行政院國家科學委員會專題研究計畫成果報告

球柵矩陣型積體電路焊線製程參數最佳化之設計

An Intelligent Approach for Simultaneous Optimization of a BGA Wire Bonding Process

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一、中文摘要

本計劃結合「類神經網路」、「基因演算法」與「指數希求函數」針對球柵矩陣型積體電路焊線製程進行參數最佳化。為了達到半導體製造業零缺點的目標，本計劃首先建立製程規格與參數的非線性多變量函數，並針對製程需求推導出最佳參數的組合。本研究所提出的方法藉由台灣某家半導體廠商進行確認實驗，其執行結果在製程能力指標上獲有顯著的改善，表示本計劃所提方法的可行性。

關鍵詞：**球柵矩陣型積體電路、焊線、類神經網路、基因演算法、指數希求函數**

Abstract

This project presents an integrated method in which neural networks, genetic algorithms, and exponential desirability functions are used to optimize the Ball Grid Array (BGA) wire bonding process. As widely anticipated, the BGA package will become the fastest-growing semiconductor package and push IC packaging to higher level of compactness and density. However, wire bonding in BGA is difficult owing to its high I/O count, fine pitch wire bonds, and long wire lengths. This project addresses two fundamental issues in the semiconductor assembly facility on its quest towards a defect-free manufacturing environment. First, the problem of exploring the nonlinear multivariate relationship between parameters and responses and second, obtaining the optimum operation parameters with respect to each response in which the process should operate. The implementation for the proposed method was carried out in an IC assembly factory in Taiwan; results in this project demonstrate the practicability of the proposed approach.

Keywords: Ball Grid Array (BGA), Wire Bonding, Neural Networks, Genetic Algorithms, Exponential Desirability Function

二、緣由與目的

BGA packages provide a high interconnect density and lead count using standard pitch dimensions. Wire bonding designs include ultra fine pitch and cavity-up, which conduct heat from the die through the substrate and interconnect. Owing to their intrinsic design, BGAs are technically complex to bond, and are designed for high I/O counts, i.e., up to 500 leads is common. They also demand fine-pitch (≦ 85 μm) wire bonding and require long wire lengths, straight loops and small first and second bond areas [1]. With high I/O count, fine pitch wire bonds, and long wire lengths, wire bonding in the BGA assembly is difficult. Exploring a manufacturing solution for the BGA requires an integrated study for wire bonding parameters.

The wire bonding process begins from targeting the capillary on the bond pad and positioned above the die with ball formed on the end of the wire and pressed against the face of the capillary. The capillary descends bringing the ball in contact with the die. The inside cone, or radius, grips the ball in forming the bond. In a thermosonic system, ultrasound vibration is then applied. After the ball is bonded to the die, the capillary raises to the loop height position. The clamps are open and wire is free to feed out the end of the capillary. The lead of the device is positioned under the capillary, which is then lowered to the lead. Wire is fed out the end of the capillary, forming a loop. The capillary deforms the wire against the lead, producing a wedge-shaped bond, which has a gradual transition into the wire. In a thermosonic machine, ultrasonic vibration is then applied. The capillary raises off the lead. Leaving the stitch bond. At a pre-set height, the clamps are closed, while the capillary is still rising with the bonding lead. This prevents the wire from feeding out the capillary and pulls at the bond. The wire will break at the thinnest cross section of the bond. A new ball is formed on the tail of the wire, which extends from the end of the capillary. A hydrogen flame or an electronic spark may be used to form the ball. The cycle is completed and ready for the next ball bond.

Wire bonding is used throughout the semiconductor industry as a means of interconnecting the dies, substrates and I/O pins. Ultrasonic metal welding technology can be used for many different applications by appropriately utilizing its sound wave and high frequency mechanical energy characteristics. Ultrasonic energy is used to improve the structure of materials in metallurgy. The acoustic irradiation of molten mass improves degasification and the finer grain structure during the hardening process.

