Budapest University of Technology and Economics
Department of Electronics Technology

QUALIFICATION OF ELECTRONIC BOND INTERFACES BY ATOMIC FORCE MICROSCOPY IMAGING AND ANALYSIS

Thesis Booklet

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B U D A P E S T

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Background of Research

The electronics manufacturing continues to face two challenges: one is the miniaturization and the other is the required reliability. The reduction in size of electronic components raises manufacturing issues. Moore's Law, which describes the complexity of integrated circuits (IC), can be formulated in many ways, but each has the message, that the complexity of current ICs increases exponentially, and this trend has not changed for three decades. Size reduction of the terminals of ICs, and bonding surfaces on the circuit boards is a direct consequence of the growth of the complexity.

The size reduction requires inserting new examination methods into the electronics technology "toolbox". In recent decades, microscopes offering higher and higher resolution spread all over in the field of electronic materials characterization: optical microscopy and Scanning Electron Microscopy (SEM) extend the capability of naked eye examination.

Electronics manufacturing technology is extremely diverse: many circuit substrate and component types exist; in my Thesis, steps of manufacturing printed wiring boards using surface mount technology and hybrid circuits with ceramic substrate are described. Typical bonding technology of the printed wiring boards is reflow soldering, where the solder is melted and by solidification the solder will play the role of electrical connection and mechanical fastening. By diffusion between the molten solder and the soldering surface and dissolution processes, intermetallic compounds (IMC) are formed according to the phase diagram of materials involved. In my Thesis, properties of IMC interface formed by solder with SAC (Sn96.5Ag3.0Cu0.5) composition and immersion tin coated copper were investigated after laser welding. The importance of the topic is the fact that the mechanical properties of intermetallic compounds are disadvantageous to the mechanical stability of the Sn-Cu soldering system, and thus, the excessive formation of this IMC is undesirable.

In this Thesis, contact surface of silver-palladium alloy used as thick film layer in hybrid circuit technology is examined during ultrasonic wire bonding. The process of thick film wire bonding is quite sensitive to surface properties (composition, impurities, geometrical surface parameters), and in extreme cases, the wire bonding may fail if the surface is not properly prepared.

Motivation and Objectives of Research

During my research I set the goal looking for possible applications of scanning probe microscopy (SPM), and particularly the atomic force microscopy (AFM) in the field of micro-structural analysis of electronic joints. The great diversity of micro-electronics bonding was narrowed down to a few special bonding technologies, where materials science phenomena are now actively being researched.

Thus the first topic choice was the surface examination of thick film hybrid circuits. In the case of these thick-film layers, connections towards the integrated circuits are formed by ultrasonic bonding of a wire (diameter d = 25 μm), while towards the terminals of the encapsulated appliance, ultrasonic wire bonding (with wire diameter d = 200μm) is used as well. The bonding strength of ultrasonic wire bonding between the thick-film layer and aluminum wires depends strongly on several attributes, e.g. the existence of contaminations on the surfaces. Thus, the classification of surfaces is very important before wire bonding, which can be performed by AFM.

The second topic area was examination of solder interface between the solder material and copper soldering surface, where intermetallic compound (IMC) is formed. In common procedures of intermetallic structure analysis, only average thickness of the layer is taken into consideration, and besides, qualitative comparison is usually based on scanning electron microscopy images. The literature of soldering structure analysis agrees on the need for three-dimensional analysis of the intermetallic layers, which can be routinely applied. The previously developed procedures are inaccurate in the surface normal direction. My aim was to find an atomic force microscopy-based method to perform the three-dimensional analysis of IMC's.

During investigation of bonding surfaces, a data evaluation problem of atomic force microscopy images was encountered. The surface of thick-films and the intermetallic compounds on the soldering interfaces have a particle size with a typical scale of 1 micron, so these applications are pushing the limits of the typical operating range of the AFM, and in the most informative scan sizes (e.g. 10 × 10 μm^2) the ratio of vertical and horizontal sizes of structures can reach 1:10 or greater. From this point of view this is not a typical application of AFM surface analysis, and the well-known image filtering and leveling procedures usually result in significant relative measurement errors in this range. Therefore, my aim was to

establish an AFM image filtering algorithm which can be applied in the cases of such aspect ratios.

