

Pre-Analysis of Printed Circuit Boards Based On Multispectral Imaging for Vision Based Recognition of Electronics Waste

Florian Kleber, Martin Kampel

Abstract—The increasing demand of gallium, indium and rare-earth elements for the production of electronics, e.g. solid state-lighting, photovoltaics, integrated circuits, and liquid crystal displays, will exceed the world-wide supply according to current forecasts. Recycling systems to reclaim these materials are not yet in place, which challenges the sustainability of these technologies. This paper proposes a multispectral imaging system as a basis for a vision based recognition system for valuable components of electronics waste. Multispectral images intend to enhance the contrast of images of printed circuit boards (single components, as well as labels) for further analysis, such as optical character recognition and entire printed circuit board recognition. The results show, that a higher contrast is achieved in the near infrared compared to ultraviolet and visible light.

Keywords—Electronic Waste, Recycling, Multispectral Imaging, Printed Circuit Boards, Rare-Earth Elements.

I. INTRODUCTION

EMERGING green technologies such as photovoltaics (PV) and solid-state lighting (SSL) do heavily depend on the use of raw materials like gallium, indium and rare-earth elements. Fig. 1 (a) shows the projected growth for gallium and Fig. 1 (b) indium, indicating that global supply will increasingly lag behind on demand if the current circumstances pertain [1]. The growing demand is driven by PV, SSL (notably light-emitting diodes, or LEDs) and electronics (integrated circuits) for gallium and by PV and electronics (liquid-crystal displays, or LCDs) for indium. The supply of these materials is limited, because the primary production and trade of these materials is highly controlled by a few countries and particularly by China. A further complication for both gallium and indium is that they are mined as by-products of other materials.

Recycling systems to reclaim these materials from waste from electrical and electronic equipment (WEEE, or E-waste) such as TV sets, computers and mobile phones are not yet in place which challenges the sustainability of these technologies. Hence there is a need to establish recycling systems for PV, SSL, as well as for other electronic waste to reclaim gallium, indium and rare-earth elements. The prospective recycling technology should be able to reclaim the targeted materials from present and future E-waste. The EU FP7-NMP funded RECLAIM [2], [3] - Reclamation of Gallium, Indium and Rare-Earth Elements from Photovoltaics,

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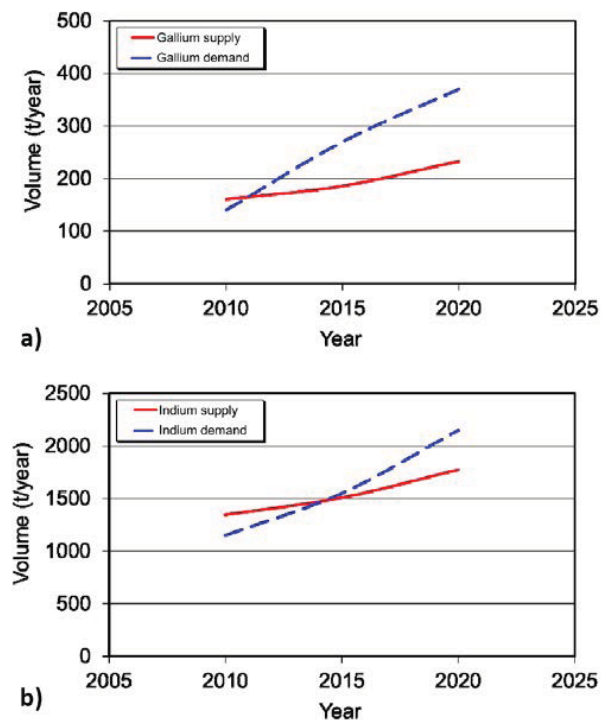


Fig. 1. World-wide supply and demand forecasts for (a) gallium and (b) indium [1]