The wire bonding operation attempts to develop a high yield interconnect and low wire sweep process with a sufficient long-term reliability to satisfy customers requirements [2]. To achieve a high level of wire bonding performance and quality, the appropriate bonding process parameters must be accurately identified and controlled. The task of the process engineers is to identify and control these parameters to obtain desired wire bonding quality for optimizing multiple responses (e.g., maximum ball shear strength, wire pull strength, and appropriate ball size), based on their experience or equipment provider’s recommendations iteratively. However, this task is complicated and difficult due to coupled multivariable system, which makes it impossible to adjust a single parameter without affecting the others. Therefore, this multivariate operation requires an intelligent system capable of evaluating the process and determining the optimum adjustment [3].

The use of statistical experimental design techniques in semiconductor manufacturing has been proven very beneficial in process modeling, optimization and control. This approach in process has yielded fairly good empirical models for processes such as plasma etching and LPCVD [4]. However, statistical modeling in semiconductor manufacturing relies on response surface methods (RSM) to construct process models following experimentation. Himmel and May [5] demonstrated that RSM models are lack accurate and robust than models constructed using neural networks.

This project presents an integrated approach not only for exploring empirical models between process parameters and responses via neural networks, but also for optimizing the process through certain parameter settings using genetic algorithms and exponential desirability function for the BGA wire bonding process. A comparison through confirmatory trials between RSM and proposed approach with respect to each response is conducted as well.

三、結果與討論

This project proposes an integrated neuro-genetic-exponential desirability function algorithm capable of optimizing the parameter settings in a BGA wire bonding process. The proposed approach consists of two stages. The first stage procedure involves using of a BP network to derive the relationship model between input parameters and output responses. Notably, the trained network can accurately predict the behavior of possible parameter combinations. Thus, tuning the input parameters in the trained network allow us to obtain the corresponding responses. The exponential desirability is then used to transform the multiple responses into a single response. During the second stage, GA is applied to obtain the optimum degree of satisfaction (λ). Herein, the chromosome is used to represent the possible solution. Each gene in the chromosome represents the value of the input parameter. For example, a manufacturing process has three input parameters S, T, and U. A chromosome can represent the value of the three parameters (S, T, U), respectively. The essential operations are conducted to obtain the optimal response, which is evaluated by the fitness function. Therefore, the optimal parameter of the problem can be obtained [6~11].

An engineering experiment on the 52-micron fine pitch BGA wire bonding process is conducted to optimize the wire bonding process with respect to each response. This project conducted a comparison between the RSM and the proposed approach for benchmarking purposes. The proposed approach reveals better performance more than 10% on the wire pull and ball shear in terms of short term process capability.

The effectiveness of the proposed approach is conducted at a semiconductor assembly line in Taiwan that was undertaken to optimize the BGA wire bonding parameters. The implementation results under mass production over eight months confirm that the proposed approach outperforms the conventional RSM method in optimizing a BGA wire bonding process. According to the quality trend chart from the shop floor, the wire bonding yield has been risen to an average around 99.92% over eight months from 98.1% which equivalents to a reduction of 18200 DPPM (defect parts per million). The annual cost saving is expected to exceed 1.1 million US dollars from implementing the proposed approach in Month 2, whereas the expenditure for the experiment was below USD 2,000.

四、計劃成果自評

This project has demonstrated that integrating BP neural networks, genetic algorithms, and exponential desirability function can optimize the BGA wire bonding process. Although statistical experimental design techniques in semiconductor manufacturing have greatly benefited in process modeling, optimization and control, statistical modeling that heavily relies on response surface methods (RSM) to construct process models following experimentation are less accurate and robust than neural networks models. The neural network approach is better than statistical method largely owing to that the neural network is explicitly nonlinear through hidden layers. It is a more general mapping procedure in which a specific function format is not required in model building. This project also demonstrated the superiority of the proposed approach over RSM base on criteria such as degree of satisfaction, testing the difference about two population means, and short term process capability. The proposed approach can easily achieve optimization of the complex process with multiple responses. These settings facilitate process engineers in achieving acceptable process control during the production. In addition, the improvement in process performance allows the factory to more easily fabricate products with superior quality in the IC assembly industry.

The above research results have been accepted for publication in *IEEE Transactions on Electronics Packaging Manufacturing* (**SCI**, **EI**).

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