Research History in the Department of Electronics Technology

Methods of analysis and atomic force microscopy methods described in my thesis are an integral part of the profile of Department of Electronics Technology in BME, where my studies have been performed. Application of hybrid circuit technology and manufacturing and assembling printed wiring boards goes back in decades. Beside the conventional soldering methods (e.g. wave soldering), the Department's infrastructure will enable other, more specialized technologies as well, such as laser or vapor phase soldering.

The publications of the Department were also the basis for my work, and these scientific papers fit the theme of my Thesis. In the topic of laser soldering, Dr. Péter Gordon and his colleagues carried out studies, in which a significant portion of the laser-matter interaction processes was revealed by applying thermal analysis and simulation [1,2]. The heat transfer in the case of laser soldering is fundamentally different from the conventional soldering technologies, and therefore, the main equations describing the physical-chemical phenomena between the molten solder and the solid surface can also be totally different. More PhD Thesis is being written in the areas of morphology and mechanical properties of intermetallic layers. Tamás Hurtony applies scanning electron microscopy and other methods of metallographic analysis in his doctoral work, mainly on laser-soldered joints [3].

New Scientific Results (Theses)

Thesis Group I

Atomic Force Microscopic measurement method was developed for classification of surfaces where ultrasonic wire bonding is applied.

a. I used contact and tapping mode atomic force microscopy for examination of wire bonding surfaces. Based on these measurements, it can be clearly decided that the surface is clear enoght in terms of wire bonding. The atomic force microscopy measurements proved that the wire lift-off (a failure mode) can be caused by surface adsorbed impurities, whose presence may goes together with water adsorption from atmosphere. I excluded the possibility that the contamination spots are image artifacts from PID feedback.
b. I have shown that the method described in Thesis I.a. can be used as a qualification method of the AgPd thick-film wire bonding surfaces and also based on the AFM measurements, I proposed an effective cleaning procedure. An annealing with a certain temperature (T = 150 ° C) and duration (t = 10 min) significantly reduced the number of relay connections and increased the pull strength values.

The information from the image distortion was determined: the mechanical strength of the interaction between the AFM tip and bonding surface indicates the presence of impurities, so based on the AFM images, locally, qualitative picture of the surface inhomogenities can be acquired. I set up the correlation between the strength of wire bonding pull strength value and the contamination distortion signs of the AFM images.

Thesis II

An atomic force microscopy measurement method was developed that allows measurement of grain structure of IMC's between Cu surface and SAC solders. This includes determining particle size distribution and performing three-dimensional statistical analysis.

A selective electrochemical etching was applied on the specimens; after removing IMC, the direct measurement of the IMC can be performed. As

a three-dimensional characterization of intermetallic structure top-view atomic force microscopy images were created of the solder interface. The scallop-like grained range of IMC layer can be identified by atomic force microscopy images and the total volume of the particles distribution can be determined. The evaluation is hard to be automated, so the following steps were performed:

1. The middle of the particles is indicated in the height maps.
2. By dilatation of the marks, the size of marks will be increased, until the neighboring grains merge. Then a good approximation of the grain boundaries.
3. The total value of the grains can be calculated after determining the base-line of each grain.
4. The entire surface is described and characterized by the histogram of the grain volume values resulted from Step Nr. 3. Together with the cross-section thickness measurements, a full geometric characterization of the intermetallic layers can be achieved.
   Publications: [L3], [K2]

Thesis III

A new evaluation method for AFM data was developed, which is suitable for large surfaces with high ratio. It enables automatic leveling and detecting certain types of image artifacts.

The method based on analyzing a surface-describing measure called structural entropy. The advantage of this method compared to the previously developed widespread leveling method is that the algorithm identifies a leveling function without user intervention. This enables leveled image generation.

In the case of samples with large aspect ratio, atomic force microscope data filtering algorithms do not lead to satisfactory results. A structure-dependent measure must be defined to gain a proper filtering. If one examines a sample, where the surface does not change significantly, the shape of the particles on the surface can be characterized by a local parameter and this parameter can be used for image filtering. During the filtering, the following steps are performed:

1. The measure of the characteristic shape of the particles is determined,
2. This measure is calculated over the entire surface of the image field. If the sample has undesirable background, this value is inhomogeneous.
3. The inhomogeneties of the structural metrics are minimized using trial functions. As the structural metric, structural entropy was chosen, which was previously used in image processing and molecular dynamics calculations. The validation of leveling procedure was performed on a caliber with defined geometry.
   Publications: [L2], [L4] [L5]

Practical Uses of Theses

As a result of Thesis group I, the defined cleaning procedure was applied by an automotive product manufacturer. In Robert Bosch Elektronika Kft. Hatvan, the annealing of AgPd thick-films is being used, and it resulted in yield improvement.

