Non-Destructive Characterization of CMP Pads Using Scanning Ultrasonic Transmission

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Abstract. An automatic scanning ultrasonic transmission (UST) technique was developed and applied to non-destructive metrology and analysis of visco-elastic properties in full-size chemical mechanical planarization (CMP) pads prior to their use in CMP processing. The system is comprised of a specially designed ultrasonic transmitter as an emitter of acoustic vibrations and an ultrasonic probe as a receiver. Both, the transducer and the probe are positioned on the moving X-Z stage, while the circular pad is attached to a rotary motor. The probe is aligned with the center of the transmitter and measures with high accuracy and repeatability the amplitude of the transmitted ultrasonic vibrations through the pad at a pre-selected depth in the pad in the contact mode or at a certain elevation above the surface using non-contact mode. The UST system is computer controlled and fully automated. Inhomogeneity of commercial pads with a diameter up to 32" were revealed and analyzed. Typical UST map exhibits almost regular stripes of high and low acoustic transmission, which are superimposed with global inhomogeneity where the UST amplitude changes circumferentially. Aside from the UST mapping, the system allows for the study of visco-elastic behavior of pad components using UST transient curves.

As device dimensions shrink in the integrated circuit industry, tolerances also shrink. In this respect, Chemical Mechanical Planarization (CMP) technology becomes a critical step for state-of-the-art microelectronics. A more thorough understanding of the process and the ability to model it are paramount if progress is to be maintained at the current pace. This paper addresses the problem by introducing a nondestructive characterization technique to one of the major CMP consumables – CMP pads. The mechanical properties of the pads used in CMP technology can be determined by various methods, all of which are, to date, destructive in nature. The pads have been modeled by examining samples cut from full pads rendering them useless for production purposes. One of these methods extensively applied to pad material characterization utilizes dynamic mechanical analyses [1]. This technique assesses the dynamic shear modulus of samples cut from a whole pad. Evidently, this approach is unacceptable for characterization of CMP production pads due to its destructive nature. The need for a nondestructive characterization of full-size CMP pads has become apparent in recent years. Uncontrollable variations in removal rate and planarization results from pad to pad are creating difficulties in optimizing procedures. A nondestructive metrology is required to examine the pads on an individual basis.

In this paper, we present a new experimental approach utilizing a transmitted ultrasound signal to determine how the mechanical properties of the pad vary over its geometry. With regard to CMP pads, sending an ultrasonic wave through the pad and measuring the change in transmitted signal at different spots, one can create a UST map of the underlying pad structure. The UST amplitude can be monitored as a function of time, height above pad and depth below its surface (application of compression) at different transmitted frequencies. This picture may be correlated with the pad life and performance in order to predict these variables. This could increase yield by reducing the number of rejected wafers as the pad ages prematurely or

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lengthen production time by indicating which pads have more desirable properties.

UST MAPPING SYSTEM

The ultrasonic transmission (UST) system developed at the Center for Microelectronics Research is comprised of two key elements: (1) a resonance circular piezoelectric transducer as an emitter of acoustic vibrations of selected amplitude and frequency, and (2) an acoustic probe as a receiver of ultrasonic vibrations (Figure 1).

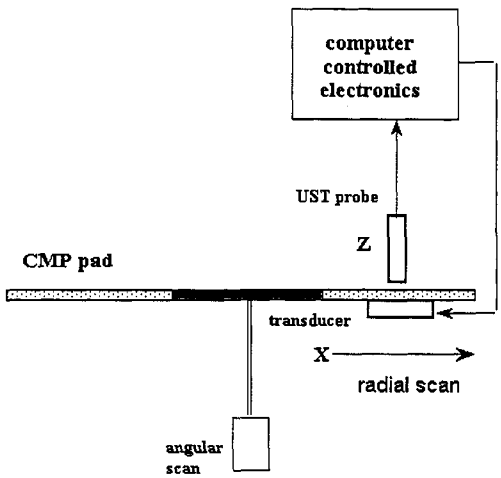

FIGURE 1. A schematic of the UST system for scanning diagnostics of full-size CMP pads.

