Cost-efficient metallographic preparation methods of electronic components and assemblies

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Control of the soldering process and failure analysis are an important part of quality assurance at today manufacturers of electronic components and assemblies. Many methods exist – non-destructive and destructive, each capable to reveal different types of defects and characteristics. Metallographic cross-sectioning is often used in the electronic industry to determine or measure different kind of layers, material structures and defects as cracks, voids, delamination, etc. Producers of laboratory metallographic consumables offer big variety of products that can be successfully used in cross-section preparation methods of electronics. This article describes each process step focusing mainly on the special points related to analysis of electronic components and assemblies. In addition to the traditional preparation method, proposed is an optimized method and both methods are compared. Special attention is paid to cost and time reduction and use of new types of consumables for instance patterned segment grinding surfaces. Represented are some of the investigation results, detailed description of process parameters and the image analysis process.

Икономически изгодни методи за металографски анализ на електронни компоненти и модули (Георги Фърков, Валентин Видеков). *Контролът на процеса на спояване и анализът на грешката са важна част от осигуряване на качеството в днешните производители на електроника. Съществуват много методи – неразрушителни и разрушителни, всеки способен да открие различни дефекти и свойства. Изговянето на металографски микрошлифове често се използва в електронната индустрия за определяне или измерване на различни слоеве, структури на материали и дефекти като пукнатини, пори, деламинация. Производителите на лабораторни консумативи предлагат голямо разнообразие на продукти, които могат успешно да бъдат използвани в методите за изготвяне на микрошлифове в електрониката. Тази статия описва всички процесни стъпки, фокусирайки се върху особеностите при изготвянето на шлифове на електронни компоненти и модули. В допълнение към традиционния метод за изготвяне е предложен оптимизиран метод, като двата метода са сравнени. Специално внимание е обърнато на намаляването на разходите и времената, както и употребата на нови типове консумативи, например повърхности за шлайфане. Представени са резултати от изследванията, детайлно описание на процесните параметри и анализа на изображенията.*

I. Introduction

Nowadays, there are plenty of complex electronic devices in mass production. Control of the soldering process is required during the initial samples, as well as during the standard production on regular basis. Important factor for the long lifetime of the products is the solder joint reliability [1].

In general, the quality of solder joints depends on the materials taking part in the process (e.g. solder pad, component leads, solder and flux) and the process flow. Typical defects leading to low reliability and malfunction are cold solder joint, bad wetting, deviations in intermetallic layers and presence of solder voids. These defects are result of improper process parameters (temperature/time), oxidation or contamination of component leads or humidity [2].

The analysis of solder joint quality (quality control) could be performed by optical and physical methods. Those methods will reveal the necessary information for the solder joint, e.g. appearance, wetting, solder voids [3].

There are defects/problems, which cannot be investigated without using destructive methods. In those cases metallographic cross-sections are widely used [4].

The significant difference between classical metallographic analysis and metallographic analysis of electronic assemblies is in the type of the grinded/polished surface. During the cross-section preparation of electronic assembly materials with widely differing properties (for example hardness) are processed at once [5].

That means it is necessary to have a special approach and use some specific methods.

II. Purpose

The main goal of this investigation is development of optimized technological method for preparation of metallographic cross-section of electronic assemblies. The method should assure the necessary quality of analysed surface, which in most cases is metal, but also could be interface between metal and dielectric or metal – ceramics, epoxy resin and polymer and others.

Problems that often occur during cross-section preparation of electronic specimens are smearing of metals and polymers, contaminations, damage of glass or ceramic and embedded abrasive particles [6]. Therefore different methods and process parameters for metallographic cross-section preparation will be investigated, compared and represented.

In addition the overall cost of preparation is interesting. Preparation time, operator time and the amount of used consumables for the total preparation process should be optimized and reduced.

III. Metallographic analysis

The complete preparation process is divided into several steps. Each step must be performed in the correct way in order to achieve satisfactory final result. The main process steps are *cutting*, *mounting*, *grinding* and *polishing* [7]. The preparation must be performed systematically to ensure reproducible results.

III.1. Cutting

Depending on the size or shape of the piece of material in some cases it has to be cut. The sample taken must represent the features of the parent piece from which it is cut. A plain surface, with as little deformation as possible, is required to facilitate and expedite further preparation. One of the most appropriate cutting methods is the abrasive wet cutting. It introduces the least amount of damage in relation to the time needed.

The abrasive wet cutting utilizes a cut-off wheel consisting of an abrasive and a binder. Cooling liquid is used to avoid damaging of the sample.

