New Generation CMP Equipment and its Impact on IC Devices

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Abstract

This paper will review and report advancements in new generation CMP equipment (MIRRA® CMP equipment) development for different CMP applications in IC fabrication: SOI, silicon/polysilicon, shallow trench isolation (STI), oxide (PMD and ILD), W, Cu, Al. The impact of new generation CMP equipment on IC device fabrication and its performance will also be discussed.

Introduction

New generation MIRRA® CMP equipment utilizes 4 heads and 3 platens for higher productivity in terms of wafers per hour per ft^2. Different processes (by varying parameters such as pressure, rotation speed, slurry, pad) can be employed on each platen for process flexibility and potentially wider process windows. Among many advancements in new generation CMP equipment development are polishing head design, endpoint system design, and pad conditioner/disk design.

New Polishing Head Design

The challenge in polishing head design is to assure superior process performance (low non-uniformity, high removal rate, low defects, good head-to-head matching, and low-pressure/ high-speed capability), short qualification time, and low cost of ownership. Conventional polishing heads use a rigid plate, covered with carrier film, to apply a pressure to the wafer backside-surface. Since the pressure is transmitted to the wafer via the carrier film, the pressure distribution on the wafer backside-surface is, in part, determined by the properties of the film. Changes in carrier film properties over time can cause a drift in polishing performance and lead to poor head-to-head matching. A new polishing head (TITAN HEAD™) design features a flexible membrane that applies a uniform pressure to the wafer's backside. In the new design, a retaining ring with independent pressure control is used to modulate the removal rate at the edge of the wafer.

By controlling the retaining ring pressure, a significant improvement in within-wafer (WIW) and wafer-to-wafer (WTW) non-uniformity (NU) is achieved. Results of experiments designed to study the influence of retaining ring pressure and rotational speeds on WIWNU, demonstrate that superior process performance is achieved by optimizing these parameters. The influence of the rotational speed on the WIWNU is different for different retaining ring-to-membrane pressure ratios (retaining ring pressure over membrane pressure). Consistent with literature reports based on conventional heads, the polishing removal rate is a function of rotational speed, pressure, slurry flow rate, as well as other parameters. Optimization of these parameters has led to robust processes for different CMP applications which have been crucial to fabricate different sub-half micron IC devices for needed photo (depth of focus) budget, low defect density, reliable global and local interconnects, and area economic effective isolation.

Using a new retaining ring AEP™ design in an extended run of 800 wafers, excellent WIWNU (average 2.0% 1 sigma, upper control limit 4.0% 1 sigma, 5 mm edge exclusion, 200 mm wafers), WTWNU (2.6% 1 sigma), high average thermal oxide removal rate (4053 A/min.), and low defect density (0.06 defects of >0.25u per cm^2) were achieved. As compared to the previous design, the new generation retaining ring significantly reduced both the qualification time and the defect density.

New Endpoint System Design

Commonly-used metrology for endpoint measurements in CMP is either *ex-situ* or *in-situ*. The former has an adverse impact on throughput. The latter faces the challenge of lower measurement accuracy, complex signal analysis and potentially-limited reliability.

The new endpoint system, in situ rate monitor (ISRM™ system), is a non-contact and laser-based device. It detects the endpoint by measuring the relative thickness changes of thin film layers and stops polishing when the required amount of a film is removed. The new end point system records the optical signal which correlates to the change of thickness of the film being polished. An optical signal pattern recognition algorithm ensures successful endpoint detection after processing the optical signals which exhibit reproducibility for a given type of wafers.

The new endpoint system exhibited 100% successful rate in detecting the endpoint on IC production lines for STI CMP regardless of polishing removal rate and initial film thickness variation. It has also successfully applied to W CMP, polysilicon CMP, SOI CMP, oxide (PMD and lower level ILD) CMP in IC production. Its feasibility for Cu and Al CMP has also been demonstrated in R&D facilities of IC manufacturers. The new endpoint system ensures successful CMP for STI, Cu, Al applications by minimizing over-polishing, thereby minimizing dishing and erosion and thus potentially reduces the defect density on IC devices which will ultimately lead to increased device reliability and improved die yield. As compared to polishing by time, polishing by endpoint increases the tool availability and throughput by better controlling the wafer-to-wafer film thickness variation and reducing rework. The

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need for monitor wafers is also reduced, thereby improving availability and lowering cost-of-ownership (COO).