Both, the transducer and probe are aligned and can be moved synchronously in the X-direction performing radial scans on full-size CMP pads. The transducer operates at approximately 26 kHz, which is the first resonance frequency of its radial vibration mode. The transducer is designed in a way that the pad can be pressed against its surface by a vacuum contact. This mechanical contact provides a reliable transfer of acoustic energy from the transducer to the pad. The acoustic probe is attached to the Z-stage and positioned with an accuracy of a few microns above the pad. In the UST mapping regime, the probe can move vertically in the Z-direction relative to the transducer, aligned with its center. A circular pad is inserted between the probe and transducer and is attached to a rotary motor and held flat by a support table. A programmable function generator and wide-band amplifier drive the transducer. The UST amplitude from the probe is monitored by a lock-in amplifier, synchronized by frequency and phase with a reference signal from the function generator. A step-motor controller provides three independent but synchronized movements in the system:
(1) movement in the X direction for the transducer-probe combination, (2) in the Z direction for the probe and (3) an angular movement of the pad. An electrically actuated vacuum control valve driven by a programmable power supply provides release and reapplication of the vacuum, which is used for mechanical coupling of the transducer and CMP pad. The UST amplitude was measured at an appropriate probe-to-transducer separation, which was determined for each pad and held constant for the duration of that pad's mapping. This would put the probe at approximately the same depth below the surface of the pad for each point measured.

The CMP pads used in this study consisted of a dual layer construction. The bottom layer (Suba IV) is felt, impregnated with polymers. The top layer (IC1000) is formed by use of urethane beads placed in a mold, cooked and then cured. By varying the curing time and temperature different mechanical characteristics can be achieved, such as variation in the visco-elastic behavior of the pad.

RESULTS

The UST amplitude depends upon the distance between the transducer and the probe. In Figure 2, we present a typical depth dependence of the UST amplitude versus Z-coordinate of the

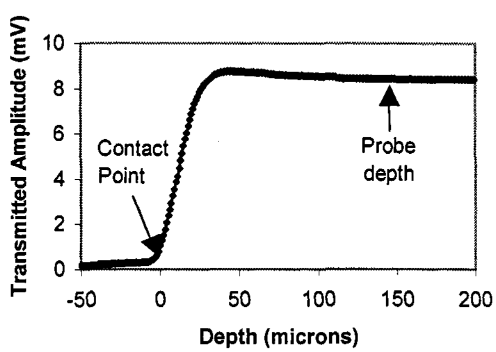

FIGURE 2. A dependence of the UST amplitude versus probe-to-pad distance. Positive x-values correspond to a physical contact between probe and pad. Depth selected for UST mapping of 150 μm is indicated by vertical arrow.

probe. The zero point in the graph represents the point of physical contact between the probe and pad surface. The contact point is characterized by a steep increase of the acoustic amplitude when the probe approaches the pad. This depth behavior of the UST amplitude was utilized for a control, within an accuracy of a few microns, of the contact point. For the UST mapping the probe penetrated into the pad at a constant depth of 100μm below the contact point. By measuring the UST signal at different probe depths we documented that this depth was sufficient to avoid an influence by the pad's thickness variation no the topography of the UST mapping. This result is presented in Figure 3. It is obvious that the acoustic amplitude measured close to the contact point reflects an inhomogeneity in the pad thickness. By going 100 μm into the pad's bulk and deeper, we found the UST amplitude no longer depends upon the contact point variation but rather reflects a profile of the acoustic properties of the pad. This is shown in Figure 3 as the two UST line-scans measured at 100 μm and 345 μm probe depth which have essentially the same distribution.

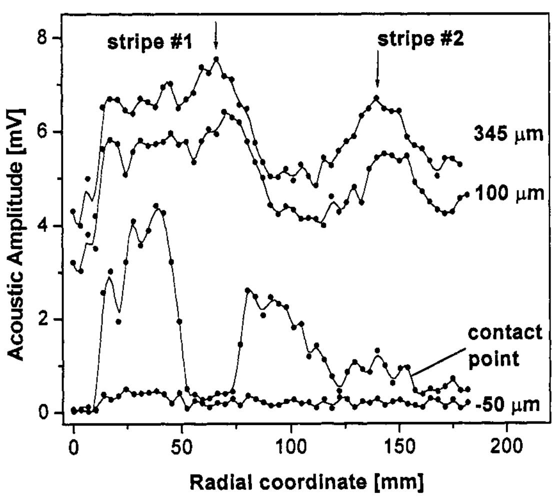

FIGURE 3. Radial scans of the UST amplitude measured at different depth of the probe below the contact point.

