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Disentanglement of random access memory cards to regenerate copper foil: A novel thermo-electrical approach

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ABSTRACT

This paper reports the development of a novel process combining thermal and electrical treatments, which are optimised to provide efficient recovery of copper foil from Random Access Memory cards (RAMs). A primary thermal transformation at 900 °C facilitates a highly efficient recovery of copper foils from RAMs during the secondary processing in the electrical fragmenter, using only 10 pulses at 150 kV. The process yield was 98% and inductively coupled plasma (ICP) analysis showed that the copper foils had 98% purity. X-ray diffraction (XRD) confirmed the presence of copper in a crystalline face-centred cubic (FCC) form. Scanning electron microscopy (SEM) – energy dispersive spectroscopy (EDS) analysis of the foils assisted in understanding the underlying mechanism of electrical separation. Transmission electron microscopy (TEM) gave a new perspective on the regeneration of copper foils wherein new copper grains depicted a ribbon like growth pattern. The copper foils had an electrical conductivity similar to that of commercially available pure copper sheets. Thus, the mechanism of thermo-electrical transformation was studied in detail and regenerated copper foils of high electrical conductivity were afforded from end-of-life RAMs.

1. Introduction

Globally, electronic waste (e-waste) is growing at an alarming rate. According to a recent report by the UNU (United Nations University) 44.7 million metric tonnes (Mt) e-waste was generated in 2016 and it is set to accelerate to 52.2 Mt in 2021 (Baldé et al., 2017). E-waste generated by various countries in 2014 is provided in Fig. S1. Waste personal computers (PCs), mobile phones, routers, pocket calculators, telephones, and printers form a significant portion of e-waste. Random access memory cards (RAMs) – an essential component of PCs – also find themselves in landfills when the latter gets disposed.

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RAMs act as memory storage devices for PCs and are broadly categorised into static RAM (SRAM) and dynamic RAM (DRAM). The latter generates global revenues of $\sim$11 billion USD per quarter which is equivalent to $\sim$40 billion USD per year ("Computer memory and storage mediums - Statistics and facts"). SAMSUNG, a leading memory module manufacturing company made 11.2 billion USD in the second quarter of 2018 through DRAM sales (Statista.com, 2018) Production of a single 32 MB RAM consumes 32 L water, 1.6 kg fossil fuels, 700 g gases and 72 g miscellaneous chemicals (Goosey, 2009). A 2006 UNEP report showed that manufacturing one PC and monitor necessitated consumption of at least 240 kg fossil fuels (Charles et al., 2017).

Thus, RAMs are of great economic importance but at the same time are environmentally taxing too. RAM cards are rich source of base metals such as copper, tin, nickel, zinc, lead and precious metals such as gold, silver, palladium and platinum. They have been reported as high value scrap for e-waste recyclers by Charles et al. (2017) and Razi (2016). Charles et al. (2017) have reported 80% reduction in palladium content in RAM cards during 1991–2008. On the other hand, copper content increased 0.23 g/module/year and is estimated to increase by 75% from 2008 to 2020. Due to limited natural resources and the obvious high cost of precious metals, a shift towards their decreased usage is justifiable. On the contrary, copper is gaining impetus in the RAM manufacturing industry. Bidini et al. (2015) have studied RAMs as an energy resource. They have reported RAMs to possess char and tar energy equivalent to 4300 kJ/kg and 29,000 kJ/kg respectively. Also, the heat generated from burning the volatile matter from RAMs was 4273 kJ/kg. Advanced Technology Materials Inc., has developed a pilot plant

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for chemically desoldering the external components from the RAMs and reusing them. Gold was recovered by leaching the gold contacts of the treated RAM base boards (Jiang et al., 2012). Lu et al has extracted sponge gold of 99.747% purity from RAM modules by a combined extraction – distillation – calcination process (Lu et al., 2017). Thus, characterisation of RAM cards, their use as an energy resource and gold recovery from them has been reported. However, copper recovery from RAM modules has not been studied in detail.

Different forms of copper have been recovered from e-waste using thermal operations (Cayumil et al., 2017; Cayumil et al., 2014; Shokri et al., 2017b; Shokri et al., 2017a) hydrometallurgy (Havlik et al., 2010; Xiu et al., 2013), electrochemical processes (Haccuria et al., 2017) and biohydrometallurgy (Işıldar et al., 2016). However, use of highly corrosive acids in hydrometallurgy leads to secondary pollution (Awasthi and Li, 2017; Perkins et al., 2014). In case of biohydrometallurgy, high metal content of e-waste sometimes inhibits microbial growth and protoplasmic poisoning may also occur (Bryan et al., 2015; Madrigal-Arias et al., 2015). Furthermore, commercialisation of biohydrometallurgy is also in its infancy.