Results of Thesis II can be used for determining the properties of intermetallic layers formed by laser soldering. Based on this results, the optimal duration of soldering can be determined.

Based on Thesis III, an automatic filtering software is being developed which can be applied for AFM image filtering. The structural entropy itself has more potential fields of applications (e.g. surface characterization of electrochemical electrodes), which are currently investigated by my collegues.

Publications connected to Theses

Regular Papers

[L1] **László Milán Molnár**, Szabolcs Dávid, Gábor Harsányi: Qualification of AgPd Thick Films Using Atomic Force Microscopy. MICRO AND NANOSYSTEMS 2:(3) pp. 143-148. Paper 1876-4029/10. (2010)

[L2] **L. M. Molnár**, Sz. Nagy, I. Mojzes: Structural entropy in detecting background patterns of AFM images. VACUUM 84: pp. 179-183. (2009)

[L3] **László Milán Molnár**, Tamás Hurtony, Attila Bonyár, Péter Gordon, Gábor Harsányi: Intermetallic layer formation during laser soldering: an AFM study, J. OF ALLOYS AND COMPOUNDS, bírálat alatt.

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[L5] Sz. Nagy, A. Fehér, **L. M. Molnár**: Structural Entropy Based Localization Study of Wavelet Transformed AFM Images for Detecting Background Patterns. PIERS ONLINE 7:(5) *pp. 441-445.* (2011)

Conference Proceedings

[K1] **László Molnár Milán**, Szabolcs Dávid, Gábor Harsányi: Atomic Force Measurement of adsorbed water on AgPd thick films, MPA-2010 International Meeting on Developments in Materials, Processes and Applications of Emerging Technologies, Portugal, 28-30 July 2010, MPA185, abstract: 122. oldal.

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Publications not connected to Theses

Regular Papers

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[L7] Domján Dániel, **László Milán Molnár**, Eszter Bognár, Tibor Balázs: Development of Polymer Coatings for Coronary Stents. MATERIALS SCIENCE FORUM 659: pp. 141-146. Paper 10.4028/www.scientific.net/MSF.659.141. (2010)

[L8] Varga Bernadett, Mojzes Imre, Nagy Szívia, **Molnár Milán László**: Fractal properties of AlGeNi layers on GaAs surfaces. VACUUM 84:(1) pp. 251-253. Paper 278. (2009)

[L9] Olivér Krammer, **László Milán Molnár**, László Jakab, András Szabó: Modelling the effect of uneven PWB surface on stencil bending during stencil printing process, MICROELECTRONICS RELIABILITY 52 pp. 235-240. (2012), doi:10.1016/j.microrel.2011.08.012

[L10] Molnár Gergely, **Molnár László Milán**, Bojtár Imre: Preparing a comprehensive analysis of the mechanical classification of structural glass, MATERIALOVÉ INZINIERSTVO-MATERIALS ENGINEERING (ISSN: 1335-0803) 19:(2) pp. 71-81. (2012)

Regular Papers (in Hungarian Journal, written in English)

[L11] **L. M. Molnár**, I Mojzes, S. Misák: 1D nanostructures grown on GaAs and InP, PERIODICA POLYTECHNICA-ELECTRICAL ENGINEERING 52: pp. 111-115. (2008)

Regular Papers (in Hungarian Journal, written in Hungarian)

[L12] Molnár Gergely, **Molnár László Milán**, Bojtár Imre: Multi-scale analysis of structural glass, imaging of the mesostructure: A szerkezeti üveg többszintű vizsgálata – a mezostruktúra feltérképezése ANYAGVIZSGÁLÓK LAPJA (ISSN: 1215-8410) 1: pp. 1-16. (2012)

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[K6] Dániel Domján, **László Milán Molnár**, Eszter Bognár, Tibor Balázs: Development of Polymer Coatings of Coronary Stents. In: Development of Polymer Coatings of Coronary Stents. Balatonkenese, Magyarország, 2009.10.11-2009.10.13. p. 1. Paper P-21.

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Book (in Hungarian)

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