An interesting property of CMP pad is exhibited by the transient behavior of the UST amplitude. In Figure 4 we show a variation of the signal versus time of data collection after the probe started measurements at 100μm below the contact point on two different IC1000 samples. The transient behavior can be satisfactorily fit with a double exponential curve, and can be accounted for by the viscoelastic property of the polyurethane [1]. The analyses of the UST signal transient in a scanning mode yields an access to non-destructive mapping of the pad's viscoelasticity, which is another critical parameter in CMP processing.

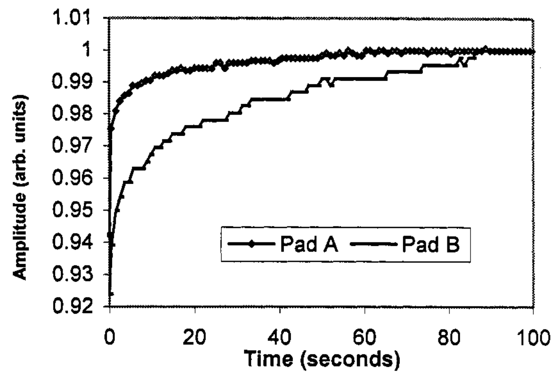

FIGURE 4. Transient behavior of the UST amplitude measured on pads with different IC1000 layers.

In Figure 5, we presented one of the UST maps measured on a full sized toroidal (donut shaped) commercial CMP pad with a 32" outside diameter and 15" inside diameter. The automatic procedure for UST data collection consisted in a set of radial scans with the transducer and the probe moving synchronously in the X-direction of the pad radius with 7 mm step. These radial scans were intermitted by an angular rotation of the pad. The first quarter, from the 12 o'clock position to the 3 o'clock position, was measured with 1-degree angular steps to gain a high-density picture. The remaining three quarters were measured with 3-degree angular steps. The total number of data points was 5,520 per individual map. In this manner we have measured a set of 24 dual-layer pads with different specific gravity of the IC1000 top layer. A typical map consists of similar oriented stripes of high and low UST amplitude with inter-stripe distance of 80 to 100 mm. By mapping the individual components of CMP pads, Suba IV and IC1000, we have found that stripes of the acoustic amplitude are observed only on the Suba IV layer, while the IC1000 contributes to a global circumference distribution of the acoustic transmission amplitude.

An important result of the UST mapping study is that the pads show a substantial variation of UST amplitude both within an individual pad and also between the pads. Specifically, the average amplitude of the UST transmission varies between 8.1% and 14.7% in a set of 24 pads with identical geometry.

One of the reasons for such variation is a change of the IC1000 density, which was intentionally introduced as one of Design of Experiment parameters. It is known that pad density strongly contributes to the CMP processing results. Alternatively, a spatial variation of pad elastic modulus and viscosity coefficient could account for observed inhomogeneity of the UST amplitude across the pad. This allows the suggestion that UST amplitude mapping can be a sensitive tool to assess a global variation in CMP pad elastic-mechanical properties.

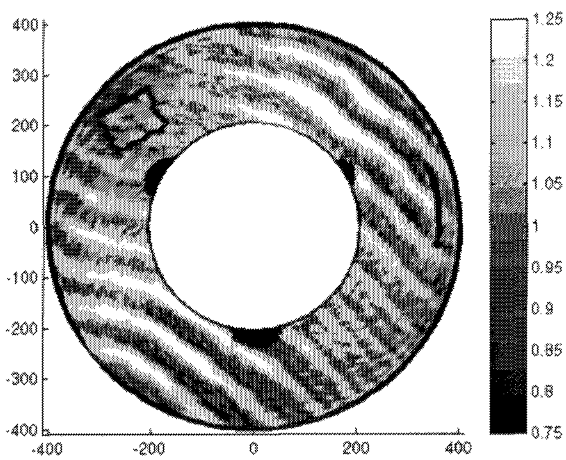

FIGURE 5. UST map of 15"x32" full size dual-layer CMP pad. The UST amplitude is normalized to the average value of 16% in the particular pad. This UST amplitude is expressed in percentages to transmission of single-side polished Cz-Si wafer. The rectangular feature in the upper left corner is the manufacturers label on the under side of the pad.

CONCLUSIONS

Ultrasonic Transmission diagnostic for CMP pads offers non-destructive analyses of pad material including full-size pad metrology. The technique shows promise and versatility specifically capability to scale up to any pad geometry and size. Such parameters of the pad components as density, elastic modulus, and viscosity can be analyzed.

ACKNOWLEDGEMENTS

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