Solid-State Lighting and Electronics Waste - project deals with the development of technological solutions that relieve current bottlenecks in the recycling of gallium, indium and rare-earth elements, and a demonstration of their application potential by means of a pilot plant implementation in an industrial setting. Within this project vision based methods are introduced for the detection and recognition of entire PCBs and single valuable components. For the chemical analysis a Light-Induced Breakdown Strategy (LIBS [4]) is used. The chemical analysis allows to define components, which contain the desired materials. Based on the analysis, the vision based recognition is focused on these elements. Currently, industrial vision systems [5] and automated inspection systems (e.g. for PCBs) [6] are mainly used for production systems. This paper shows the vision based pilot plant and focuses on the results of the Multi-Spectral (MS) analysis of Printed Circuit Boards (PCB). It is shown, that the use of MS images can enhance the

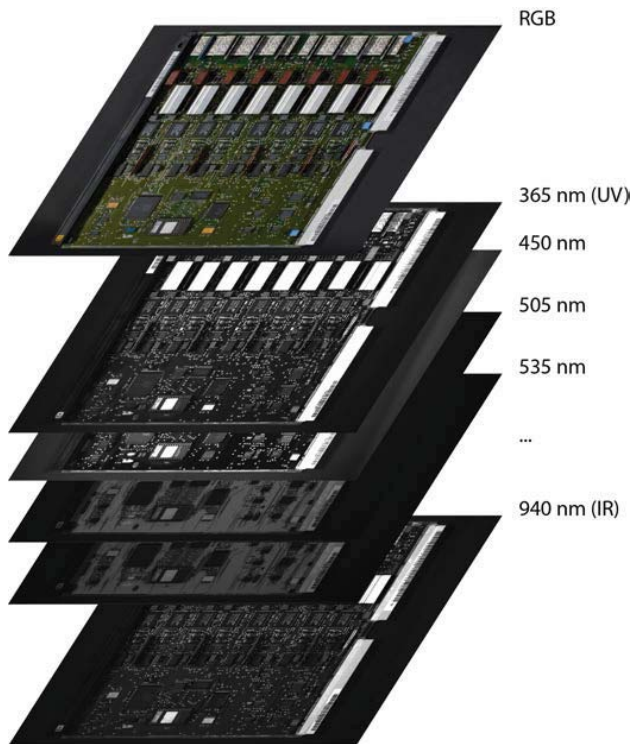


Fig. 2. MS images of a PCB

contrast of the PCB board, as well as the labels of Integrated Circuit (IC) components. This paper is organized as follows: Section II summarizes the state of the art in MS imaging in general and related to PCBs. The setup for the vision based analysis, i.e. MS imaging, is shown in Section III. Section IV shows first results of the MS imaging. Finally, a Conclusion is drawn in Section V.

II. RELATED WORK

MS imaging was originally developed for remote sensing applications and has recently found its way to the field of conservation [7]. In addition to its applicability for art conservation [8], the imaging technique has also proven effective for the analysis of historical and degraded documents [9], [10], [11]. Simply stated, a MS image can be described as the same image of one scene in different spectral ranges.

Fig. 2 illustrates MS images of a PCB board with different wavelengths ranging from 365 nm to 940 nm. MS imaging systems use non-destructive methods called InfraRed (IR)-reflectography, UltraViolet (UV) reflectography and UV fluorescence imaging. IR radiation has the property that it is less scattered than visible light and therefore can penetrate materials that are opaque under VIS illumination [12]. When an object is irradiated by UV light, the light is either reflected from the object (UV reflectography) or absorbed by it to produce fluorescence in the VISible (VIS) part of the electromagnetic spectrum (UV fluorescence). The reflected and fluorescent light, therefore, appear in different parts of the spectrum. Alternative blocking of each region by a long-wave

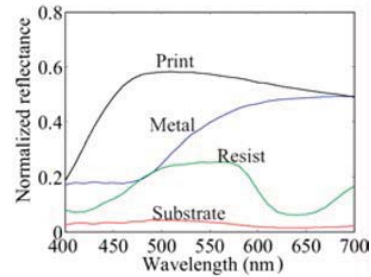


Fig. 3. Surface spectral reflectance of PCM material elements, courtesy of Ibrahim et al. [16]

or short-wave pass filter allows one to measure reflected or emitted light independently from each other. Both types of imaging are especially powerful when one studies objects composed of materials with different optical properties. Fig. 2 shows that the components of a PCB and the PCB itself have different reflectance options. The MS test images of PCBs are shown in Section IV.

