MATERIAL IDENTIFICATION IN ELECTRONICS

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Abstract: If an electronic designer wants to make an electronic module more recyclable, a way to quantify the impact of the design changes on the recyclability of the module is needed. One of the most important aspects to quantify the impact of design changes is information about the materials that are used in the electronic module. This paper will explain how the material composition of electronic components or an electronic module can be described. It will also give an overview of the dedicated models that are developed to estimate the material content of electronic components, in case the material composition of these components is unknown.

1. INTRODUCTION

When recycling an electronic device, or more specific a Printed Board Assembly (PBA), it is important to know which materials are present. If a designer wants to influence the recyclability of his product, he needs to know what impact his changes will have on the material content of the product. To achieve this, full material declarations (FMD) are necessary for each component existing on the assembly. These FMDs describe in detail which substances are present in the component and in which amounts. Although the number of suppliers providing FMDs for their products is steadily increasing, information on the material composition of active and passive electronic components is still missing for a significant portion of the market. Consequently, the material composition of these components needs to be estimated using dedicated models. The aim of these models should not be to provide a detailed material declaration of a component, but to intelligently identify key materials relevant for recycling.

2. FULL MATERIAL DECLARATIONS

A Full Material Declaration lists all the substances that are present in a component or product. Contrary to e.g. RoHS and REACH declarations which only declare the presence or absence of certain (usually hazardous) substances in the component, the FMD declares all the substances that are present in the component, with their respective weights.

In the industry a standardized format [1] is available to communicate FMD information. The material declaration standard supports various levels of materials disclosure each with their own level of detail. The Full Material Declaration at a homogeneous level gives the most extensive level of detail.

For each homogeneous material, the mass for each substance that exists within that homogeneous material is disclosed. According to the EU RoHS directive definition taken over by IPC, a homogeneous material is “A material that cannot be mechanically disjointed into different materials.” The term “mechanically disjointed” means that the materials can, in principle, be separated by mechanical actions such as: unscrewing, cutting, crushing, grinding, and abrasive processes. From a material science point of view a homogeneous material is a material with homogeneous (or gradually varying) physical properties bounded by material interfaces established by adjacent homogeneous materials with physical properties that change discretely or in a very narrow region at or near the interface.

An example is an electronic component where the different homogeneous materials include the bond wire, die attach, lead frame, lead finish, molding compound, etc. Figure 1 gives an example of the homogeneous

Homogeneous M...	Material Group	Mass	UoM	+	-	Level	Substance Category	+	-	Substance	CAS	Exe...	Mass	UoM
Bond Wire		3.57	mg	+	-	Supplier	Gold and Gold Com...	+	-	Gold	7440-57-5		3.57	mg
Leadframe Plating		4.55	mg	+	-	Supplier	Silver and Silver Co...	+	-	Silver	7440-22-4		4.55	mg
Die Attach Material		5.04	mg	+	-	Supplier	Silver and Silver Co...	+	-	Silver	7440-22-4		3.9312	mg
				+	-	Supplier	Proprietary Material...	+	-	Epoxy (EP)			1.1088	mg
Ext. Plating		6.16	mg	+	-	Supplier	Tin and Tin Compo...	+	-	Tin	7440-31-5		6.16	mg
Silicon Die		37.87	mg	+	-	Supplier	Silicon and Silicon ...	+	-	Silicon	7440-21-3		37.87	mg
Leadframe		178.85	mg	+	-	Supplier	Copper and Copper...	+	-	Copper	7440-50-8		176.79...	mg
				+	-	Supplier	Chromium and Chr...	+	-	Chromium	7440-47-3		0.53655	mg
				+	-	Supplier	Tin and Tin Compo...	+	-	Tin	7440-31-5		0.4471...	mg
				+	-	Supplier	Zinc and Zirconium ...	+	-	Zinc	7440-66-6		1.0731	mg
Mold Compound		463.96	mg	+	-	Supplier	Proprietary Material...	+	-	Epoxy Resin (EP)			41.7564	mg
				+	-	Supplier	Proprietary Material...	+	-	Phenolic Resin			32.4772	mg
				+	-	Supplier	Carbon and Carbon...	+	-	Carbon black	1333-86-4		2.3198	mg
				+	-	Supplier	Silicon and Silicon ...	+	-	Silica, vitreous	60676-86-0		382.767	mg
				+	-	Supplier	Bismuth/Bismuth C...	+	-	Bismuth	7440-69-9		4.6396	mg

Figure 1: Homogeneous material composition declaration

materials build-up according to Full Material Declaration IPC 1752 sheets

The IPC 1752 format is supported by an XML schema and a UML model. This makes the FMDs machine readable and easy to use in any kind of software tool. There is an open source tool [2] available to read, edit and create FMDs according to the IPC 1752 format.

