Modelling tools in dedicated electronics technology applications

PhD thesis

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2010.

Motivations of the research

Wide varieties of physical-chemical effects exist in the manufacturing processes of the electronics technology. Modelling of these effects or rather development of modelling tools is beneficial in the practice for more reasons. On the one hand there are such processes, in which case the manufacturing parameters can not be planned exactly due to the nature of the technology. This means we can not predict what manufacturing parameters need to be adjusted for expected fabrication outcome. In this case adjusting and controlling of the parameters is made by the aid of test-pieces in a heuristic way. This rather time consuming adjusting process causes loss in mass production. However, minimizing the adjusting iterations with experiment need to be eliminated because of the high cost of applied technology and material as well.

Modelling of the manufacturing processes can also be useful, when inspection of some parts of the processes is not possible due physical or economic reason. In this case the flaw of the final product can be not corresponded to a dedicated element of the manufacturing process. Namely, there are cases, when the defect of the product is known exactly, but we can not proved, which manufacturing step have caused this flaw. So we can not improve the process for the sake of avoiding additional faulty products.

There are numerous problems in field of electronics technology, which are correspond to the condition above. There is a specific group of processes, in which not only individual cases can be examined effectively, but modelling tool for facilitating comprehensive approach of the problem can be made.

I have had opportunity to join many different research and industrial projects at the Department of Electronics Technology. I am presenting in my dissertation the results, which I managed to achieve during these activity and besides their usefulness are considered as new scientific results.

1. Laser ablation

Laser micromachining is ranked among traditional technology in field of the electronics. Manufacturers apply this technology generally, among others for making small vias, precision cutting, data code engraving. However, novel problems

arise due to the miniaturization. Nowadays the dimensions of the structures need to be realized are in the same order as the focal diameter of the lasers, which fact can cause novel processing anomalies. Main reason of this the inhomogenities of the work-piece, so it has more than one patterned layer.

Recently laser appliances do not take into consideration the above mentioned aspects for setting the manufacturing parameters. Because of this partly experiments can be necessary for finding the correct parameters, partly this fact puts a stop to reach finer resolution. Therefore I felt it necessity to create a tool for modelling the laser micromachining, by this means planning the exact parameters can be possible.

The applied ablation model examines the process from thermal viewpoint, so such tool was wanted, which is proper for modelling thermal phenomena. However, there was no solution in the literature and in the field of modelling software, which can handle the ablation; the changing the geometry of the structure during the simulation. So, it was necessary to create such modelling tool, which is capable to handle the ablation, by this means it can serve as basis of software for planning machining parameters.

2. Mechanical modelling of high complexity printed circuit board and solder joints

The mechanical investigations gain more and more importance in the electronics technology due to the miniaturization and the reliability requirements. Analysis of solder joints of BGA (Ball Grid Array), micro-BGA (fine pitch BGA) and WL-CSP (Wafer Level Chip Scale Package) has key of importance, because the solder joints of these case types can be exposed to extraordinary mechanical stress. The reason of this partly the large size of the “area array” cases, partly the small size of the solder joints (bumps).

The investigation and mechanical modelling of the solder joints has decennial past, the literary background of the field is widespread. However, these research works deal with the fatigue of the solder joints, namely the phenomena, which can cause fatigue cracks of the joints during the normal using of electrical appliances. At the same time the printed circuit boards can be exposed to mechanical impacts, which can cause immediate joint cracks. Taking into consideration the difficulties of the

in-situ mechanical measurements, I felt it necessity to create a mechanical modelling tool. By the aid of this tool the impact can be determined, which is capable to damage the solder joints.

3. Modelling of proton beam micromachining of silicon

Proton beam micromachining (PBW) of silicon makes possible to implement 3D structures, so this technology has key of importance in the field of prototyping MEMS (Micro-Electro-Mechanical Systems) devices. During the PBW, the high energy protons induce defects into the crystal lattice. The accelerated ions lose their energy when penetrating the crystalline silicon and coming to rest at a well defined depth, this causes a high vacancy concentration along the ion path. Applying high ion dose drastically increases the damage to the local resistivity of the crystalline silicon, thus causing significant changes to its electrochemical behaviour. The electrochemical etching of irradiated silicon can be performed in a diluted HF solution. The buried regions of the high vacancy concentration silicon, inhibits the etching process so that embedded single-crystalline 3D elements can be developed.

