Enhancements to Picosecond Acoustic Metrology for application in FO-WLP Process

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Abstract

Fan out wafer level packaging (FO-WLP) is one of the fastest growing advanced packaging segments due to its versatility for a wide variety of applications. It's compatibility with large scale, low cost, ultra-thin and high-density packages has made it very attractive. Cu redistribution layer and multiple metal under bump metallization stack play critical role in the FO-WLP process especially with shrinking line/space size and increasing density. We previously discussed the adaptation of PULSE™ technology, with the integration of a visible reflectometer and high resolution camera as a comprehensive in-line metrology tool for the advanced packaging applications. In this paper, we present results from some recent work on enhancements to the configuration for measurements of very thick, rough RDL films. The modifications provided significant improvement (9x) to throughput while maintaining gage capable repeatability. Cross-section SEM measurements on 1µm RDL structures were used to validate the extendibility of the technique.

Keywords

FOWLP, Metrology, Picosecond Ultrasonics, RDL

I. Introduction

Fan out wafer level packaging (FO-WLP) has been shown to be very versatile, thus lending itself attractive to a wide variety of applications. FOWLP is expected to have the highest growth rate, exceeding $2 billion by 2020, including all platforms [1]. First generation "core" fan-out was geared toward mobile applications and redistribution lines (RDL) were typically 10/10µm (line/space). High density fan out (HDFO) has seen remarkable growth (Fig. 1) in recent years in large part due to entry and adoption by key players [2]-[4]. Second generation HDFO processes, which were developed to integrate multiple chips in a single package, use multi-level RDL lines at smaller width and tighter pitch, down to 2/2µm and potentially shrinking even further.

As design rules for HDFO approach those of front-end processes, requirements for process control and the need for more accurate and repeatable automated metrology are becoming a necessity. Until now, manufacturers have characterized metal films, such as RDL and under bump metallization (UBM), using semi-automated measurement tools, such as contact profilometers, which are easy to use and relatively inexpensive. However, these tools are not the best solution for measuring a variety of products with varying topographies in high volume production. The thin wafers/substrates used in HDFO processes can also be warped significantly at several different steps in the process, most notably by the mismatch between thermal expansion coefficients of the molding compound and the die.

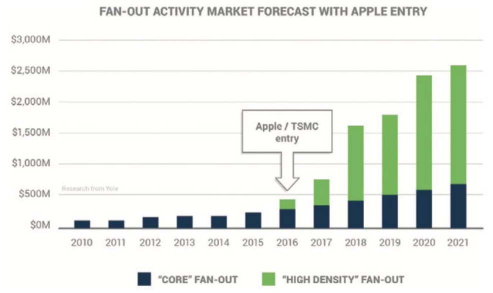

Fig. 1. Fan-out activity revenues forecast breakdown by fan-out market type.

Warpage of 2mm or more will need to be routinely handled. Additionally, the metrology system must be able to measure on product wafers, thus requiring a non-contact, non-destructive system capable of measurements on small structures [5].

Picosecond ultrasonic (PULSE™) metrology is a workhorse for metal film thickness measurements in front-end wafer fabs, and has proven capability for measuring RDL, and UBM layers, among other applications. We previously [6]-[7] discussed the configuration changes that were made to adapt the technology to meet growing metrology needs in advanced packaging, by integrating a high resolution visible reflectometer for resist measurement and enhancements to vision system to provide dimensional information about the structures. In this paper, we discuss the challenges of measuring the thick, rough RDL films, as-plated and post etch processes. Post etch thickness measurements are critical to the RDL performance as they provide insight into the final electrical test performance. These wafers posed measurement challenges and in order to meet P/T <10, extensive averaging was required making the measurements prohibitively slow for high volume manufacturing. We present details of the hardware modifications and illustrate the improvements by comparing performance between the standard configuration vis à vis the new configuration. Additionally, results from successful measurements of thinner RDL (<2µm) lines are included to demonstrate the readiness of the technology for high density, fine pitch processes.

II. Measurement Methodology

Picosecond ultrasonic metrology 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.

The optics schematic of this technology is shown in Fig. 2. The system uses a pump-probe setup. A 0.1ps laser pulse (pump) is focused to about 5×7μm^2 spot onto a wafer surface to create a sharp acoustic wave. The acoustic wave then travels away from the surface through the film at the speed of sound. At the interface with another material, a portion of the acoustic wave is reflected and comes back to the surface while the rest is transmitted. When the reflected acoustic wave reaches the wafer surface, it is detected by another focused laser pulse (probe) which was diverted from the pump pulse by the beam splitter. There are two different methods of detecting the reflected acoustic wave at the surface. The first method is to detect the change of optical reflectivity that is caused by the strain of acoustic wave. The second method is to detect the deflection of reflected probe beam that is caused by the deformation of surface due to the acoustic wave. The second method requires a position sensitive detector (PSD) and is described in detail elsewhere [8].

