Comprehensive In-Line Metrology for Advanced RDL Process Monitoring

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Abstract

The growth in mobile device market and the increasing demands for higher level systems integration is driving significant advancements in packaging technologies. Next generation semiconductor devices demand redistribution layers that are shrinking to accommodate multiple chips on a single package. In this paper, we present the application of Picosecond Ultrasonics (PULSE™) in combination with high resolution reflectometer to provide a comprehensive in-line metrology for full process characterization of the redistribution layer. This first principles technique provides gage capable measurements for production monitoring and is capable of providing measurements on various types of structures such as dense lines, pads, and bumps. Accuracy of the measurements have been validated using cross-sectional scanning electron microscopy.

I. Introduction

With the rapid growth of the mobile device market, advanced packaging is seeing demands for a higher level of system integration, increased I/O's and functionality. This demand is driving 2.5D/3D integration of IC devices which in turn requires sophisticated packaging technologies. Among various approaches, Fan-Out Wafer-Level Packaging (FOWLP) is gaining more traction as Outsourced Semiconductor Assembly and Test (OSAT) houses and wafer foundries are rolling out their own technologies. First generation FOWLP was geared towards mobile applications and redistribution layers (RDL) lines were typically 5/5µm (line/space) and larger. Second generation growth is driven by the requirement and ability to integrate multiple chips on a single package with more RDLs of tighter pitch 2/2µm and smaller package [1].

Metal film measurements, such as RDL and Under Bump Metallization (UBM) have been characterized using semi-automated measurement tools such as contact profilometers due to their ease of use and low cost of ownership. However, they have been found to be inadequate in high volume manufacturing when a variety of products of varying topographies have to be measured. Several commercially available scanning white light interferometer (SWLI) systems are also in use for RDL process monitoring. These methods rely on interference patterns for providing thickness information but as the RDL films get thinner, signals are complicated and the accuracy of the measurement is affected. At the 2µm and below RDL line widths, accuracy of the thickness measurements becomes critical for process monitoring and control. Critical dimension (CD) measurements of the RDL lines and via CD are also important parameters for monitoring the RDL process. Manual optical CD tools are tedious to use and have been replaced by CD measurement options on interferometer systems. Wafer fabs also rely on CD-Scanning Electron Microscope (SEM) and cross-sectional SEM to for more accurate CD measurements.

Picosecond Ultrasonic (PULSE™) technology is a proven workhorse for metal film metrology in leading edge wafer fabs for front-end-of the-line (FEOL) and back-end-of-the-line (BEOL) applications. We have previously demonstrated the successful adoption of stand–alone optical and acoustic metrology techniques for monitoring advanced packaging processes [2]. In this paper, we report on the results of a successful integration of a high resolution visible reflectometer to provide accurate transparent film thickness in addition to the RDL thickness on product wafers. Additionally, we report on the capability to deliver CD measurements in tandem with the thickness measurements thus providing users with complete information needed for process control.

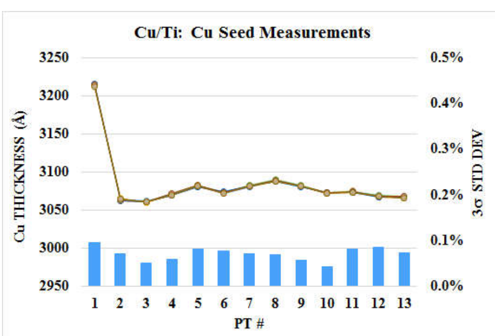
II. Measurement **Methodology**

Picosecond ultrasonics is a small spot non-contact, non-destructive technology and allows measurement directly on-product wafers. In addition to thickness measurements, the technology has shown sensitivity to monitor other process parameters such as roughness, density, and elastic modulus. Thickness is calculated from first principles using the round trip transit time of the acoustics through the film using known speed of sound in the material. The technique provides accurate measurement of metal films, single or multi-layers ranging in thickness from 40Å to 12µm. Metal film measurements of Cu seed/barrier, RDL line (dense, isolated) structures are easily characterized without the need for calibration standards, or reference wafers. During this study, we assessed capability of the technique to measure RDL lines that are currently in high volume manufacturing as well as those under development. Results were validated by comparing the picosecond ultrasonic results to existing interferometer techniques as well as cross-section microscopy. Selected data from the study is presented in the following section.

