eco-friendly and integrated process for the recovery of valuable metals from discarded computer motherboard PCBs via a hydrometallurgical route. Chemical pre-treatment liberates metallic fractions from PCB layers, followed by nitric acid leaching to obtain a copper-rich solution. We synthesize copper oxide nanoparticles (CuO NPs) from the reclaimed copper, adding value to the recovered material. Furthermore, the recovered value-added material is explored as a potential photocatalyst for degradation of textile dyes in the presence of visible light. The thesis begins by highlighting the global issue of electronic waste, emphasizing the increasing generation of waste electrical and electronic equipment (WEEE) and the inadequate recycling rates, which lead to environmental hazards and resource loss. It emphasizes the need for efficient and environmentally friendly recycling techniques, especially considering the valuable metallic components in electronic waste. The subsequent chapter delves into the methodology employed for the recovery process. It covers the characterization of waste PCBs, the liberation of metallic fractions using chemical pre-treatment processes, and subsequent leaching methods to selectively dissolve copper, zinc, and nickel, leaving a tin-rich residue. Following this, the thesis details the recovery of copper oxide nanoparticles from the leached solutions through precipitation routes. It explores different conditions and temperatures, resulting in various morphologies and structures of the synthesized copper oxide nanoparticles. It focuses on characterizing these nanoparticles using techniques like XRD, TEM, SEM-EDS, XPS, BET, UV-visible spectroscopy and elucidates their properties such as particle size, morphology, surface area, and bandgap energy. The subsequent chapter then examines the photocatalytic properties of these synthesized nanoparticles, particularly their effectiveness in degrading textile dyes under visible light irradiation. It compares different samples and identifies specific nanoparticles with better photocatalytic activity attributed to factors like particle size, morphology, surface area, and pore volume. The thesis also discusses the recovery of copper-based nanostructures using alkaline precipitation and low-temperature aging methods, further emphasizing their potential as effective photocatalysts for wastewater treatment. Finally, the thesis concludes by summarizing the key findings and contributions of the research work, emphasizing the importance of recycling and recovering valuable materials from electronic waste for environmental sustainability and efficient resource utilization.

The thesis is structured into seven chapters:

- Chapter I: Reviews e-waste generation, composition, and recycling techniques, emphasizing high-value materials recovered from electronic waste.

- Chapter II: Details the experimental methodology used for recovery steps.
- Chapter III: Discusses the characterization and leaching of bare PCBs from computer motherboards, achieving high leaching efficiency for copper and zinc.
- Chapter IV: Illustrates the recovery of copper as copper oxide nanoparticles from the leach liquor of waste PCBs of computer motherboards by precipitation followed by calcination route and details the structural analysis.
- Chapter V: Focuses on evaluating the photocatalytic properties of the synthesized nanoparticles for degrading textile dyes Congo Red and Methylene Blue.
- Chapter VI: Explores the recovery of $Cu(OH)_2$/CuO and CuO nanostructures, via alkaline precipitation and low-temperature aging methods using the strip solution originated from laboratory-scale spent mobile phone printed circuit board recovery process and demonstrated their photocatalytic activity by evaluating Rhodamine Blue degradation.
- Chapter VII: Summarizes conclusions, outlines future work, and provides a bibliography and publication list.

Overall, the thesis provides a comprehensive overview of a systematic approach to recover valuable metals from electronic waste, particularly focusing on PCBs from computer motherboards, and highlights their potential applications in producing functional nanomaterials for environmental remediation, particularly in wastewater treatment, thus offering a sustainable solution to electronic waste management while contributing to environmental and economic benefits.