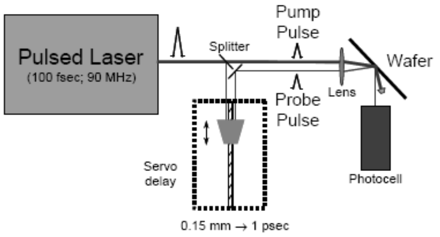

Fig 2. Schematic representation of PULSE™ technology setup.

The servo-delay controls the time difference between pump and probe, which allows us to measure the round trip travel time of the acoustic wave within the film. Combining this with speed of sound in the material, one can readily calculate the thickness of the film using the following equation (1);

$$d = (v)(t)/2 \qquad (1)$$

where d is the film thickness in Å, v is the speed of sound in the material in Å/ps and t is the transit time in ps.

Thickness, thus measured, is based on first principles using the round trip transit time of the acoustics through the film using known speed of sound in the material without the need for calibration standards or reference wafers. The technique provides accurate measurement of metal films, single or multi-layers ranging in thickness from 40Å to 12µm. RDL lines (dense, isolated) structures are easily characterized. The technique, as noted previously, has been used qualitatively to report roughness values of several thick, rough films such as aluminum, tungsten or as-plated copper. However, in advanced packaging applications, depending on the process, films are generally much rougher and coarse grains can create some challenges.

In the standard configuration, described in the preceding section, the pump beam is modulated at

5.5MHz while the probe beam is unmodulated. The signal is demodulated at the same frequency as the pump beam modulation frequency. The rough surface of Cu RDL scatters the measurement beams excessively thus increasing the noise and reducing the overall signal to noise ratio (SNR). To overcome some of the challenges of the rough surface in the standard configuration, site averaging was performed by adding additional measurement sites (minimaps) to average the local surface roughness with impact to throughput.

In this study, we explored a modification to the tool configuration and studied its effect on the rougher RDL wafers. The pump beam was modulated at 5 MHz, the probe beam was modulated at 0.5 MHz and the signal demodulated at 5.5 MHz. Any scattering from both pump and probe beams were filtered out. Wafers with different RDL lines/space combinations, ranging from 1µm to 5µm, including different structures such as isolated pads, isolated lines, pad arrays, and line arrays were tested using this configuration. The accuracy of results was validated by comparing the picosecond ultrasonic results to cross-section scanning electron microscopy (SEM). Selected results from the study is presented in the following section.

III. Results and Discussion

Shown in Fig. 3 is the raw data of change in reflectivity vs time for a 5µm Cu RDL line using standard configuration as well as a dual modulation configuration for identical measurement conditions including local site maps. There is a significant improvement to signal to noise. Load/unload repeatability performance evaluated for both the data sets showed a 5X improvement in repeatability performance for the dual modulation configuration. Average 3 sigma standard deviation for the dual modulation configuration was <0.2% compared to ~1.0% for the standard single modulation configuration (Fig. 4). Since the performance with dual modulation was well within the metrology budget, we next evaluated the trade-off between repeatability and throughput by optimizing the measurement control settings such as stage sweeps and eliminating the local site maps. Raw data comparison of the dual modulation configuration with optimized measured control and dual modulation configuration with original measurement control is shown in Fig. 5. While the signal to noise is marginally lower, we were able to obtain a 9x improvement in throughput while maintaining gage capable repeatability performance.

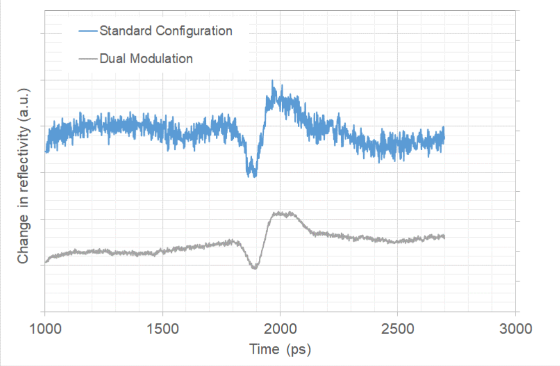

Fig 3 Raw data comparison between standard configuration and dual modulation configuration. Significant improvement in signal to noise ratio is readily apparent.

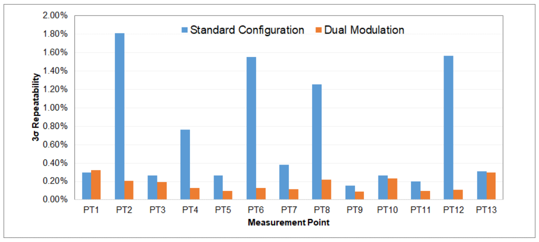

Fig 4. Repeatability performance comparison of 5µm Cu RDL using standard configuration and dual modulation configuration.