Currently, visual systems are also used for automatic PCB inspection during the production process. These systems deal mainly with the detection of production errors. A survey of PCB inspection systems is presented in Moganti et al. [13]. Thus, IR cameras (thermal cameras) are mainly used for the inspection of solder joints [14] and to “*indicate hot spots on operating PCBs indicating shorts and overstressed components*” [13]. These systems are concerned to temperature measurement on PCBs in operation, compared to traditional MS systems, which intend to receive a better contrast. Hara et al. [15] proposed an inspection system based on UV fluorescence. Therefore, the fluorescence characteristics of glass-epoxy, glass-polyimide and etching resist (circuit board base materials) are investigated to realize a “*pattern inspection*”. Ibrahim et al. [16] have proposed an unsupervised material classification of PCBs using MS images. The spectral range of the liquid crystal tuneable filter used is between 400 nm and 720 nm, thus providing a MS system within the VIS range.

Fig. 3 shows the spectral reflectance of 4 PCB materials investigated by Ibrahim et al [16]. A PCA is used for the dimension reduction, and a normalized cut and k-means clustering for the material classification [16], [17]. Tominaga [18] analysed the spectral reflectance of silk-screen print, metal wire, resist metal, footprint and substrate for a region segmentation of the presented 5 materials. The presented methods are for PCB inspection systems to evaluate the production process to detect errors. It has been shown, that MS imaging methods can be used for the segmentation of different materials. The analysis has been done in the VIS range based on the reflected or fluorescent light. Within the RECLAIM project, the proposed MS imaging system has been tested to enhance the contrast of the labels of PCB elements, especially of elements, where the label text can be covered by dirt, e.g. dust.

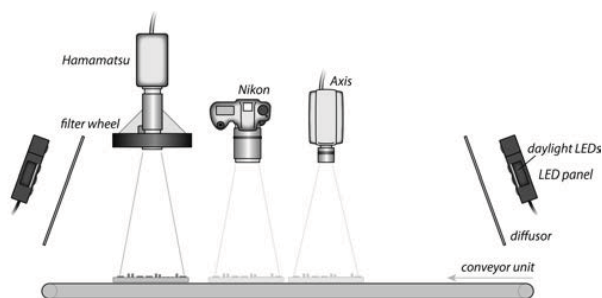


Fig. 4. Camera Setting

III. SENSORS AND ILLUMINATION OF THE PILOT PLANT

The setup intends to classify electronic waste online, i.e. PCBs, either at component level or the entire PCB board. The system for the automated classification of PCBs consists of 3 different sensor types and a LED illumination with polarized light. The sensors comprises a high resolution professional DSLR camera (Nikon D4, 16.2 MP) with a 60 mm focal length lens, an IP camera (AXIS P1346) with a resolution up to 1080p at 30 fps and a high resolution MS camera (Hamamatsu C9300-124). Fig. 4 shows exemplified an image of the setup. The MS camera has a cooled CCD chip with a sensor resolution of 4000x2672 pixel, a spectral sensitivity from UV (330nm) to NIR (1000nm) and a radiometric resolution of 12 bit. The IP camera is used for on-line analysis (sufficient data quality and a high frame rate) for PCB detection and recognition on the conveyor belt. The DSLR camera and the MS camera is used for high resolution images, which enables analysis at component level, and is triggered by the IP camera. The analysis based on the IP camera and DSLR camera is described in Kleber et al. [3].

