Advances in Printed Circuit Board Recycling

Subjects: Chemistry, Applied
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Definition

Toward improved printed circuit board recycling, recent development and research favours a strategy based on first dismantling WPCBs followed by efficiently sorting electronic components (ECs). This allows obtaining various fractions: (i) bare boards; (ii) solder; (iii) ECs sorted in elementally enriched subfractions. The goal is for each fraction, or subfraction, to have the simplest elemental composition possible, making them easier to reuse directly or recycle, and making it now possible to recover valuable metalssuch as Ti, GaBa, Ta, Nb, W, Lanthanides.

1. Introduction

The recycling of waste printed circuit boards (WPCBs) depends on both an informal sector focused on precious metals recovery using highly polluting approaches, and industrial processes based on the pyrometallurgy of centralized waste, treated in depreciated smelters to make use of the calorific value of the WPCB's 30 wt% epoxy resins [1]. Overall, only ~30 w% of the WPCBs' mass is truly recycled [2]. The rest is transformed into fumes or ends up mixed in the bottom or fly ashes. A more sustainable approach would require alternate processes that: (i) allow for improved elemental recovery; (ii) are more "green"; (iii) do not require centralizing waste over a wide geographic area, as waste transportation is becoming an increasing issue, which implies that new processes must be deployable for small waste volumes or geographic zones; (iv) avoid burning epoxy resins that can release toxic gases [3].

The PCB dismantling research effort is currently little considered in the USA but is very vibrant in the European Union and parts of Asia. It pushes for: (i) increased recovery yields; (ii) reduced CO 2 footprints; (iii) processes that are adapted to small volumes and reduced capacity to export waste and landfilling. Indeed, for many countries, options are currently limited as many cannot afford to build pyrometallurgy plants, exporting waste PCBs is becoming increasingly difficult, and landfilling is very costly due to the hazardous nature of such wastes. Some countries, such as Japan, show a real effort in improving the treatment and the importation of hazardous waste from developing countries [4]. Under the implementation of the Basel convention, the Japanese government wants to promote and develop the official recycling route to prevent illegal exports and treatments leading to environmental pollution.

It is anticipated that the dismantling approach will create new business models where, for example, the factory is brought to the waste instead of the waste to the factory, which is enabled by the containerization of processes.

2. Electronic Component Sorting

By simply using sets of sieves, components can be sorted by size. The purpose of sieving is also to separate components from dust, scrap and other compounds of the disassembly step. For example, if the disassembly involves heat, sieving may remove dust and ashes from the waste stream. Afterwards, magnetic separation, which takes advantage of the ferromagnetic properties of some elements such as Fe, Co and Nickel and some rare-earth alloys (Nd, Dy, Sm, and Gd), can separate magnetic components from the waste stream, for example, inductance coils, which usually have an iron core. Finally, dense medium separation can be carried out by assessing the floatability of the components in a liquid (typically water). If the component is denser than the liquid, it sinks; if it is of similar density, it stays in suspension; if it is less dense, it floats.

Combined with this approach, other physical separation methods could be of interest, such as Corona discharge or gravity shaking, which are not yet reported to have been used with disassembled components, except for plastic parts [5][6].

As an alternative approach, some researchers performed text recognition on PCB components [7][8][9]. Their analysis is thorough, but it is unclear how well text information can help component sorting. They further suggested using text information in combination with other methods, but this approach might not be compatible with many of the dismantling approaches that can destroy the marking by heat or chemical attack.

Furthermore, XRF only yields elemental analysis without spatial information. For sorting, any conveyor elemental mapping is obviously impossible. In this regard, X-ray imaging might be of interest. In the latter case, the X-ray beam is projected onto the components and an X-ray transmitted image of the component is obtained from an X-ray camera placed on the other end. X-ray images yield two types of information. On the one hand, the X-ray image can be analysed to identify patterns present in the internal structure of the components. On the other, the absorption strength yields information about the atomic weight of the elements present in the component, or of its thickness. Despite this, there is currently no scientific literature on X-ray imaging being applied to electronic waste, probably because this method cannot differentiate a thick light element from a thin heavy one, which both give a similar absorption.

3. Recycling at the Electronic Components Level: Processes and Opportunities

Niobium capacitors are gaining market shares due to their lower price and good reliability compared to tantalum capacitors. Hence, the niobium capacitors' market has seen its value double in the past five years and is expecting to keep growing as new opportunities for their use emerge [10][11].

For this reason, chemical processes to recover niobium are being developed. Montero et al. present a column process that is based on the leaching of crushed PCBs by a sodium cyanide solution of 4 g/L concentration [11]. This process, besides recovering niobium, also enables the recovery of gold, silver and copper and is said to be economically viable, with a 27% financial yield over 10 years, representing a net present value of USD 105,926. However, the high toxicity of cyanide raises important environmental concerns and there are still doubts if this process will constitute a real opportunity in the future. More environmentally friendly processes still need to be developed.

The recovery of REEs from whole WPCBs has been proven feasible but is challenging since their overall concentration is fairly low (in the tens of ppm), and recovering them requires high CAPEX equipment, such as smelters and large electron beam apparatus, as well as OPEX [12]. Such approaches can only be made profitable in large centralized operations. It therefore does not appear to be adapted for smaller communities nor for the development of sustainable processes. The dismantling/sorting approach seems here again perfectly adapted to increase REE concentration in the ore of urban mines. This is especially true because physical methods that use early grinding tend to break the magnet's protective packaging, leading to the deterioration of REE based magnets into magnetic powder that is attracted by magnetic machinery parts, where it quickly oxidizes and cannot to be retrieved [13][14][15].

If, however, more purification or elemental separation must be performed, additional process steps are required such as: (i) chlorination using safer agents such as NH 4Cl [16][17]; (ii) advanced leaching [18][19][20][21][22][23][24][25][26][27][28][29][30][31][32]; (iii) or even bioleaching using bacteria which avoids the use of strong acids [33]; (iv) hydrometallurgy (solid–liquid or liquid–liquid extraction) [34][35][36][37][38][39][40][41][42]; as well as (v) electrodeposition at the reduction step, including in ionic liquids [43][44][45][46][47][48][49][50][51] and molten salts [52][53][54][55][56][57], with their wide electrochemical stability [58].

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Keywords

recycling;strategic metals;spectroscopy;X-rays imaging;image recognition;artificial intelligence