Depending on the material to be cut (hardness and ductility), wheels of different composition are used. For instance, silicon carbide (SiC), cubic boron nitride (CBN), aluminium oxide (Al_2O_3) and diamond (mostly used in sectioning of electronic assemblies).

III.2. Mounting

In most cases samples are embedded in resin to facilitate their handling and to improve the preparation result. Two techniques are available in the mounting process – hot compression mounting and cold mounting. Cold mounting is especially suited for mounting specimens that are sensitive to heat or pressure. That is why it is mainly used in analysis of electronic assemblies.

The specimen is placed in a cup, resin components are measured precisely, mixed and poured over the sample.

Epoxy resins have the lowest shrinkage of all cold mounting resins. The curing times are comparatively long but these resins have excellent adhesion to the mounted material surface and they are transparent.

Acrylic resins are easy to use with very short curing times and very low shrinkage. They consist of self-polymerizing components which harden after the addition of a catalyst. The transparency is not so good as epoxies, but it can be improved if the mounting is done under special conditions.

III.3. Grinding

Grinding is the first step of mechanical material removal. Actually grinding removes damaged or deformed surface material and introduces only a few new deformations. The main target of this process step is to prepare the specimen with plane surface and minimal damage. All scratches from the grinding should be removed during polishing in the shortest possible time.

Often the process of grinding is divided in two steps – plane grinding and fine grinding.

The aim of plane grinding is to equalize the surfaces of all specimens despite their condition and previous treatment. In case many specimens are mounted in a holder to process together, during plane grinding they have to be brought to the same level for the next process steps. In most cases the consumables used during plane grinding have fixed abrasive particles that remove material quicker. Water is mainly used as a cooling agent.

Fine grinding removes the deformations from plane grinding and leaves only a small amount of scratches that will be possible to disappear during the polishing process. Depending on the materials hardness, the fine grinding can be performed with abrasive papers and water or consumables of newer generation with improved characteristics and diamond suspension.

III.4. Polishing

The final and most important step before the microscope examination is polishing which has to prepare the specimen surface in the best condition, to reveal the real structure without causing any defects.

This can be achieved with some additional steps using successively finer abrasive particles. In general the polishing process can be divided in two sub processes – diamond polishing and oxide polishing.

Using diamond polishing the fastest material removal and the best planeness are achieved. This is due to unique characteristics that diamonds have, e.g. their hardness.

Some of the analyzed materials, especially those that are soft and ductile require final polishing. In most cases oxide polishing is suitable for this final step. Optimum polishing quality can be achieved using Colloidal silica with grain size of 0,04 um and pH of about 9,8. The combination of chemical activity and the fine abrasion results in absolutely scratch-free and deformation-free surface. On the market there are many different types of Colloidal silica intended to be used in different cases. Some are suitable in general for all materials and other are used in combination with reagents to increase the chemical reaction [8].

IV. Experimental results

In order to ivestigate the behaviour of most materials that are normally found in the electronic assemblies, some samples have been selected in advance - copper, several types of solder, printed circuit boards with different layer configuration and others. These samples have been divided into groups and moulded together in resin (Fig.1).

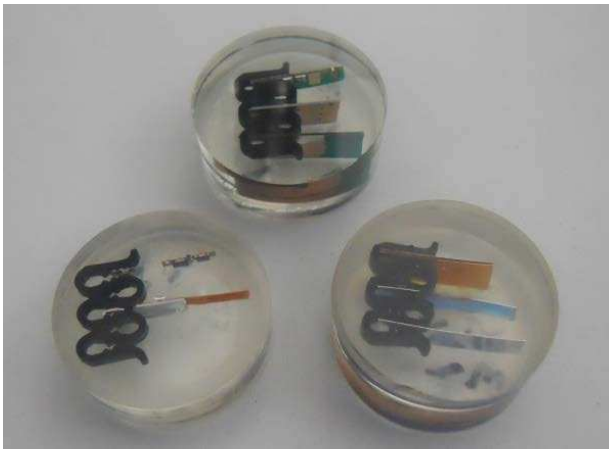

Fig.1. Specimens used in the investigation process

Each specimen contains a combination of different materials to assure processing under the same conditions. Microscope examination has been performed after each process step and the acquired images were compared, analysed and archived. Mostly used illumination techniques in the optical microscopy have been used and compared, e.g. bright field and dark field observation. The influence of changing some process parameters has been studied, e.g. pressing force. Nowadays, there are many manufacturers offering big variety of consumables. Some of the newest generations have been tested.