3. MATERIAL COMPOSITION MODELS

Unfortunately, a full material declaration for an electronic component is often not available yet, which severely limits the possibility for advanced estimation of material presence and potential recovery or even to provide the required composition information for RoHS and Reach declarations. Therefore the material composition of these components needs to be estimated using dedicated models.

The models presented here are aimed to identify the strategic materials relevant for recycling (noble metals, copper, iron, aluminum, ...). The models do not aim to predict the composition of all constituents accurately. Moulding compounds, different laminates, and other polymers are of less interest in recovery although they might affect the recovery yield to some extent as well as impact the required recycling energy. Additionally, the models should be able to assess the presence of recovery inhibiting substances, either because they present a health hazard or they negatively impact the recovery process itself.

3.1. Printed circuit board

A printed circuit board (PCB) is an integral part of a vast majority of electronic devices on the market. It provides a stable platform for interconnection of various electronic components, which together provide the necessary functionality of an electronic system. Because of this core functionality, electronic waste contains a large fraction of PCBs.

A PCB can be considered as a highly customized part. Because it is of such specific nature, full material declarations are rarely available.

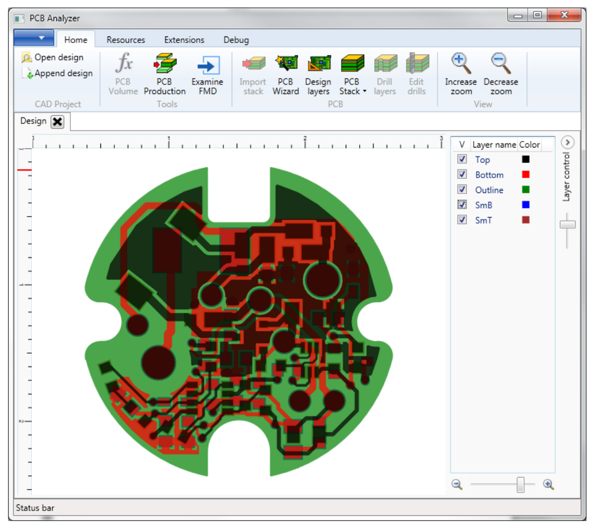

Figure 2: Philips LED lamp driver PCB design loaded in the prototype application

The concept of estimating the PCB material content is relatively simple:

1. Obtain the layout information for a particular PCB design.
2. Use computational geometry to calculate the actual volumes of various parts of the PCB (copper, solder mask, dielectric).
3. Gather material data for the various substances present in the PCB.

4. Translate volume fractions into weight fractions combining the results from the second and third step.

Within the GreenElec Project a tool is developed that can cover these steps. In Figure 2 an example is shown of the layout of one of the GreenElec test case products loaded into the application.

3.2. Solder

The solder is a fusible metal alloy used to attach the electronic components to the printed circuit board. The most commonly used solders are Tin-Silver-Copper (SAC) alloys. Before the RoHS directive [3] was issued, mainly Tin-Lead solder alloys were used in the electronic industry. Today lead based solders are still used in electronics that fall outside the scope of lead-in-solder banning directives such as RoHS and End-of-Life-Vehicles (ELV) or fall under the exemptions of these directives. Examples are electronics in means of transportation except those covered by ELV (trucks, trains, planes, ships,...), industrial installations, central office telecom equipment,....

Estimating the material content of the solder for reflow soldering can be done in a similar way to that of a PCB:

1. Obtain the solder paste stencil information for a particular PCB design.
2. Use computational geometry to calculate the actual volumes of the apertures in the stencil.
3. Gather material data for the solder alloy that is used.
4. Translate volume fractions into weight fractions combining the results from the second and third step. A rule of thumb is that 50% of the printed solder paste will remain on the board.

3.3. Active Components

Various packaging types are used for IC components to accommodate electrical, thermal, cost and other requirements. Given the package type, the material content is more or less determined by parameters such as package dimensions, number of contacts and contact pitch. For the most commonly used package types (BGA, QFP, QFN, SOIC, TSOP, ...) a model is developed to estimate the material content.