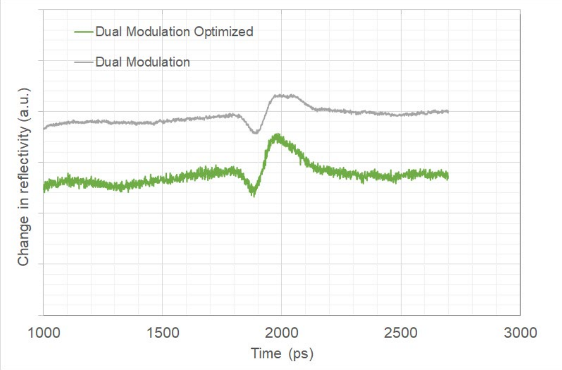

Fig 5. Dual modulation configuration optimized for throughput (green) compared to dual modulation baseline.

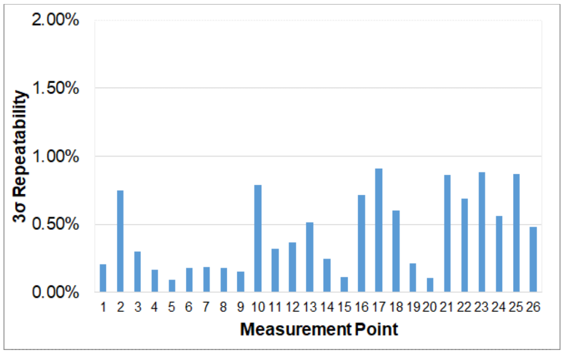

Fig 6. Repeatability performance of Cu RDL structures using dual modulation configuration with optimized measurement control. Shown in x-axis are an assortment of different structures varying from 1µm-5µm RDL.

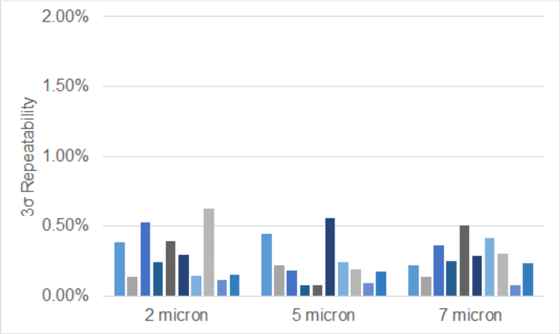

Fig 7. Repeatability performance of dense RDL structures, varying line width. 3sigma repeatability is well within the requirement for a metrology tool.

Shown in Fig 6 is the repeatability performance of the dual modulation at the faster measurement speed. The x-axis represents an assortment of different structures-pads, isolated lines and line arrays. Difference in performance between the sites is attributed to positional/placement inaccuracies on the isolated lines. This was confirmed by performing subsequent tests using site by site pattern recognition to improve the positional accuracy with minimum impact to throughput. Shown in Fig. 7 is load/unload repeatability tests for dense RDL lines. The 3 sigma repeatability test at site level is < 0.5% on most of the sites. This more than adequately meets the process requirement.

SEM cross section was performed to verify the accuracy of the picosecond acoustic measurement for RDL thickness measurement. Fig 8 shows the comparison of the picosecond thickness with cross-section SEM. The average thickness for the 9 wafers compared shows excellent correlation and the mismatch delta between the technologies is <2%. This difference is within the experimental error of sample location and the underlying differences between the technologies. A correlation equation can be applied to match to the SEM data, if better accuracy is required.

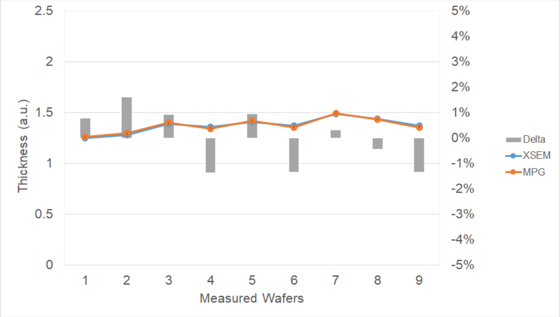

Fig 8. Correlation between PULSE measurements and X-SEM on Cu RDL structures. Mismatch across the wafers is < 2%

IV. Conclusion

We have continued to make inroads into the advanced packaging applications space with the PULSE technology. Our previous studies have demonstrated gage capable repeatability and accuracy of the technology for UBM and Cu RDL thickness measurement. With the implementation of dual modulation, we have shown the capability of the technology to handle measurements on extremely rough and challenging RDL lines. The dual modulation technique's improved SNR allowed for faster measurements (up to 9x) and met both repeatability and throughput requirements for the high volume manufacturing environment. The configuration is user selectable and is a part of the recipe set up process providing the flexibility needed to optimize for both performance and throughput. Additionally, we also demonstrated the readiness of the technology to measure 1µm RDL lines with excellent correlation to cross-section SEM.

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