During the electrochemical etching unwanted effects, anomalies arise. Near to the irradiated region the velocity of the etching accelerates, and slows down (or stops) inside small closed regions. These anomalies restrict the possibilities of the technology and can not be eliminated. However, by applying proper manufacturing parameters deleterious effects can be reduced. Because of the physical background of the proton beam micromachining is not known in every detail, I felt it necessity to throw light on this background and to create a phenomenological model of the process. By the aid of this model planning of the proper manufacturing parameters can be possible.

Aims of the research

Chief object of my research work is to create computer models of dedicated manufacturing processes in the field of the electronics technology. By the aid of these models can be improved and optimized the processes.

Objective 1

In the field of the laser micromachining the aim of my research was to create a modelling tool, which can provide an opportunity to plan and optimize the manufacturing parameters. The modelling tool taking into consideration the ablation of the material as thermal process, in this way it makes it possible to consider the heat accumulation in case of consecutive laser shots. The transform of the laser energy to heat is taken into consideration by the aid of adjustable factors. Because of the beam distribution of the applied 355 nm, frequency tripled UV Nd:YAG laser appliance is not uniform, the modelling tool can handle the measured beam distribution. Because of the high thermal gradient near to the laser spot, applying non-uniform meshing was basic requirement. For modelling the ablation process, possibility of varying the geometry under investigation had key of importance.

Objective 2

Mechanical examination of solder joints of "area array" components raises several special requirements. First, it has to be emphasized that the geometry of the patterned copper layers is so complex, which complexity precludes the possibility of modelling according to the real geometry. I felt it necessity to create a method, which is capable to simplify the geometry of the copper layers, so makes possible the mechanical modelling of the printed circuit boards. Further problem of the modelling that the dimensions of the solder joints under investigation are smaller more than one order of magnitude than the dimension of the printed circuit board. Because of this, aim of my work was to create a solution, which makes it possible the calculation of the mechanical stress arises in the solder joints as a function of the deformation of the printed circuit board.

Objective 3

Because of during the electrochemical etching of the silicon (after the proton beam irradiation) the above mentioned unwanted effects arise; the aim of my work was throwing light on the background these processing anomalies and create a modelling tool, which is capable to calculate the etching process. For carrying out the calculations, determining the electric current is necessary, because this plays the most important role in the etching process. The electric current is function of the specific resistivity of the silicon, which can be increased by the implanted high energy ions. With the knowledge of the current, the velocity of the etching front can be calculated, so the geometry can be

determined. Thus aim of my work was to create a modelling tool, which is capable to calculate the effect of the irradiation in the silicon bulk and makes it possible to describe the process of electrochemical etching.

New scientific results

Thesis 1: I have made a modelling tool to simulate laser ablation of polymers. The modelling tool taking into consideration the ablation of the material as thermal process, in this way it makes it possible to consider the heat accumulation in case of consecutive laser shots. The transform of the laser energy to heat is taken into consideration by the aid of adjustable factors. Furthermore, investigation of inhomogeneous structures is also be possible.

Related publications: [L1], [L2], [L5], [R1], [R2], [R3], [R4]

The tool taking into consideration the laser energy transformation to heat by the aid of adjustable factors for the effectiveness. Furthermore, it can handle the measured beam distribution. I have built the modelling of heat transformation effects upon the thermal cell method (Beuken). I have introduced a special descriptive structure, which can handle the connections between the thermal cells and makes possible applying non-uniform mesh and varying the geometry during the simulation. The system of equation for the thermal simulation can be generated according to the descriptive structure. I have complemented the solution with an adaptive mesh refinement routine, which determines the mesh density according to the absorbed energy. I have realized the tool in Matlab environment, where I have applied built-in Runge-Kutta functions for running simulations. I have compared the output of the modelling tool with measurements of Kapton® HN polyimide foils processed with 355 nm UV Nd:YAG laser. I have established that the accuracy of the modelling tool is 3 μm in case of consecutive shots. At the same time the necessary cell number can be reduced remarkably due to the adaptive mesh refinement.

Thesis group 2: I have made a modelling method to investigating the mechanical behavior of solder joints of "area array" components. The method makes it

possible the calculation of the mechanical stress arises in the solder joints as a function of the deformation of the printed circuit board.

