ARTICLE IN PRESS

Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Soldering mask laser removal from printed circuit boards aiming copper recycling

Marcus Paulo Raele *, Lucas Ramos De Pretto, Denise Maria Zezell

Nuclear and Energy Research Institute, IPEN-CNEN/SP, Av. Prof. Lineu Prestes, 2242 Cidade Universitária, CEP 05508-000 São Paulo, SP, Brazil

A R T I C L E I N F O

Article history:
Received 15 March 2017
Revised 8 July 2017
Accepted 12 July 2017
Available online xxxx

Keywords:
Laser
WEEE
PCB
Copper
Printed circuit boards
Recycling

A B S T R A C T

Management of waste of electric and electronic equipment (WEEE) is a key issue for modern societies; furthermore, it contains valuable materials that can be recycled, especially in printed circuit boards (PCB), which have approximately one-third of their weight in copper. In this study we demonstrated the use of laser to strip the covering soldering mask on PCB's, thus exposing the copper underneath so that extraction techniques may take place. Using a Q-Switched Nd:YAG laser operating at 1064 nm and 532 nm we tested the procedure under different energy conditions. The laser stripping of the soldering mask was achieved with satisfactory results by irradiation with 225 mJ at 1064 nm. However, when using similar parameters at 532 nm the process of the coating ejection was not promoted properly, leading to a faulty detachment. Infrared laser PCB stripping presents itself to be technically viable and environmental friendly, since it uses no chemicals inputs, offering one more option to WEEE treatment and recycling.

1. Introduction

One of the most challenging issues for society in the near future is handling and processing the waste of electric and electronic equipment (WEEE). Technology advances drive the production of new electronics while making them more accessible to the final customer, an increase in WEEE in recent years comes as no surprise. Studies suggest that between 20 and 50 million metric tons of WEEE are produced per year, with an annual increase of 3–5 percent (Luda, 2011; Neto et al., 2016; Yamane et al., 2011). However, awareness of this subject is also growing (Akcil, 2016), prompting the search for new ways to reutilize these components. To illustrate this scenario, entries related to the keywords "printed circuit board recycling" in scientific databases[1] indicate an increase of the number of publications at a rate of 35% per year on average over the last decade.

WEEE disposal presents a broad spectrum of materials in its composition, leading to a complex processing for its reuse. However, motivations for recycling do exist. For instance, it helps to reduce environmental impact due to mining, appeasing the growing demand for electronic inputs (metals and precious metal). Also, it promotes appropriate handling of hazardous materials that exist in such equipment, which pose an environmental threat.

A common item found in almost every piece of electronic system is a copper-based printed circuit board (PCB) (Kasper et al., 2011; Luda, 2011). It is reported that 23%–30% of the PCB weight in Cu are recoverable using chemical methods (Imre-Lucaci et al., 2012). An estimate shows that the fraction of PCB in the overall WEEE ranges from 3 to 8 percent (Luda, 2011), which translates to, at least, 3% of 20 million metric tons of WEEE produced, resulting in 600 thousand tons of PCB. Recovering 23% of such material would yield 138 thousands of tons of copper, worth a little over 1.2 trillion dollars each year - values that may increase as a consequence of the growing trend of WEEE produced.

The mainstream methodology to recover metals from PCB (Luda, 2011) consists in size reduction as dismantling and grinding, followed by material separation by physical properties such as magnetic and density, among others (Chagnes et al., 2016). In a further step, the metal extraction/separation is achieved using a leaching process to dissolve metals in an acid/alkali solution (Castro and Martins, 2009; Kiddee et al., 2013). This technology is easily scalable, but it ends up shuffling all kinds of materials together in the first step, requiring the segregation afterwards. There are interesting efforts pushing this approach ahead, as an example the cryogenic milling study (Tiwary et al., 2017) demonstrated an environmentally friendly route, but energetically costly.

* Corresponding author.
E-mail address: mpraele@ipen.br (M.P. Raele).

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http://dx.doi.org/10.1016/j.wasman.2017.07.019
0956-053X/

Some other studies approached the problem without the crushing process, using either: anodic dissolution to recover the copper (Imre-Lucaci et al., 2012); or cathodic electrodeposition (IMRE-LUCACI, 2011). Having the advantage of being energetically less demanding, these methods require the removal of the Soldering Mask (SM) - an epoxy coating which protects the copper layer - so the electrical contact may be established. Usually, a solution of sulfuric acid (H_2SO_4) is applied to expose the copper (Imre-Lucaci et al., 2012) for the recovery by electrical means to take place. Another study has shown that it may take up to 24 h with a 10 M sodium hydroxide solution to perform a faulty SM removal (Jadhav and Hocheng, 2015), posing a time consuming task.

An innovative approach to remove coatings such as paintings or varnishes is via laser irradiation with a technique known as Laser Stripping or Laser Coating Removal. Several applications have been reported, ranging from radioactive waste management (Potiens et al., 2014) to painted artwork cleaning (Georgiou et al., 1998) and varnish removal from brass (Mateo et al., 2009). This method presents several advantages over the conventional approaches, e.g.: no need for chemical substances, high cleaning speed and easy automation. However, in a thorough review (Luda, 2011) no mention of attempts at applying laser as a WEEE recycling tool was found.