The illumination consists of 2 BiColor LEDs with an adjustable color temperature of 3300 6300 Kelvin and 2 Eureka!Light™ (Equipoise imaging) LED panels, which allow the use of 11 different wavelengths as shown in Fig. 5. To provide a uniformly distributed illumination, diffusers are placed between the lighting and the object. The use of LEDs with different spectra replace the need for a filter wheel, which eliminate the optical distortions of the filters. Only three filters SP400 (1), LP400 (2) and LP800 (7) must be used for UV fluorescence (400 nm long-wave pass filter, 40 nm, Full Width Half Maximum) /reflectography (400 nm short-wave pass filter, 40 nm, Full Width Half Maximum) and IR reflectography (800 nm long-wave pass filter, 40 nm, Full Width Half Maximum) imaging.

Since the filters in front of the camera are replaced by the illumination system, the acquisition setup has to be used in a darkened area. In front of the LED panels diffusers are mounted to provide a uniformly distributed illumination. To avoid specular reflections polarizers are used to provide polarized light. Since metallic parts on the PCBs are possible, polarization filters in front of the camera and a polarized illumination must be used. Fig. 6 shows the difference of an

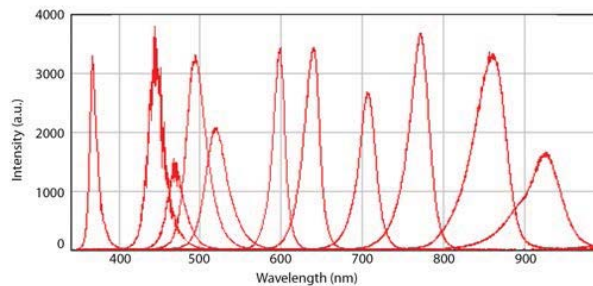


Fig. 5. Eureka!Light LED Panel Spectra

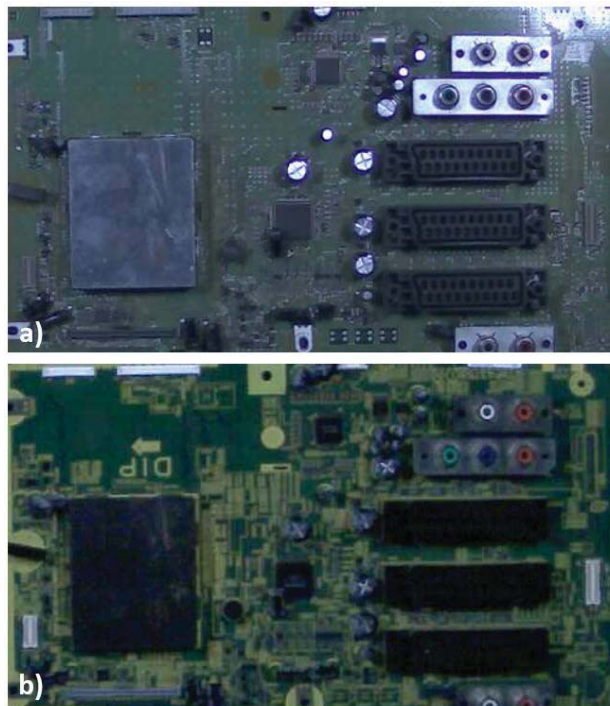


Fig. 6. Image without polarized light and filters (a) and with polarized light and filters (b)

image of a PCB which is taken without polarization filters (Fig. 6 (a)) and with the use of polarization filters (Fig. 6 (b)). It can be seen that specular reflections are suppressed and a uniform illumination is achieved.

Additionally, the contrast of the board is enhanced.

IV. RESULTS

This Section summarize the MS acquisition of PCBs. The PCB boards are analyzed according the spectral properties. Three representative PCBs have been chosen as test objects and are captured with the MS system at all available wavelengths. Fig. 7 shows RGB images of the PCBs investigated, consisting of heat sinks, Integrated Circuit (IC) elements, Surface Mounted Devices (SMD), connectors, Small Outline Package (SOP) and Quad Flat Package (QFP) elements, capacitor elements, etc.

