氏名	Ju　Yang 巨　陽
授与学位	博士（工学）
学位授与年月日	平成11年3月25日
学位授与の根拠法規	学位規則第4条第1項
研究科、専攻の名称	東北大学大学院工学研究科（博士課程）機械知能工学専攻
学位論文題目	A Study on Microwave Nondestructive Evaluation of Delamination in IC Package （マイクロ波による電子パッケージ内のはく離の非破壊評価に関する研究）
指導教官	東北大学教授　坂　真澄
論文審査委員	主査　東北大学教授　坂　真澄　　東北大学教授　庄子　哲雄 東北大学教授　高木　敏行

論文内容要旨

Chapter 1　Introduction

With the development of IC technology, the size of IC chip has been enlarged to raise the level of integration, and the package has been made thinner and smaller to increase the density of surface mount. Therefore, the reliability of the package has become more and more an important issue in the design of IC package. During the soldering process, the stress and pressure can cause delamination in IC package, and the delamination will grow and propagate until the chip pad interface is substantially or fully delaminated, thereby cracks occur at the sides of the chip pad. Therefore, an inspection technique to detect and evaluate the delamination in IC package has become an urgent need for increasing the reliability of IC package. In case of x-ray inspection, as the thickness of delamination is very thin, the absorption for x-ray due to the delamination is very small. Thus the delamination cannot be detected. Although scanning acoustic tomography (SAT) technique has been used for inspection of delamination in IC package, the limitation of the requirement of a coupling medium makes it impossible to observe the mechanism of delamination under the similar conditions of soldering. In addition, when the package is very thin, it is difficult to separate the echoes from the surface of the package and the delamination. Therefore, in this study, a new technique of microwave nondestructive testing (NDT) has been developed in an attempt to evaluate the interfaces of IC package. Microwave imaging of IC package was also demonstrated for observing the area of delamination which is one of the most important reliability concerns for IC package. The sensitivity to the change in dielectric properties of materials, the ability to penetrate deeply inside dielectric materials, and the characteristic to reflect completely from the metal surface make microwave inspection highly sensitive to detect such delamination. On the other hand, since the detected result is not based on density but dielectric property, the properties of package concerning the moisture and temperature are also possible to be estimated.

Chapter 2　Fundamental Experiment

The study on nondestructive evaluation (NDE) of the delamination in IC package has begun at the research for evaluating defects in packaging materials nondestructively. Microwave technique has been used for testing voids, delaminations, porosity etc. in a variety of dielectric materials. However, for detecting small defects, waveguide that was used in the above researches presents some frequency limitations. The existence of cutoff frequency does not allow to make the waveguide aperture small enough, thereby the spatial resolution was limited by the aperture size of waveguide. In contrast with the conventional microwave methods, here, a coaxial line sensor is proposed to be used for increasing the spatial resolution. Coaxial line technique has been used to measure the constitutive parameters of dielectric materials, but has not yet been used for NDE of defects. The primary advantages of coaxial line sensor are that it can work on a wide frequency range (radio frequency and microwave), and the aperture, which is independent of working wavelength, can be made in very small dimensions for increasing the spatial resolution. This study employed swept-frequency technique to measure the magnitude of transmission coefficient in discontinuous coaxial line, and analyzed its first abrupt transition with some epoxy composite samples containing artificial defects. The results indicated that the present technique is very effective and convenient for testing such material. Coaxial line sensor technique was confirmed to be a powerful tool for detecting defects in dielectric materials. The magnitude of transmission coefficient was found to be sensitive to the change in dielectric properties of materials.

Chapter 3 Evaluation of Delamination Based on Magnitude Measurement

A kind of novel open-ended coaxial line sensor improved from the sensor that has been used in Chapter 2 was employed to detect the delamination in IC package. In case of detecting delamination in IC package, the incident wave will be reflected completely at the surface of the chip pad (conducting sheet). Thus the reflection measurement was introduced in the study. The principle of this technique is based on the interaction of electromagnetic wave with IC package. The coaxial line aperture acts as a source of microwave that transmits into the package; the same aperture also acts as the receiver of the signal reflected by the chip pad. A network analyzer (HP8510) was used to generate a continuous wave signal fed to the coaxial line sensor and measure the magnitude of effective reflection coefficient at the coaxial line aperture. A computer was employed to process the data output from the network analyzer and control the stage translation in the x- and y-directions. The sensor having an inner and outer radii, a=0.46 and b=1.50 mm, respectively, is terminated into a flat metallic flange with radius c=14.50 mm. To conduct the experimental study, four IC packages were used as samples. Two of them are free from delamination, and the others contain artificially introduced delamination that has been confirmed by the SAT testing. The thickness of the delaminations introduced here is around 20μm. The frequency, on which the difference of the magnitudes measured between the two category packages with and without delamination takes the biggest value, was selected as the operation frequency. The standoff distance that is sensitive to the magnitude difference between the two category packages was fixed for later measurement. Finally, the magnitude of effective reflection coefficient was measured by scanning the samples in the x- and y-directions with the selected operation frequency and standoff distance. The measured results showed the difference between the two category packages with and without delamination very clearly. The curves of the magnitude of effective reflection coefficient versus measurement position were smooth and showed smaller decrease for packages without delamination, but fluctuating and larger decrease for packages containing delamination. The potential of improving the resolution of microwave NDT by the open-ended coaxial line sensor has been confirmed in the study. The delamination in IC package was detected successfully without using any coupling medium, and hence it is possible to estimate the reliability of package by evaluating its delamination.