The traditional method often used for cross-section preparation of electronic parts consists of many steps successively performed one after another. Plane and fine grindings are normally done with silicon carbide grinding papers starting from grit sizes #180, #320, #800 and up to #1200 or even #4000. Grinded specimens are cooled with water. Some improvements in the results can be achieved using SiC foils instead of SiC papers at the same cost, e.g. no wrinkling and better flatness of the consumable. The following polishing process is done with water-based monocrystalline or polycrystalline diamond suspensions and water-based green cooling lubricant. In general there are three steps – 6um, 3um, and 1 um polishing. Special attention should be paid to find and use the optimum suspension/lubricant ratio. Oxyde polishing is an optional step performed just in some cases if necessary or required. The parameters of traditional method are described in details (Table 1).

The biggest disadvantages of this method are the big number of process steps and the short lifetime of grinding consumables. The removal rate of SiC papers dramatically decreases in just 40 seconds, making the second use impossible.

Table 1

Traditional preparation method

Process step / Parameter	**Plane grinding**			**Fine grinding**		**Diamond polishing**		
Surface	SiC 180	SiC 320	SiC 800	SiC 1200	SiC 4000	MD Dac	MD Floc	MD Nap
Lubricant	Water (H_2O)					Lubricant (water-based)		
Suspension	---	---	---	---	---	6 um	3 um	1 um
rpm	250	250	250	250	250	150	150	150
Direction								
Force [N]	30	30	30	30	30	20	20	20
Time [min]	*	*	*	*	*	3	3	4

* - as long as necessary

Some of the results achieved with the traditional preparation method are represented on Fig.2 and Fig.3.

In order to optimize the traditional preparation method the current consumables market has been studied. In the last years, the leading manufacturers offer many newer generation consumables for grinding and polishing.

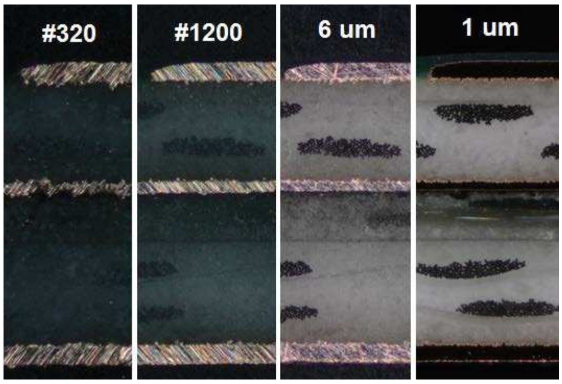

Fig.2. Specimen status at different process steps, dark field observation.

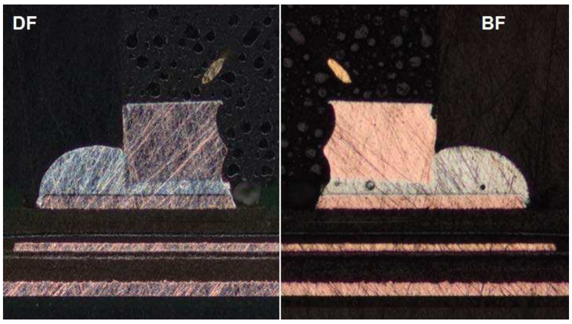

Fig.3. Specimen status after 6um polishing, dark field observation(left) and bright field observation (right).

The newest grinding surfaces [9] have a patterned segment surface structure (see Fig.4), specifically designed for each grinding phase, which minimizes build up of abraded material, allowing consistently high material removal rates and optimum planeness.

Fig.4. Magnetic disc and different types of patterned segment grinding surfaces. (source: struers.com)

According to the specifications of these articles their usage leads to fewer preparation steps, reduced preparation time and costs, better quality of specimens. To investigate the results in case of electronic assembly cross-section preparation, different preparation surfaces have been tested and the influence of most important process parameters has been checked. Appropriate sequence and process parameters for achieving comparable and better surface quality results to the traditional preparation method are described in Table 2.

Table 2

Optimized preparation method

Process step / Parameter	**Plane grinding**	**Fine grinding**	**Diamond polishing**	
Surface	MD-Primo (120) 220	MD-Largo	MD-Dac	MD-Nap
Lubricant	Water	---	---	---
Suspension	---	DiaPro9	DiaPro Dac3	DiaPro NapR1
rpm	300	200	150	150
Direction				
Force [N]	20	20	20	20
Time [min]	*	3	3	4

* - as long as necessary

Plane and fine grinding steps are done with patterned segment surfaces MD-Primo and MD-Largo developed by company Struers.