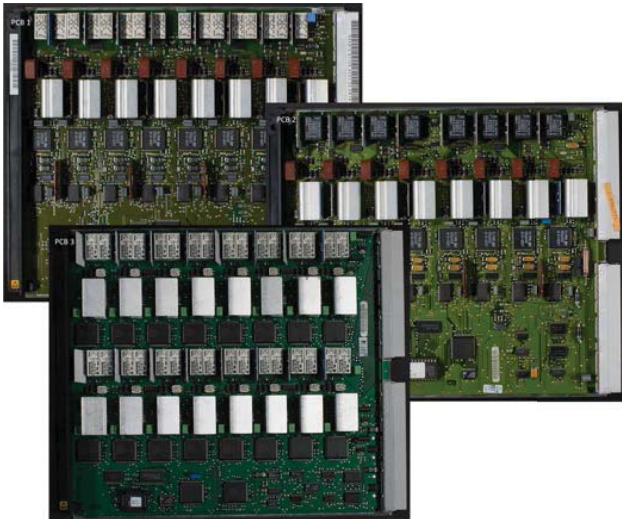


Fig. 7. Representative PCB selection

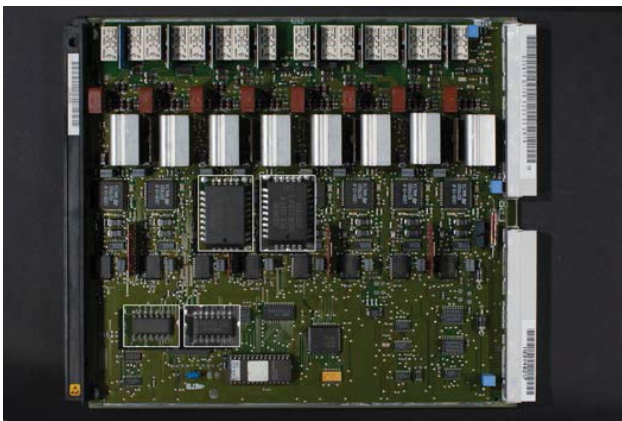


Fig. 8. Panel 1 with detail of 2 ICs in VIS compared to Amber (570 nm)

As shown in Fig. 7 some of the elements have a labeling (either light gray or black text) on the surface or at the side, and e.g. resistor elements can be color coded with stripes. Fig. 8 shows a RGB image of PCB 1 of a Nikon D4 SLR camera. As a detail two Small Outline Integrated Circuits (SOIC) and Quad Flat Package (QFP) elements are shown: the left side shows a detail of the SOIC and QFP element captured with white light LED illumination (Nikon D4), and the right side shows a detail of the SOIC and QFP element captured with Amber (570 nm) illumination (Hamamatsu). It can be seen that the label of the elements are not visible in VIS compared to Amber.

The influence of the incident angle of the light is illustrated in Fig. 9. The upper row shows details of the 8 QFP elements from PCB 1 (mounted on the PCB from the left to the right side) illuminated with white light LEDs and the images are taken with the Nikon D4. The lower row shows the same details of the 8 QFP elements illuminated with Amber (images are taken with the Hamamatsu). Due to the different position on the PCB (QFPs are equally distributed from left to right)

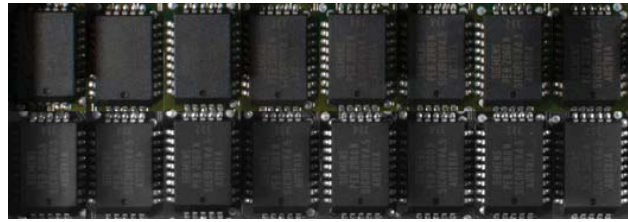


Fig. 9. Panel 1: first row (VIS) compared to second row (Amber, 570 nm)