Laser Stripping has already been reported and explained (Roberts, 2004) as a process in which the laser is partially transmitted by the paint/varnish and absorbed by the underneath metal, which sublimates, ejecting the coating above. This sublimation is a process known as laser ablation (Phipps, 2007) in which the material is heated quickly and locally by a pulsed laser, passing from solid to a plasma state, which generates pressure, stripping away the coating. There are a great variety of lasers with different irradiation conditions, each one producing ablation with different features (Chichkov et al., 1996). For Laser Stripping, in general, the laser applied has pulse duration of a few nanoseconds and tens of milijoules, resulting in a megawatt peak power. As the process is achieved using pulsed lasers the amount of energy transferred is on average low, ideally leading to small overall temperature increases of the material under treatment. In this way, it is possible to use this phenomenon to remove the Soldering Mask without chemicals. Fig. 1 illustrates the laser beam interacting with a PCB, resulting in the varnish ejection.

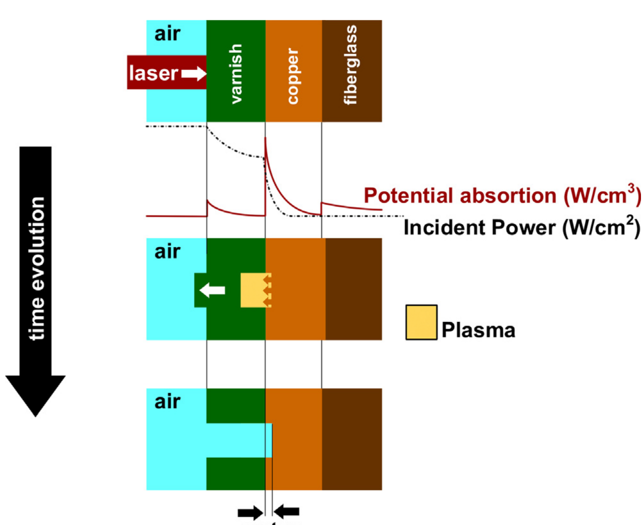

Fig. 1. Laser coating ejection process schematic figure (out of scale). The laser is transmitted by the varnish and is absorbed by the metal, causing an explosion leading to coating removal.

Thus, supposedly, running the laser beam over the PCB area without any previous treatment should remove all the SM when using the correct laser irradiation parameters to expose the copper allowing it to be recovered by an anodic dissolution approach.

Thus, the objective of this work was to study the laser stripping as an approach to Soldering Mask removal from used Printed Circuit Boards, enabling the recovery of the exposed copper using methods such as electrochemical or leaching processes.

2. Experimental

The laser source used was a pulsed Nd:YAG laser (Brilliant, Quantel Laser, Les Ulis Cedex, France) operating at 1064 nm or at 532 nm through the use of Second Harmonic Generator (SHG) with nominal maximum energy per pulse of 350 mJ@1064 nm and 160 mJ@532 nm, repetition rate of 20 Hz and both with 5 ns of pulse duration. The optical setup was restricted to a pair of dielectric mirrors for directing the laser beam, which was used without focusing optics, i.e., collimated for the infrared laser (1064 nm) and a using 1000 mm converging lens for the green laser (532 nm) at 300 mm from the sample to compensate the divergence introduced by the SHG module. To move the sample, a pair of motorized translation stages (LTS300/m, Thorlabs Inc., New Jersey, USA) were mounted with 300 mm of travel range, 50 mm/s maximum speed.

The laser path over the surface to process an area is done using a pattern known as "raster". Considering that a pulsed laser is used, it is necessary to ensure overlapping so all the surface can be irradiated by the laser shots, as shown in Fig. 2. For this purpose, a program was developed to control the translation stages in a LabVIEW (National Instruments, Texas, USA) environment.

To ensure operator and environmental safety all the tests were carried in a fume box with filters. A schematic view of the experimental setup is presented in Fig. 3.

To evaluate the efficacy of the laser stripping of the Soldering Mask from the Printed Circuit Board a scanning electron microscope (SEM, TM3000, Hitachi, Tokyo, Japan) was used along with an Energy Dispersive X-ray detector (EDS, Quantax 50, Bruker, Germany) and in order to measure the diffuse reflectance of the Cu and SM a spectrophotometer (Cary 5000, Agilent, California, USA) was employed.

3. Results and discussion

The first experiment aimed to check the feasibility of ejecting the varnish layer from a PCB by applying laser radiation. Thus, a study was conducted using a scrap PCB, fully mounted with all the original components. The laser energy was gradually increased

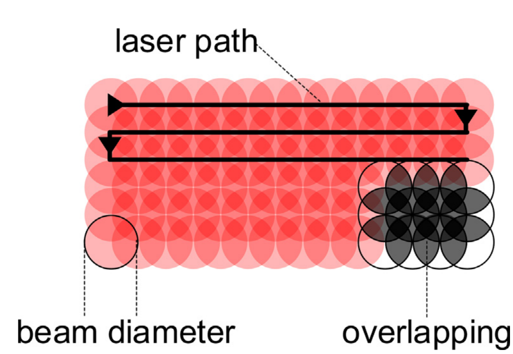

Fig. 2. Illustration of the laser rastering process used to remove the soldering mask from the Printed Circuit Board. At the bottom right, in black and white, the superposition of processed areas by the laser pulses are highlighted, in this example with of 50% of overlap was used.