New Disk/ Pad Conditioner Design (1)

Four different pad conditioning approaches have been reported in the literature to improve polishing performance. The first approach is dressing/eroding the polishing pad with an abrasive disk which typically uses diamonds embedded in a substrate. Many disk manufacturing processes have been reported to solve the problems associated with the diamond loss and substrate corrosion.(2) However, little extended-run and production data have been reported. Improved polishing performance has also been reported by process optimization, such as by optimizing speed and dwell time to control pad topography.(3-4) The second approach is vacuum-cleaning the pad.(5) More data is needed to evaluate this approach as compared to other approaches. The third approach is vibrating the pad with ultrasound.(6) This approach has yet to be developed to show better uniformity and edge exclusion than those achieved on a lapping tool. The fourth approach is cooling the pad during polishing. This approach has been implied by the investigations on the polishing rate as a function of temperature. Little data has been published.

The new disk in our work was fabricated by using a proprietary high temperature Ni-Cr brazing process which enhances the bonding of evenly distributed 100-grit diamond crystal particles with the Ni-Cr matrix on a stainless steel disk. The new disk mounted on a new pad conditioner (PC) was evaluated as compared to a conventional disk widely used in industry. The comparison studies were carried out by using the process parameters optimized through designed experiments. The results showed that the conventional disk was losing diamonds during polishing and the lost diamonds caused significant wafer scratching. The disk life was 15 hours (900 wafers). In contrast, the new disk increased disk life more than 3 fold (50 hours and 3000 wafers) at a low non-uniformity (<5%), a small edge exclusion (3 mm), a stable removal rate, and the low defect counts which are comparable to those using the conventional disk with all other variables kept constant (see Figure 1). The pad life using the new disk/PC was more than doubled at 3 mm edge exclusion (1200 wafers, Figure 2) as compared to the conventional disk (500 wafers, Figure 3). When the new conditioning disk was used (Figure 2), the pressure was increased to compensate a lower removal rate which is characteristic for the new disk at a low pressure (4/4.6/4 psi membrane/ retaining-ring/inner tube). Significant improvement of disk/pad life and polishing performance by using a new pad conditioning disk have also been achieved in extended-run tests and beta-site tests at different IC production fabs.

Scanning electron microscope (SEM), optical microscope, and profilometer have been employed in evaluating the morphology/topography of the new and conventional disk and the pad before and after polishing for varying length of time to understand the mechanism of the improvement of polishing performance by the new disk. Improved disk life and uniformity are attributed to improved flatness of substrate (Ni-Cr) and better process control in both distribution/orientation of diamond grains and their adhesion to the substrate. A SEM picture of the new diamond disk is shown in Figure 4A. The uniform diamond distribution/orientation and the stronger adhesion force between diamond and Ni-Cr matrix assured even pressure during conditioning and complete elimination of diamond loss which could cause scratching on wafers and have negative impact on die yield. Figure 4B showed that there was no diamond loss at the end of disk life for the new disk. In contrast, the conventional disk has some protruding diamond particles above the diamond plane formed by majority of diamonds as shown in Figure 4C. The protruding diamond particles were created by the irregular distribution of irregularly shaped diamonds and the inconsistent diamond orientation in the electroplated Ni matrix (substrate) or by a warped disk. As a result, the loss of the protruding diamond and/or the diamond weakly-bonded to Ni matrix is unavoidable during polishing for the conventional disk. Improved pad life was attributed to even pad wear during the in-situ pad conditioning assured by the new disk/PC.

Conclusion

Advancements in new generation MIRRA® CMP equipment development play an important role in ensuring successful CMP processes for different applications in IC fabrication: SOI, silicon/polysilicon, shallow trench isolation (STI), oxide (PMD and ILD), W, Cu, Al.

The new polishing head (TITAN HEAD™) design with a new AEP™ retaining ring ensures superior process performance (low non-uniformity, high removal rate, low defects, good head-to-head matching, and low-pressure/ high-speed capability), short qualification time, and low cost of ownership. The new endpoint ISRM™ system design ensures successful endpoint detection for different CMP applications: STI, W, polysilicon, SOI, oxide (PMD and lower level ILD) in IC production. Its feasibility for Cu and Al CMP has also been demonstrated in R&D facilities. As compared to polishing by time, polishing by endpoint increases the tool availability and throughput by better controlling the wafer-to-wafer film thickness variation and reducing rework as well as monitor wafers. Polishing by endpoint also reduces dishing and erosion for STI, polysilicon and metal CMP, hence potentially reduces defect density and increases device reliability and die yield. The new disk/ mounted on the new pad conditioner extended disk life more than 3 times at an excellent non-uniformity (<5%), edge exclusion (3 mm), a stable removal rate as compared to the conventional disk widely used in industry today. The pad life with the new disk/pad conditioner was more than doubled at 3 mm edge exclusion as compared to the conventional disk.