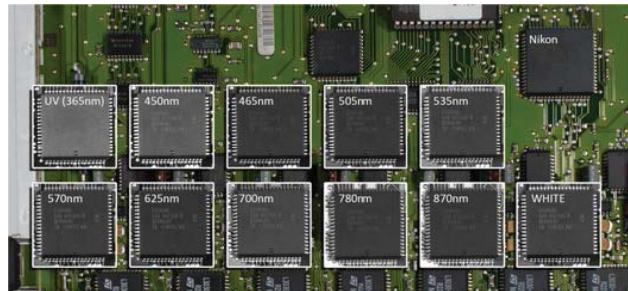


Fig. 10. Detail of Panel 2 - Caption of one IC at all different wavelengths

the contrast of the labels of the RGB images differ due to the incident angle of the light. On the left side the label is not visible, while the best contrast is achieved on the right side. However, the images of the MS camera show, that the contrast of the label of the elements can be enhanced if the PCB is illuminated with Amber LEDs (570 nm).

To visualize the influence of the contrast of the label of a QFP element, PCB 2 has been captured with all possible wavelengths of the MS system. Fig. 10 shows a QFP element and the contrast of the labels at the wavelengths ranging from UV (365 nm) to NIR (870 nm) and white light. The highest contrast is achieved at Amber (570 nm) and Red (625 nm) compared to UV (365 nm) where the label is not visible. Due to the fact, that only the wavelength is changed within the LED panels, the incident light angle is constant. Thus, only the effect of different wavelengths is demonstrated.

To visualize the effect of different wavelengths on different components and on the circuit board, images of PCB 3 are captured at all wavelengths. Fig. 11 shows the upper half of PCB 3 at UV 365 nm up to NIR (870 nm) illumination (Hamamatsu camera), compared to the lower half which is acquired at white light illumination and the Nikon D4 SLR. The best contrast for the labels is gained at wavelengths at 570 to 625 nm as shown in the previous examples.

Compared to the light gray labels of black QFPs, SOICs, etc. components, the contrast of the black label on white components is independent of the wavelengths. The best contrast of the printed circuits of the board is achieved in the NIR.

V. CONCLUSION

A pilot plant setup for vision based analysis of PCB boards for the reclamation of gallium, indium and rare-earth elements from photovoltaics, solid-state lighting and electronics waste has been presented. The shown setup focuses on MS analysis

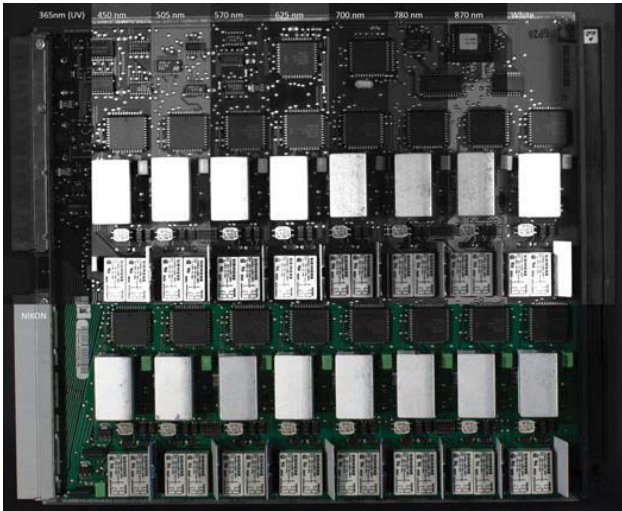


Fig. 11. Panel 3 - VIS compared to all single spectra

of PCBs and single valuable components, such as ICs. For the post-processing MS images have been investigated to enhance the contrast of the images. It has been shown that MS images of PCBs can enhance the contrast of gray labels of black components, especially at wavelengths ranging from 570 nm to 625 nm. The recognition of components and entire PCBs is described in Kleber et al. [3].

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