III. Results and Discussion

Figure 1 shows a simultaneous measurement of Cu seed/Ti layer on an RDL wafer. Measurements typically take a few seconds per site and have excellent repeatability. Typical 3 sigma load/unload repeatability, represented as bar plots is < 0.2% for Cu and < 1% for the underlying Ti layer.

(a)



(b)

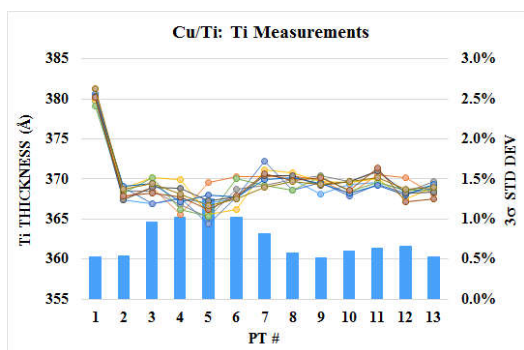


Fig 1(a) and (b) Simultaneous measurements of Cu seed and Ti barrier, respectively. Measurements show excellent repeatability of the technique and can be used for process monitoring.

RDL thickness capability (2µm-10µm) were evaluated on various structures- pads, isolated and dense line arrays at various levels. Figure 2 shows modeled fit to measured data from a 2µm pad (fig 2a) and 4µm pad (fig 2b). The raw data is characterized by high signal to noise which contributes to the excellent repeatability. The arrival times of the echo is obtained from the measurement, and with the known speed of sound in the material, we can readily calculate the thickness of the films. The acoustic echo, in figure

2a occurs at ~800ps corresponding to an RDL thickness of 2µm. In figure 2(b), the arrival time of the echo is ~1600ps and the thickness is determined to be ~4µm. This first principles method provides a robust method for determining the thickness in contrast to other indirect methods. Recipes can be set up to robustly cover the process range of interest and typical measurement time is a few seconds per site. Average repeatability (bar plot in fig 2 c) is 3 sigma < 1%. We have observed that the thicker RDL films are also characterized by higher surface roughness and local non-uniformity. Hence, any inaccuracy in wafer placement results in observable site level variations in repeatability performance. The repeatability shown here has been confirmed to be more than adequate for process monitoring. Site level performance can be further improved, if desired, by averaging over the local non-uniformity with some trade-off to throughput.