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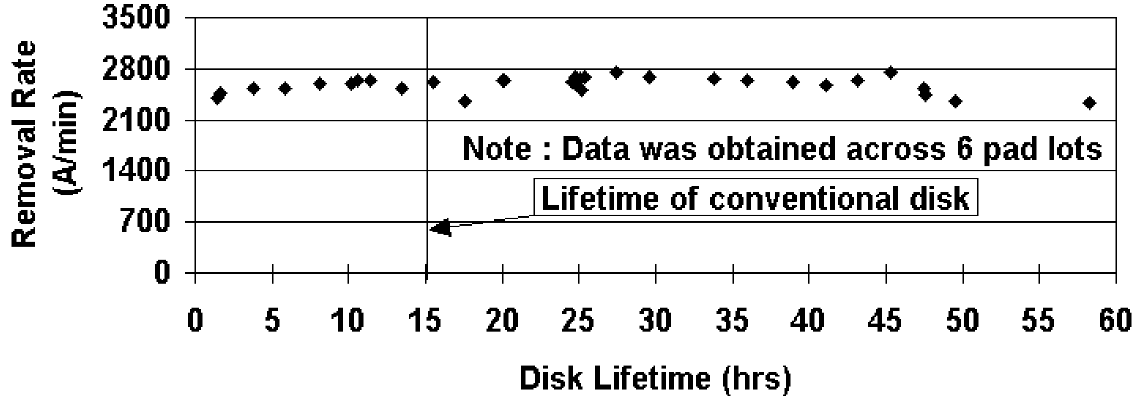

Fig. 1. Thermal oxide polishing removal rate as a function of disk life for a new conditioning disk. Pressure (psi): 4/4.6/4 membrane/retaining-ring/inner tube. (1) Speed (rpm): 93/87 platen/head. Slurry: SS12. Slurry flow rate: 200 ml/min. Pads: IC-1000/Suba IV, K-groove and 50 mm thick.

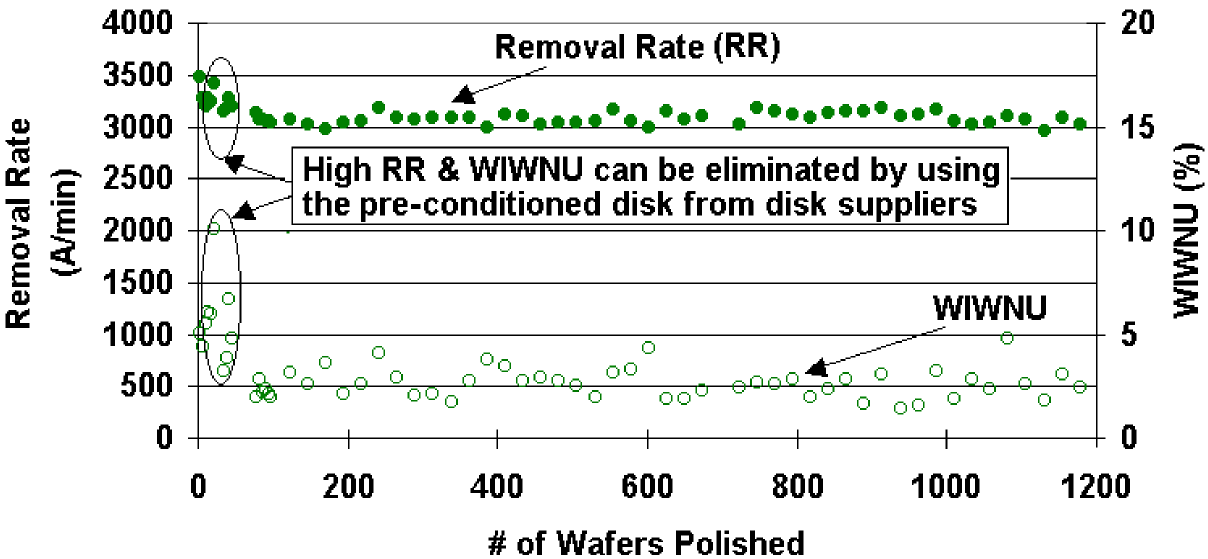

Fig. 2. Thermal oxide polishing removal rate and within wafer non-uniformity as a function of number of wafers polished using a new conditioning disk.(1) Pressure (psi): 5/5.8/5 membrane/retaining-ring/inner tube. Others: the same as Fig.1.