Chapter 4 Evaluation of Delamination Based on Phase Measurement

For detecting and evaluating the delamination automatically, phase measurement was introduced in the experiment since it is less affected by the scatter of microwave in comparison with the case of magnitude measurement. The frequency of the phase measurement can work on the relatively lower region. The experimental results showed that the sensitivity of the measurement is almost independent of the operation frequency and linear with the standoff distance in their effective ranges. It means that the operation frequency and the standoff distance are not required to optimize in advance. The phase of the effective reflection coefficient at the aperture of the open-ended coaxial line sensor, associated with the component reflected at the surface of the chip pad and varying with the thickness and also dielectric constant of the delamination layer, was measured as a characteristic signal to detect the delamination. The phase difference in cases of package with and without delamination was also calculated to evaluate the delamination and crack. In the experiment, the operation frequency was 20 GHz that is significantly lower than the case of magnitude measurement. Higher frequency can increase the spatial resolution, however the cost will also be increased. The standoff distance from the sensor aperture to the sample surface was fixed to be 0.2 mm. The experiment was performed by scanning the sample along the y-direction with a 0.5 mm pitch at the center of package. The measured phase for sample with delamination is significantly smaller than that for sample without delamination. The different phase values indicate the existence of delamination. The experimental results showed the delamination evidently; by measuring the delamination at the edge of chip pad, the extended crack in the plastic package was also estimated. The advantage of using the parameters without calibrating them in advance makes the phase measurement convenient to realize automatic inspection.

Chapter 5 Theoretical Considerations

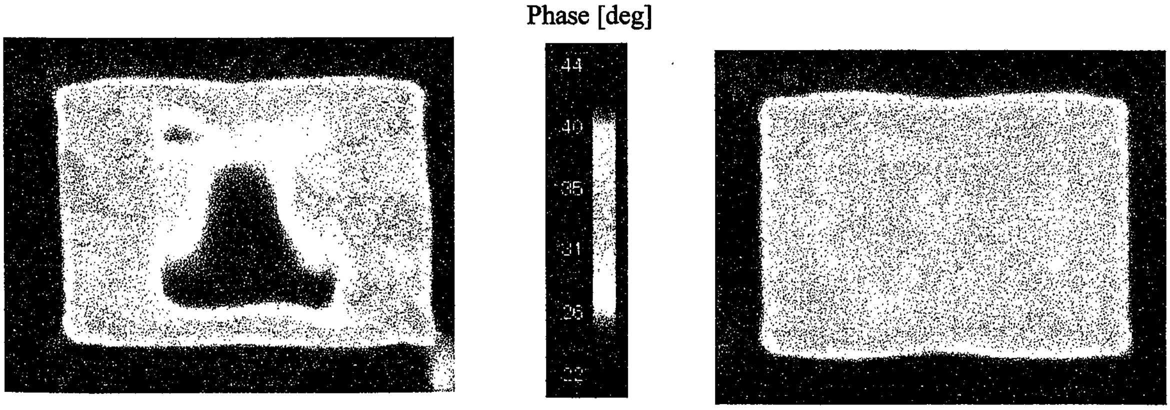
The interaction of microwave with the IC package is a complex phenomenon. In order to evaluate the experimental results and optimize the conditions of the measurement, it is important to understand the nature of this interaction. Consider an incident signal, which is transmitted into a medium and reflects at the surface of the conducting plate in the medium. The ratio of the latter signal to the former gives the effective reflection coefficient of the medium. The phase difference of the effective reflection coefficient for a medium with a defect and one without a defect is related to the thickness and also the dielectric properties of the defect. The equation of effective reflection coefficient was derived from basic Maxwell's equations, based on the considered module of microwave interacting with IC package. Using the calculation, the thickness of delamination can be estimated from the measured phase difference. In order to verify the experimental results and theoretical prediction, the predicted value of the delamination thickness was compared with its actual value. One sample measured in Chapter 4 was cut along the x-direction at the center of the package, and observed by microscope after finishing the experiment. The actual thickness of the delamination in the sample was approximately 31 μm, 1/500 of the working wavelength approximately. It is close to estimated value of 39.8 μm. One reason of their difference is on the undulation of the measured delamination. The theoretical model can be used to optimize and calibrate the experiment, and to replace the reference sample. The good agreement of the experimental results with the calculation indicates that the present technique can be used for early detection and quantitative evaluation of the potential defects in IC package or other dielectric materials.