MD-Primo is a grinding disc with SiC abrasive in a resin bond. It is intended primarily for grinding of non-ferrous metals and soft materials in the hardness range of HV 40-250. This consumable is always used with water cooling and is available in two varieties – Primo120 and Primo220 corresponding to the grit sizes of normal SiC grinding papers. Primo120 is used in case of larger specimen where high material removal is required and the specimens are clamped in holders. Primo220 is normally used with smaller samples and softer materials. One MD-Primo grinding disc replaces between 50-60 SiC grinding papers.

MD-Largo is composite disc for one step fine grinding. It is designed to be used for fine grinding of soft materials in range HV 40-250 or for grinding of composites with a soft matrix. The lifetime compared to SiC grinding papers is extremely higher. MD-Largo can be used instead of 900-1000 pieces of grinding papers. Diamond suspensions and lubricant or all-in-one diamond products like Struers DiaPro can be used during preparation on MD-Largo. DiaPro is a specially designed product to be used with such kind of grinding discs containing diamond particles and lubricant [10]. When used together the preparation time can be reduced average to 30% while achieving excellent planeness, edge retention and reproducibility. This is mostly due to the correct diamond/lubricant ratio. Last but not least is that in this way the dosing system has one more free position to be used for other consumable.

Fig.5 and Fig.6 represent some of the results achieved with the optimized prepraration method.

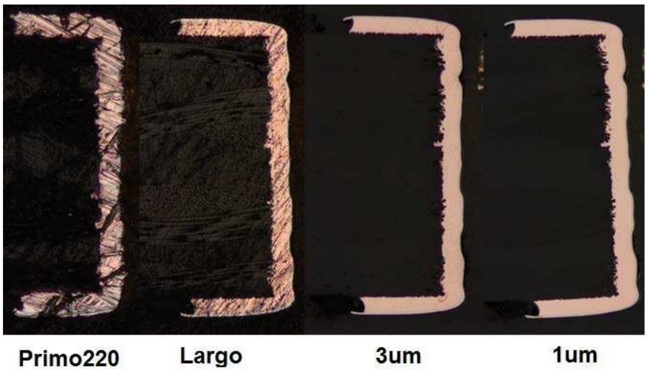

Fig.5. Specimen status at different process step, bright field observation.

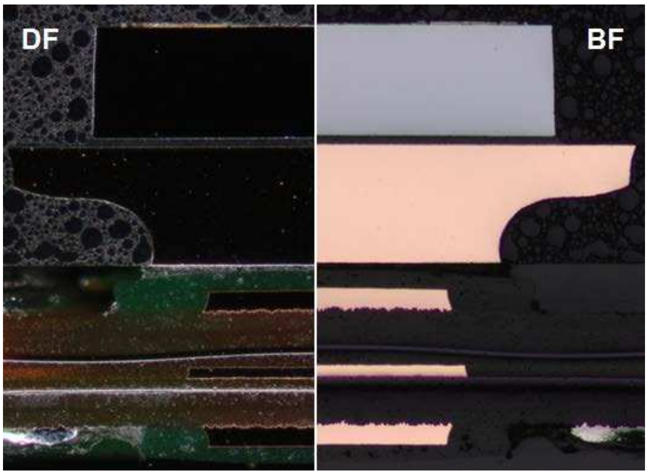

Fig.6. Specimen final status after 1um polishing, dark field observation(left) and bright field observation (right).

All images acquired on each process step during the investigations have been analysed on Olympus Stream image analysis software. Using some of the software tools (see Fig.7) it is possible to evaluate the cross-section surface and compare it for example with the previous step.

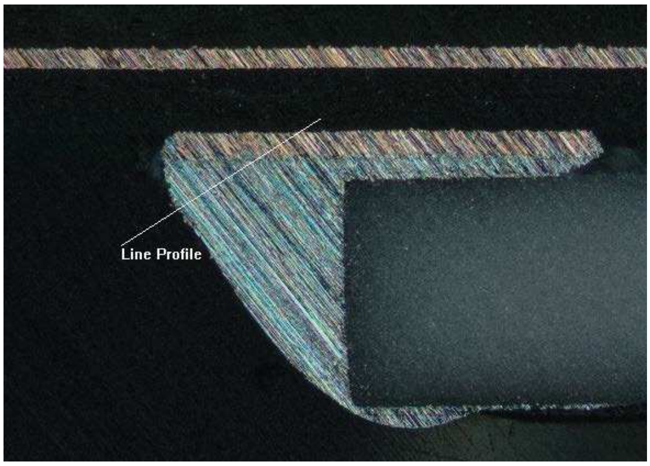

Fig.7. Line Profile creation in Olympus Stream image analysis software

The Line Profile shown on Fig.8 is represented in three channels (RGB). Further statistical evaluation is possible to determine the number of scratches. It is done locally for a specific part (material) on the image. Specific colour is extracted from the colour spectrum and being numericaly processed. Fig.9 shows restored spectrum of blue colour and the function is normalized. Normalization is performed to the highest value of certain line profile and colour. This allows comparison of images with different brightness. The comparison is done by counting the number of intersections between colour function, 65%-line and 80%-line. The result devided by 2 is assumed to be the number of scratches.