Related publications: [L3], [K1], [K2], [M1]

Thesis 2.1: I have made a method to create finite element method base mechanical model of printed circuit boards.

I have recognized and proved by deformation measurements on board that effect of patterned copper layers in printed circuit boards can not be negligible in mechanical models for examining large-scale deformation on the board. For considering the effect of copper layers I have worked out a method, which enables creating the finite element mesh of the examined structure even by high complexity of the layers. Operation of the method is based on process of images made according to the standard RS-274x format description of printed circuit boards. I have achieved the tool for generating simplified geometry in Matlab environment. I have confirmed relevance of the method with comparison of simulation results from a model made in Comsol Multiphyisics application and results of deformation experiments on multilayer printed circuit board. I have verified that method enables calculating large-scale deformation of multi-layered composite boards with accuracy under 3%, on condition of high-rate simplification on geometry of copper layers.

Thesis 2.2: I have composed a method to calculate the mechanical stresses in the solder joints of "area array" type components as a function of the deformation of the printed circuit board.

The method, I have developed, gives scope for high accuracy calculation of mechanical stress awaking in solder joints through finite element mechanical model of printed circuit board containing the actual component as well. The point of the solution is that I replace some of the solder joints with solid blocks of well-chosen parameters, so mechanical stresses in remaining joints can be calculated with high accuracy. I describe mechanical behavior of solders as well as of replacement blocks with Ramgood-Osgood equation. I have demonstrated operability of the method on an example of 240x175 mm

lateral sized, four layered, assembled printed circuit board and a 488 PBGA type component on it, in Comsol Multiphysics.

Thesis group 3: I have made a model to describe the proton beam micromachining of silicon. By the aid of the model I have explain the anomalies of the electrochemical etching.

Related publications: [L4]

Thesis 3.1: I have composed a method to calculate the increase of specific resistivity of silicon causing by the implanted high energy ions.

I have composed a Monte-Carlo model to calculate the distribution of the Frenkel-defects and the increase of specific resistivity of the silicon bulk causing by the implanted ions. The principle of the operation based on dividing of the geometry into brick-shaped elements, and the trajectory of the ions is described by the stepping over the elements. The method uses practical results to determine the increase of the specific resistivity for sake of reducing the time consumption of simulations. I have made the model proper to taking into consideration real beam profile and approval irradiation geometry. I have proved the accuracy of the method by comparing the output of the model with measuring results.

Thesis 3.2: I have made a model to describe the electrochemical etching process of irradiated silicon

I have made a model based on finite element method to describe the electrochemical etching process of irradiated silicon. The primary input of the model is the geometry of the irradiated silicon and the distribution of the specific resistivity of that. The basis of the calculation is the iterative determining of the electrical current. The velocity of the etching front can be calculated according to the current flowing through the silicon-electrolyte boundary. I have realized the model in Comsol Multiphyisics. I have proved the operability of the method by comparing the simulations with measuring results. I have verified that the etching process can be described, furthermore by the aid of the model I have explained the decreasing of etching velocity within the closed regions.

This results afford possibility to reducing the deleterious effect of the processing anomalies.

Publications

Related publications with my theses

Reviewed journal articles:

[L1] **Bálint Sinkovics**, Péter Gordon, Gábor Harsányi: Computer modelling of the laser ablation of polymers, Applied Thermal Engineering, Vol. 30, pp. 2492-2498, 2010

[L2] Péter Gordon, Bálint Balogh, **Bálint Sinkovics**: Thermal simulation of UV laser ablation of polyimide Microelectronics and Reliability, Vol. 47: pp. 347-353, 2007

[L3] **Bálint Sinkovics**, Olivér Krammer: Board level investigation of BGA solder joint deformation strength, Microelectronics and Reliability, Vol. 49, pp. 573-578, 2009

[L4] Zoltán Fekete, **Bálint Sinkovics**, István Rajta, Gabriella Gál, Péter Fürjes: Characterisation of end-of-range geometric effect in complex 3D silicon micro-components formed by proton beam writing, Journal of micromechanics and microengineering, Vol. 20, pp. 064015, 2010

Reviewed journal articles (in Hungarian journals):

[L5] Gordon Péter, Balogh Bálint, **Sinkovics Bálint**, Illyefalvi-Vitéz Zsolt: Analysis of 355 nm Nd:YAG Laser Interaction with Patterned Flexible Circuit Substrates, Periodica Polytechnica-Electrical Engineering, Vol. 52, pp. 31-37, 2008