Chapter 6 Microwave Imaging

Modern NDT technique requires the inspection technique that is not only able to detect defects correctly but also observe defects directly. Imaging technique is a possible way to observe the shape and the size of the defects. Microwave image was created by recording the phase of effective reflection coefficient continuously, when IC package was scanned. The measured package image showed the delamination in damaged package very clearly. The open-ended coaxial line sensor was faced to the back-wall of the package, so the delamination layer was located between the sensor aperture and the chip pad. A phase image was created by scanning a sample in the *x*- and *y*-directions. The scanned area was 20×25 mm and the pitch was 0.5 mm. The operation frequency was 20 GHz and the standoff distance between the sensor and the sample was 0.2 mm. Figure 6.4 (b) shows the images of a pair of samples with and without delamination using the raw data without any image processing. The dark grey region in the image of 4-S2 indicates a delamination between the chip pad and the plastic package. In the image of 4-S4, package part is observed with light grey completely, which means there is no delamination contained in the sample. The difference between the images of 4-S2 and 4-S4 illustrates the information of delamination; by comparing them, the delamination can be detected effectively. Microwave imaging was confirmed to be an effective tool to detect the delamination in IC package. By using the open-ended coaxial line sensor, the spatial resolution is improved. With the aid of the microwave imaging technique, the full mechanism of delamination is expected to be observed in the soldering conditions, thereby the prediction of the condition of delamination and crack occurrence also becomes possible.

Chapter 7 Conclusions

A new microwave NDT technique was developed for evaluation of delamination in IC packages. By using open-ended coaxial line sensor, spatial resolution was improved relative to the conventional microwave NDT techniques. Based on the specific properties of microwave that it penetrates deeply inside dielectric materials and reflects completely at metal surface, delamination in IC package was detected effectively. With the aid of this technique, the mechanism of the delamination can also be investigated. This advanced technique provides a new experimental method for integrity assessment of IC package, thereby supplying the capabilities to improve the design of packaging, as well as the reliability of IC package. Simultaneously, high sensitivity of this technique also offers a great possibility to evaluate other dielectric materials nondestructively.



4-S2

4-S4

Fig. 6.4 (b) Microwave image of series 4 samples, Sample 4-S2 with and 4-S4 without delamination

審査結果の要旨

電子パッケージの非破壊評価に，従来，超音波が使われてきている。超音波探傷においては，探触子と被検査物表面の間に超音波の伝達媒体として，水に代表される接触媒質が不可欠である。しかしながら電子パッケージは水をきらうため，超音波をオンライン検査に使用することは不適であり，これに代わる新たな非破壊評価方法が切に待たれていた状況にあった。

著者は，接触媒質を必要としない点に特徴を有するマイクロ波の活用に着目して，電子パッケージにおける代表的な欠陥である封止樹脂と素子搭載板の間のはく離を対象として，これを探査し，映像化する手法の開発に成功した。

本論文は，同開発と検証についてまとめたもので，全編7章からなる。

第1章は序論である。

第2章では，誘電体材料中の欠陥検出にあたり，従来の導波管に比べ材料の誘電率変化に敏感な同軸ケーブルを用いたセンサを考案している。電子パッケージの高感度非破壊評価に有効なセンサの提案である。

第3章では，素子搭載板でのマイクロ波の反射率の大きさに着目して，具体的に電子パッケージ内のはく離を検出できることを明らかにしている。

第4章では，第3章の成果を発展させ，より高感度なはく離の検出を目指し，素子搭載板でのマイクロ波の反射率の位相に着目した手法を導入して，検証を行っている。ここに同手法では使用周波数の選択に大きな注意をはらう必要がないことを示している。これは有益な知見である。

第5章では，電子パッケージ内の複数の界面でのマイクロ波の反射を理論解析し，受信されるマイクロ波の位相変化とはく離部の厚みとの関係を明らかにしている。同時に本解析が実験結果とよい一致を示すことも明らかにしている。これらは，マイクロ波と電子パッケージの干渉なる現象の把握のために不可欠な成果である。

第6章では，得られた成果を踏まえ，電子パッケージに対してセンサを非接触で，二次元的に，かつ自動で操作して，マイクロ波によるはく離の探査，映像化を実現している。これは実用化を狙った貴重な成果である。

第7章は結論である。

以上要するに本論文は，電子パッケージ内のはく離の非破壊評価を対象とし，マイクロ波の応用について検討し，接触媒質を不要とする新たな探査映像手法を開発したもので，機械知能工学の発展に寄与するところが少なくない。

よって，本論文は博士（工学）の学位論文として合格と認める。