Previous works regarding electrical treatments of e-waste have primarily investigated only the mechanical crushing effect (Duan et al., 2015; Martino et al., 2017; Zhao et al., 2015). For example, Duan et al. have used high voltage electrical pulses for printed circuit boards (PCBs) comminution (Duan et al., 2015). Dodbiba et al used electrical treatments for crushing liquid crystal displays (LCDs) (Dodbiba et al., 2012) and then employed leaching for recovering indium. Here again, electrical pulses were used only for size reduction purposes and the actual material (indium) was recovered through hydrometallurgical operation. Applications of electrical disintegration have been explored in the field of mineral ores (Andres, 2010; Andres et al., 2001), coal (Ito et al., 2009) and building materials (Inoue et al., 2008; Maeda et al., 2009; Narahara et al., 2007) for similar granulating purposes.

Thus, copper being one of the main components of PCBs and RAMs has been extracted using hydrometallurgical, pyrometallurgical and biohydrometallurgical processes. Electrical fragmentation has also been experimented on e-waste. However, only the physical separation aspect of a fragmenter has been explored. Our research work, has brought together thermal and electrical processing to give a clean copper product using e-waste as a valuable metal resource, a copper foil with good electrical conductivity.

2. Experimental part

2.1. Materials

Waste RAM cards were provided by Reverse e-waste, Sydney, Australia. Dynamic RAM cards of first three generations were used for this research work. Their manufacturing period laid between 2000 and 2010. The RAM cards had storage data of about 2–4 GB and the number of pins ranged from 184 to 240.

2.2. Thermal transformation

RAMs in a rectangular form of approximately 6 × 3 cm were heated in a horizontal tube furnace at temperature in the range of 500–900 °C. Inert atmosphere was maintained by passing argon gas at a flow rate of 3 L/min. The RAMs were first maintained in cold zone for 5 min and then passed into the hot zone and kept there for 20 min to avoid thermal shock. The RAMs were again kept in the cold zone for 5 min prior to their removal from the furnace to prevent oxidation of the samples due to sudden exposure to external oxygen containing atmosphere (Cayumil et al., 2015). Online IR spectrometer (ABB, A02020) was used for quantitative analysis of exhaust gases from the thermal transformation experiments. Quantitative data of carbon dioxide (CO_2), carbon monoxide (CO) and methane (CH_4) was derived from the IR gas analyser.

2.3. Electrical reform of RAM

2.3.1. Brief description of SELFRAG operation

SELFRAG primarily consists of a high voltage power supply, a high voltage pulse generator and a process vessel (Fig. 1a). The process vessel rests on the lifting table. The high voltage pulse generator produces pulses of upto 200 kV with the help of its inbuilt capacitors and switches. The process vessel contains a discharge/working electrode at the top and a counter electrode/ground electrode at the bottom. The counter electrode takes care of the grounding of the high electrical discharges and is hence called the ground electrode. While carrying out the experiments, the process vessel is filled with water and the RAM is submerged in it. The positioning of the RAM is such that it lies between the two electrodes and high voltage pulses are passed through it in an aqueous environment (Refer Fig. 1b). For each experiment, the RAM was exposed to a maximum of 10 pulses only. Each pulse has a very short life time of ~500 ns. Combination of limited exposure time and high dielectric constant of water allows the high voltage pulse to flow through the sample and prevents its discharge into the liquid medium.

2.3.2. Electrical reformation experiments

SELFRAG was used to electrically reform the thermally treated RAMs (Fig. 1a). Post thermal treatment, RAMs were inserted into the process vessel of SELFRAG. The process vessel was filled with water and electric pulses of high voltage were passed through the RAM (Fig. 1b). Frequency of 5 Hz accompanied with voltages of

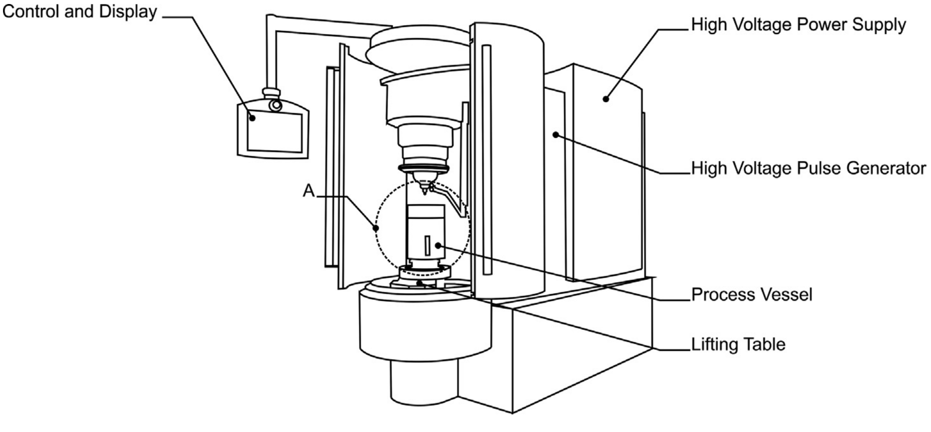

Fig. 1a. Various components of SELFRAG.