Referred conference papers:

[R1] Balogh Bálint, Gordon Péter, **Sinkovics Bálint**: Description of 355 nm Laser Ablation of Polyimide as a Thermal Process, 1st Electronics Systemintegration Technology Conference, Drezda, Németország, IEEE, pp. 360-364, 2006

[R2] Gordon Péter, Balogh Bálint, **Sinkovics Bálint**: Investigation and Simulation Methods of Polymer Ablation by UV Nd:YAG laser, 4th European

Microelectronics and Packaging Symposium, Terme Catez, Szlovénia, pp. 375-380, 2006

[R3] Balogh Bálint, Gordon Péter, **Sinkovics Bálint**: Simulation and Indirect Measurement of Temperature Change in Polyimide Induced by Laser Ablation at 355 nm, 28th IEEE International Spring Seminar on Electronics Technology, Wiener Neustadt, Ausztria, pp. 412-416, 2005

[R4] Gordon Péter, Balogh Bálint, **Sinkovics Bálint**: Thermal Simulation of UV Laser Ablation of Polyimide, 5th International Conference on Polymers and Adhesives in Microelectronics and Photonics, Wroclaw, Lengyelország, pp. 128-132, 2005

Conference papers:

[K1] Krammer Olivér, **Sinkovics Bálint**, Illyefalvi-Vitéz Zsolt, Jakab László, Szabó András Board level investigation of BGA solder joint deformation strength, International microelectronics and packaging conference, Pułtusk, Lengyelország, Paper 34, 2008

[K2] **Sinkovics Bálint**, Krammer Olivér, Jakab László: Experimental and numerical analysis of mechanical behavior of multilayer PWB assemblies, International Symposium for Desgin and Technology of Electronic Package (SIITME 2008), Brasov, Románia, Brasov, IEEE, pp. 345-349, 2008

Other publications:

[M1] **Sinkovics Bálint**, Szabó András Mechanikai vizsgálatok szerepe az elektronikai Technológiában, Elektronet, 17:(6) pp. 54-56, 2008 (ISSN: 1219-705X)

Not related publications:

Reviewed journal articles:

[L6] Olivér Krammer, **Bálint Sinkovics**: Improved method for determining the shear strength of chip component solder joints Microelectronics and Reliability, Vol. 50, pp. 235-241, 2010

Reviewed journal articles (in Hungarian journals):

[L7] **Sinkovics Bálint**, Harsányi Gábor: Modelling thermal behavior of surface mounted components during reflow soldering, Periodica Polytechnica-Electrical Engineering Vol. 52, pp. 77-83, 2008

Referred conference papers:

[R5] Olivér Krammer, **Bálint Sinkovics**, Balázs Illés: Studying the Dynamic Behaviour of Chip Components during Reflow Soldering, 30th Int. Spring Seminar on Elctronics Technology, Cluj-Napoca, Románia, IEEE, pp. 18-23, 2007

[R6] Olivér Krammer, **Bálint Sinkovics**, Balázs Illés: Predicting Component Self-Alignment in Lead-Free Reflow Soldering Technology by Virtue of Force Model, 1st Electronics Systemintegration Technology Conference, Drezda, Németország, IEEE, pp. 617-623, 2006

[R7] Hunor Sántha, Gábor Harsányi, **Bálint Sinkovics**, András Takács: Common platform for bipotentiostatic biocatalytic sensors and DNA sensors with electronically addressed immobilization, 27th International Spring Seminar on Electronics Technology, Sofia, Bulgária, IEEE, pp. 136-140, 2004

[R8] Hunor Sántha, Gábor Harsányi, **Bálint Sinkovics**, Dóra Makai: A Microfluidic Electrochemical Cell Based on Microsystem Packaging Technologies Applicable for Biosensor Development, 55th IEEE Electronic Components and Technology Conference, Lake Buena Vista, Amerikai Egyesült Államok, pp. 588-592, 2005

Conference papers:

[K3] Krammer Olivér, **Sinkovics Bálint**: Investigation of the influence of surface mounted chip component misalignment on solder joint reliability, International microelectronics and packaging conference (IMAPS2007), Rzeszow, Lengyelország, pp. 47-54, 2007