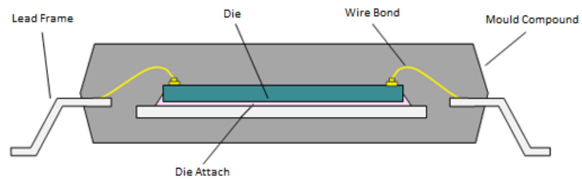

Figure 3: Example of a gull-wing leaded active component

The models all work in a similar way. Using the JEDEC outline sheets [4] as a base, the material content can be estimated in the following way:

1. Calculate the average volume of the various homogeneous materials that exist within the electronic component based on dimensions, pin count and pitch.
2. Gather material data for the substances present in the component.
3. Translate volume fractions into weight fractions combining the results from the first and second step.

Within the same package type, there may be variations on some of the package dimensions. E.g. the die size can vary from covering almost the entire surface of the component, to covering less than half. This will also affect the length of the bond wires [5]. As most electronic components will never enter the recycling process route alone, but accompanied by millions of other components, an average value can be taken for these dimensions.

For the bond wires there is a clear correlation between the volume and the number of contacts. For the leads and the plating of the leads (or solder balls, in case of BGAs) there is a dependency between the volume and the number of leads combined with the pitch. This correlation was verified in a study where the composition of the homogeneous materials was systematically analysed.

For the moulding compound the volume can be determined by calculating the total volume of the package and subtracting the volumes of the other homogeneous materials. Most manufacturers use their own, usually patented, recipe for the moulding compound. This way it is very difficult to find material data about this moulding compound. An average density however can be obtained by examining existing full material declarations of similar package types, as shown in Figure 4.

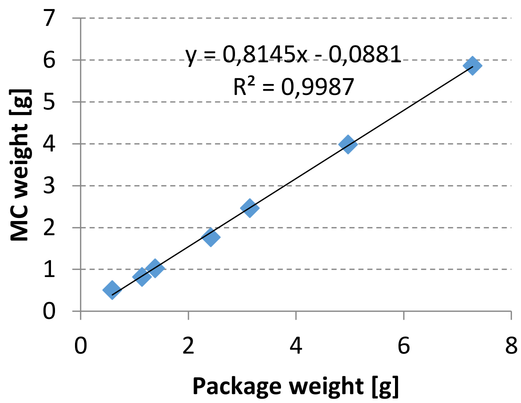

Figure 4: Mould compound weight vs total package weight for PLCC packages

Figure 5: Plastic Leaded Chip Carrier (PLCC) package

In this approach the IC die is considered as a homogeneous block of semi-conductor material. Although it is composed of a variety and continuously increasing amount of elements, these amounts are negligible due to the small dimensions (both in thickness as in lateral dimensions).

3.4. Passive Components

Capacitors and resistors are by number count the most important components but their relative weight in the total PBA is very small. As a result, a basic estimation of the average content of this type of components will provide sufficient accuracy. Figure 6 shows the average material content of a 0603 ceramic capacitor. Different dielectric ceramic materials may be used in different capacitors. As the ceramic material is not recovered in the current recycling process, there is no need to specify its composition more in detail. The focus lies on the metals present in the passive components.

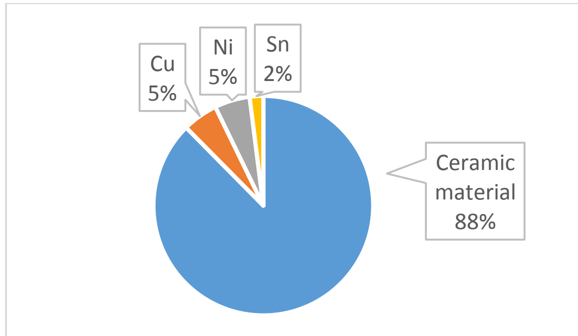

Figure 6: Weight percentages for the main materials in a 0603 ceramic capacitor

4. MATERIAL IDENTIFICATION

The starting point to determine all the substances that are present on an electronic module is the bill of material (BOM). For each component present on the bill of material, including the PCB and the solder, the material composition should be identified, either via the available full material declarations, or via the models. By adding up all the substances, the total material composition of the electronic module can be established.

If the placement data of the components is also available a visual representation of the location of all materials on the PBA can be given. Figure 7 shows a screenshot of a software tool developed within the GreenElec project, to show the distribution of a specific material on a printed board assembly. The example gives the distribution of gold on the top side of a PBA of one of the test case products in the project. Any substance present on the board can be selected. The colored components all contain the selected substance; the color code determines how much of that substance is present in absolute value.