Surface quality of all specimens that have been processed with the above described optimized preparation method is acceptable and comparable to the traditional method. What is more remarkable is the decreased number of process steps (8 down to 4) and consumables used, thus reducing significantly the preparation and operator times, which reflect of course the overall cost of preparation – in this case approximately -20 % on average.

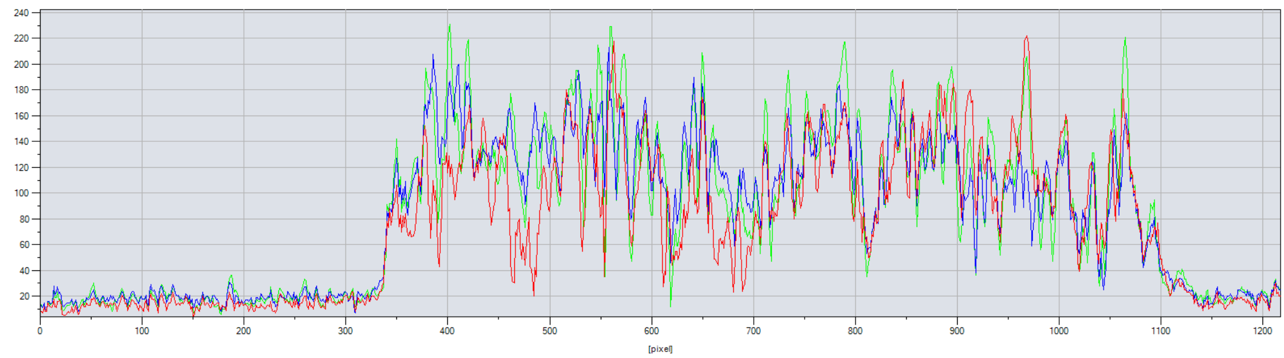

Fig.8. Line Profile chart in Olympus Stream image analysis software

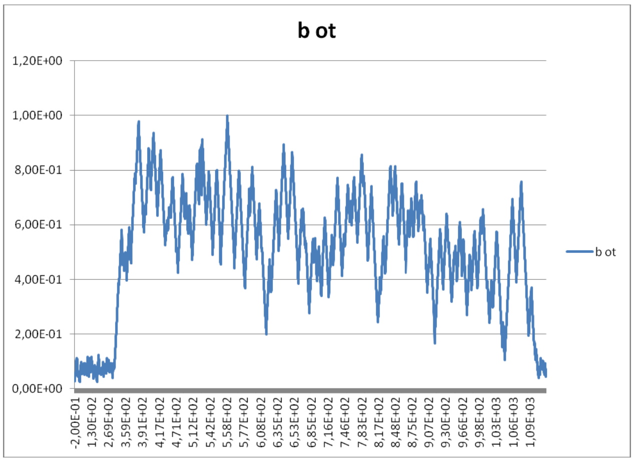

Fig.9. Line Profile chart – blue colour (normalized)

V. Conclusion

Normally we are interested to achieve precise picture of examined specimen structure. But ideal result without any defects near the preparation surface (real structure) is only possible theoretically. Even using the best mechanical preparation methods there will be still some small deformations on the cross-section's surface. However these micro damages are not revealed by the optical light microscope and does not influence the examination results. In most cases acceptable preparation result is needed and any further preparation than necessary is only an increase of overall cost of preparation.

The usage of cheapest consumables do not always guarantee the lowest price per sample. The lifetime of each single consumable and the quality of the surface it produces are really significant. For example if a plane grinding step is included in the used method only because of its high material removal rate, the following fine grinding step probably should be extended to remove all the deformations caused by the previous step. And that should be taken into consideration when calculating the total preparation time and cost.

Taking into consideration the experimental results of all analysed electronic assembly specimens it can be concluded that the proposed optimized preparation method is applicable and also better approach compared to traditional preparation method. The expected decrease of preparation time and consumable cost are confirmed and calculations show it is really significant, without any compromise of surface quality.

Another important factor is the evironmental friendly composition of the new consumables. Their decreased number in the optimized preparation method additionally helps to protect the nature.

VI. Acknowledgements

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