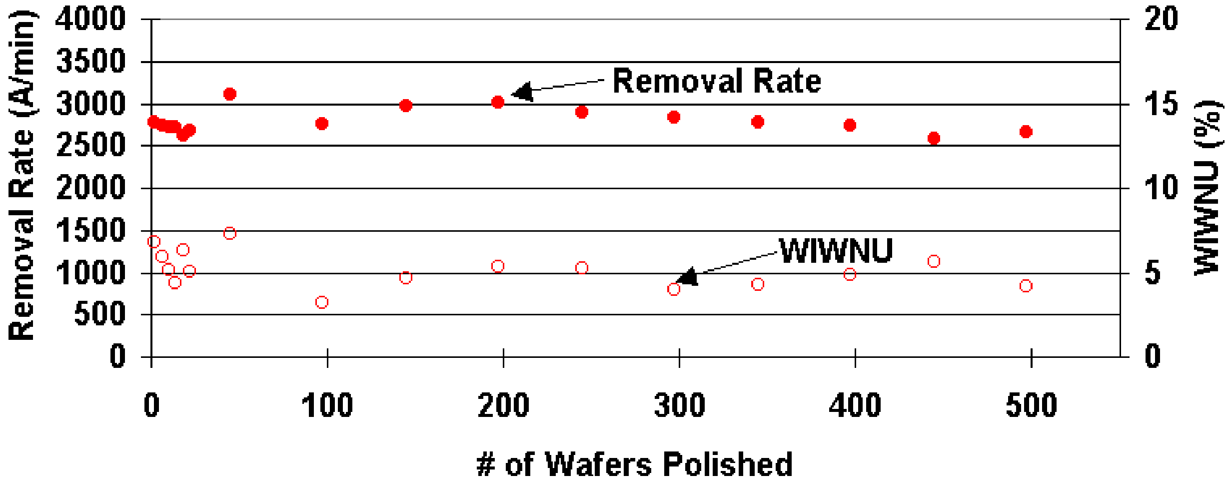

Fig. 3. Thermal oxide polishing removal rate and within wafer non-uniformity as a function of number of wafers polished using a conventional conditioning disk.(1) Pressure/others: the same as Fig. 1.

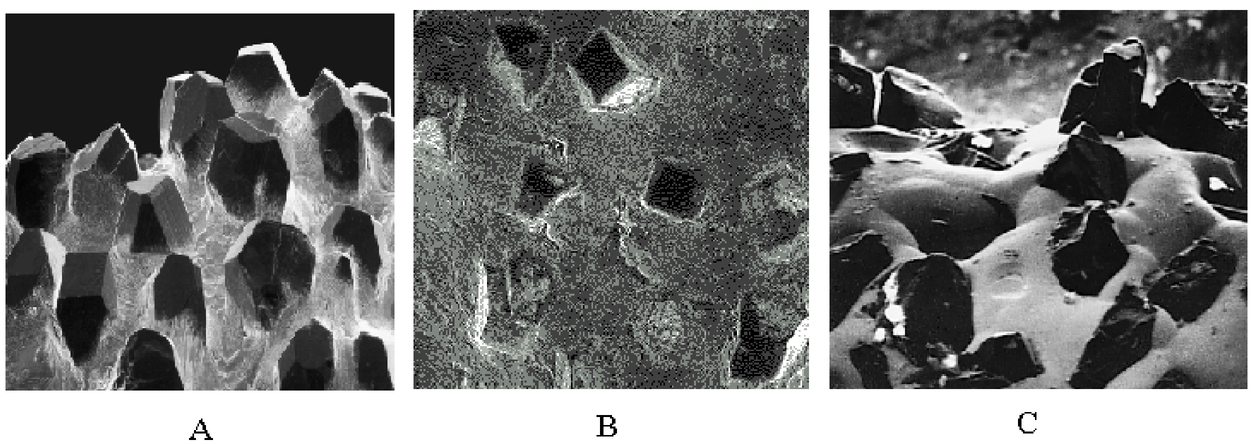

Fig. 4. SEM micrographs of a new diamond disk (tilted view) before pad conditioning [A], a new diamond disk (top view) after pad conditioning [B], and a conventional diamond disk (tilted view) before pad conditioning [C]. (1)