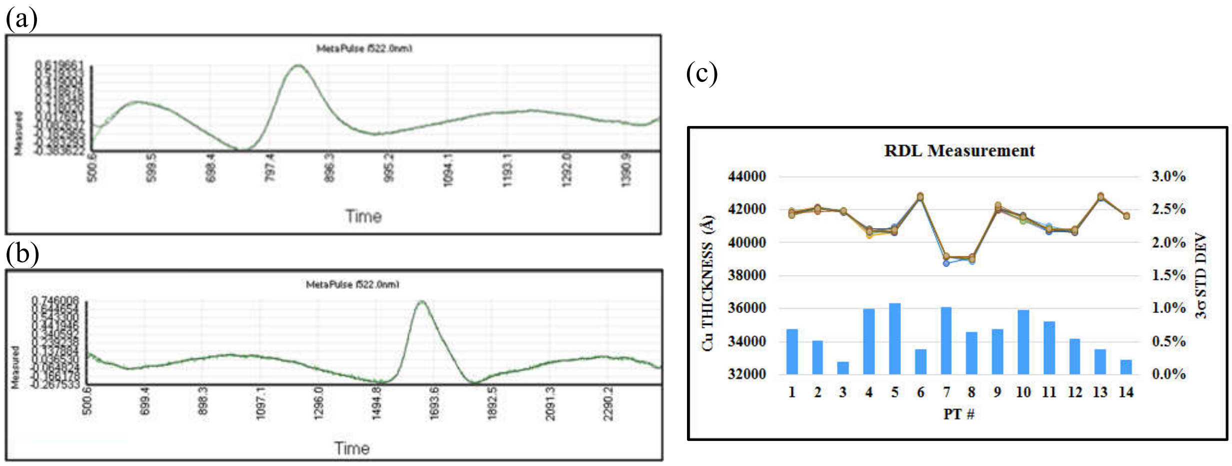


Fig 2. (a) Modeled fit to measured data from a 2um RDL film. Echo arrives at ~800ps corresponding to a 2µm film. (b) Echo arrival time ~1600ps corresponding to a 4µm RDL film. (c) Cross-wafer thickness variation and repeatabilty performance shown.

During process development, more extensive sampling of the wafer can be performed to obtain information about cross-wafer uniformity. Shown in figure 3 are examples of using picosecond ultrasonics for characterizing within wafer uniformity profiles of an RDL dense line array (L/S 1:1). The non- uniformity varies from 3.5% (fig 3a)-2% (fig 3c) for the three different structures.

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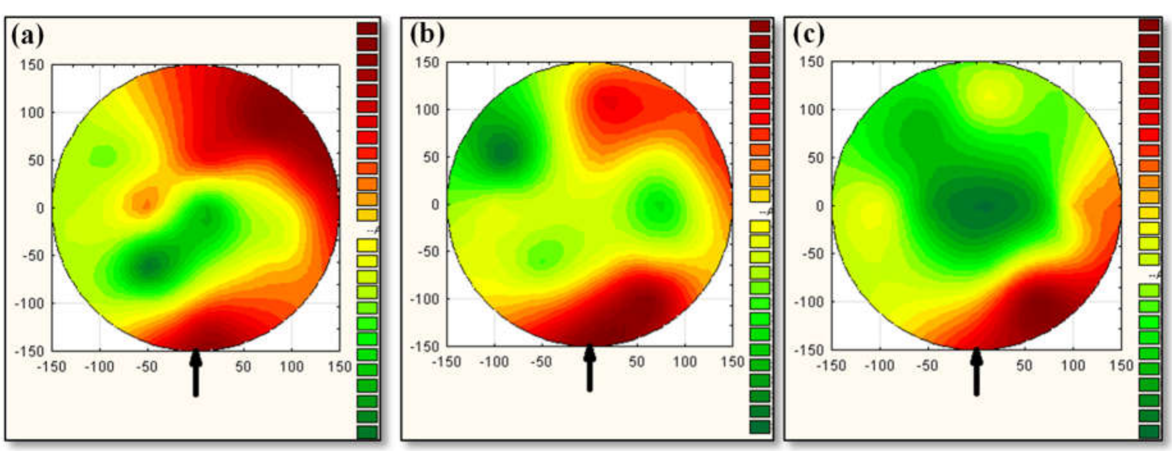
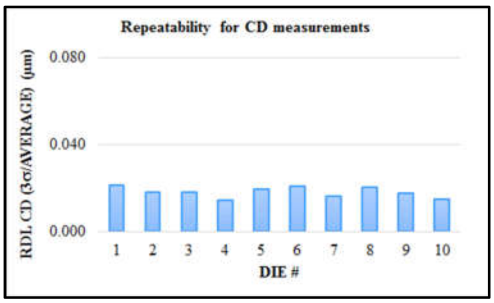


Fig 3.Within wafer uniformity maps of RDL Lines from varying stages of development. (a) 3.5% non-uniformity and (b) 2.3% non-uniformity (c) 2% non-uniformity