5. DESIGN FOR RECYCLING

Identifying the materials in a product is the starting point for design for recycling. This information can be used to make more detailed and quantified assessments on recycling aspects.

Knowing which materials are present in the product and where they are located also gives the designer the opportunity to make his product more recycling-friendly. He can avoid using components containing substances that hamper the normal recycling processes. E.g. aluminum containing

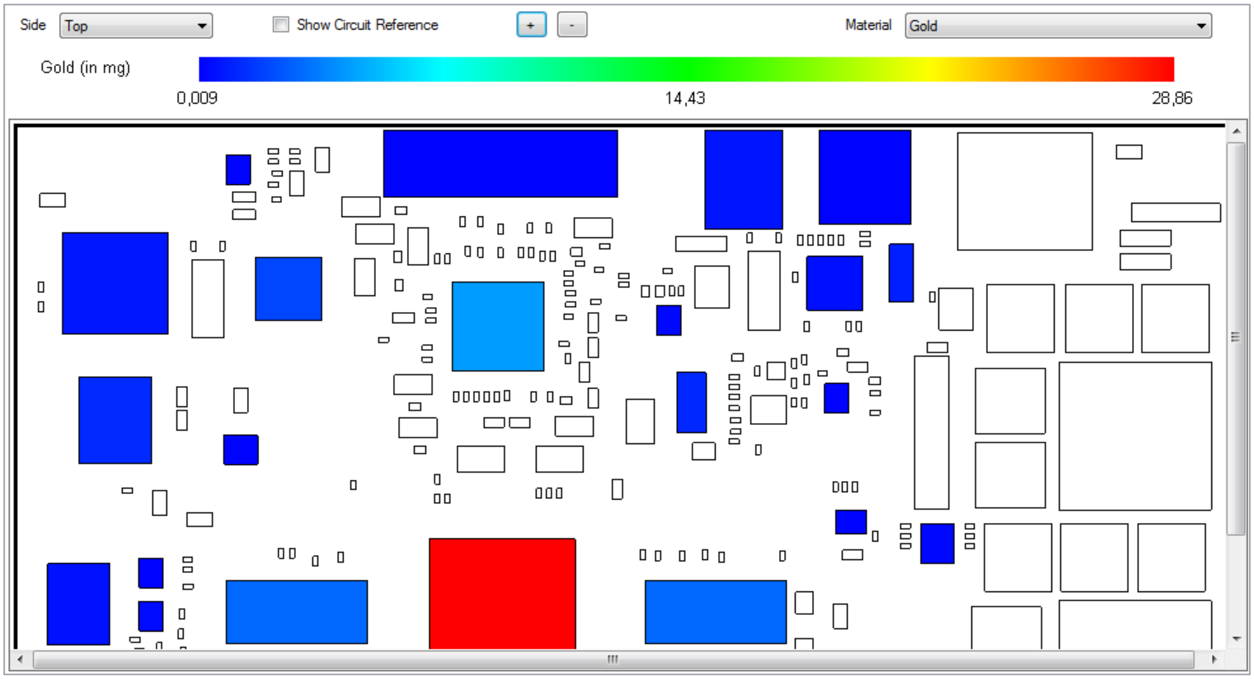

Figure 7: Gold distribution on a printed board assembly

components, such as electrolytic capacitors and heat shields, or iron containing components such as transformers, are preferably not combined with or should be made easily detachable from high value components containing a lot of gold or silver; as the presence of aluminum and iron can have a negative effect on the recovery of precious metals. If these components cannot be avoided, clustering or moving them to a separate PBA to remove them easily from the more valuable part of the product becomes a potential solution.

6. CONCLUSIONS

Identification of materials in electronic modules is one of the key elements to guide design for recycling. To identify the materials present in the product the substances in each of the individual components have to be known. Full material declarations give a complete and detailed overview of which substances are present in electronic components. In case the FMDs are not available the dedicated models developed in the GreenElec project can be used to provide a sufficiently accurate estimation of materials present in the components. Combining this material information with placement data of the components gives both designers and recyclers a useful instrument to improve recyclability of electronic products.

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7. REFERENCES

[1] IPC-1752A Materials Declaration Management, February 2010

[2] Open source tool: http://sourceforge.net/projects/ipc175xutils/

[3] Restriction of Hazardous Substances in Electrical and Electronic Equipment, Directive 2002/95/EC

[4] JEP95: JEDEC registered and standard outlines for solid state and related products

[5] EIA/JESD59, Bond Wire Modeling Standard, June 1997