Figure 4 summarizes the load/unload repeatability results from CD measurements. The precision to tolerance (P/T) ratio was calculated and was < 0.1 and confirmed the capability of the technique for production monitoring. Measurements for CD are performed in tandem with thickness measurements and take < 1s for a 13 point map across the wafer. Accuracy of the technique was validated by performing cross-sectional SEM measurements across various structures (L/S 1:1). On an average, the mismatch with respect to SEM ~1.2%. Additionally, using the integrated visible reflectometer capability, polyimide thickness on the RDL wafers can be measured. During development, both thickness and refractive index values are reported to help optimize the process. Figure 5 shows modeled fit to measured data of a 11µm polyimide film from a 20x20µm site along with typical repeatability performance. The visible reflectometer provides capability to measure films up to 65µm thickness.

(a)



(b)

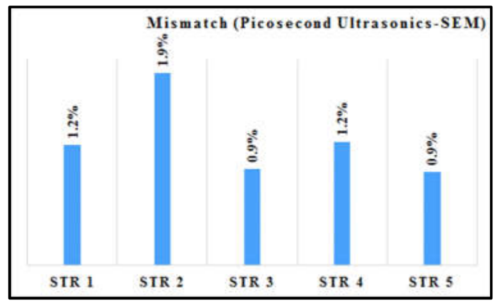
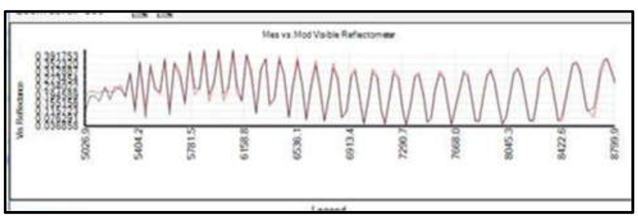


Fig 4(a). Load/unload repeatability measurements of RDL CD from an advanced process. Typical repeatability shown. (b) Structures 1-5 shown in the x-axis represent various RDL strcutures (2µm-4µm). Mismatch between picosecond ultrasonics and SEM on an average is ~1.2%

(a)



(b)

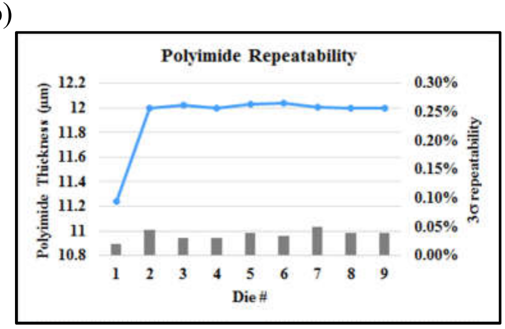


Fig.5 (a). Modeled fit to measured reflectance spectra from an 11µm polyimide film. Refractive index of the film was also calculated as 1.540

Fig 5(b). Polyimide thickness measurements in a 30µm site. 3sigma repeatability < 0.05%

IV. Conclusions:

PULSE technology is a proven work horse for metal film metrology in wafer fabs. With the addition of CD and reflectometer capability, we have demonstrated the advantages of having a comprehensive in-line metrology tool for RDL process monitoring thus eliminating the need for routing the wafers to multiple tools or technologies.

References:

1) Y. Jin, X. Baraton, S.W. Yoon, Y. Lin, P.C. Marimuthu, V.P. Ganesh, et al., "Next generation eWLB (embedded wafer level BGA) packaging," Proc. 12th Electron. Packag. Technol. Conf., 2010, pp. 520–526.
2) Parker Huang, Bruce Chiu, Jay Chao, Chun Hung Lu, Stephen Chen, Jay Chen Fei Shen, Jian Ding, Johnny Dai, Priya Mukundhan, Timothy Kryman, Optical and Acoustic Metrology Techniques for 2.5 And 3D Advanced Packaging, IMAPS 2014.