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Investigation of Pad Deformation and Conditioning During the CMP of Silicon Dioxide Films

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An understanding of different aspects of chemical-mechanical polishing (CMP) is sought with emphasis on the polish pad degradation and conditioning during the polishing of silica films. *In situ* and *ex situ* conditioning have been compared. *In situ* conditioning has proven to yield higher removal rates with improved, within wafer uniformities. Some of the factors contributing to the pad deterioration such as the conditioning tool down force, tool speed, and the type of solubilizing ions in the slurry is examined. The dependence on diamond particle sizes, nickel plated on to the conditioning discs, is discussed. The extent of pad wear caused by all of the above factors has been quantitatively determined and presented.

Key words: Chemical-mechanical polishing, oxide films

INTRODUCTION

The increased complexity of current and future generation microelectronic devices demands fabrication of chips with multilevel interconnects. With the depth of focus requirements becoming stringent at the submicron level, achieving global planarity has become an absolute necessity to accommodate all the different metallization levels. Chemical-mechanical polishing (CMP) has the capability of achieving such global planarity over step heights of several microns.

Some of the manufacturing concerns associated with the successful implementation of CMP technology[1] are low throughput, degradation in removal rate with time, nonuniformity of material removal, high cost of ownership and high defect density. Some of these concerns can be addressed by understanding the role of pad deformation that occurs during wafer polishing. The degradation of the polishing pad is highly detrimental to the maintenance of a stable process. The pad properties are restored by a process of pad conditioning. In this report, the nature and influence of conditioning parameters on pad wear and the polish process are investigated for the case of thermally grown silicon dioxide films. The removal rates and uniformities for oxide polishing are functions of many process variables such as the machine parameters, type of polish pad, the slurry type, the polish table temperature, and the polish pad conditioning process. The stability of the removal mechanism depends significantly on the parameters used for conditioning the pad. In the following sections, the variation of removal rate and within wafer (WIW) uniformities using *ex situ* and *in situ* conditioning of the pad are discussed. Pad deformation data as a function of the conditioning tool speed and the down force are presented. The pad wear resulting from the utilization of different abrasive particle sizes and solubilizing ions are also examined. Finally, stabilization of the removal of oxide by a proper choice of conditioning parameters will be discussed.

PAD CONDITIONING

Deterioration of the pad, resulting from a combination of blockage of slurry transport channels and pad deformation, drastically reduces the rate of oxide removal during polishing. The conventional tech-

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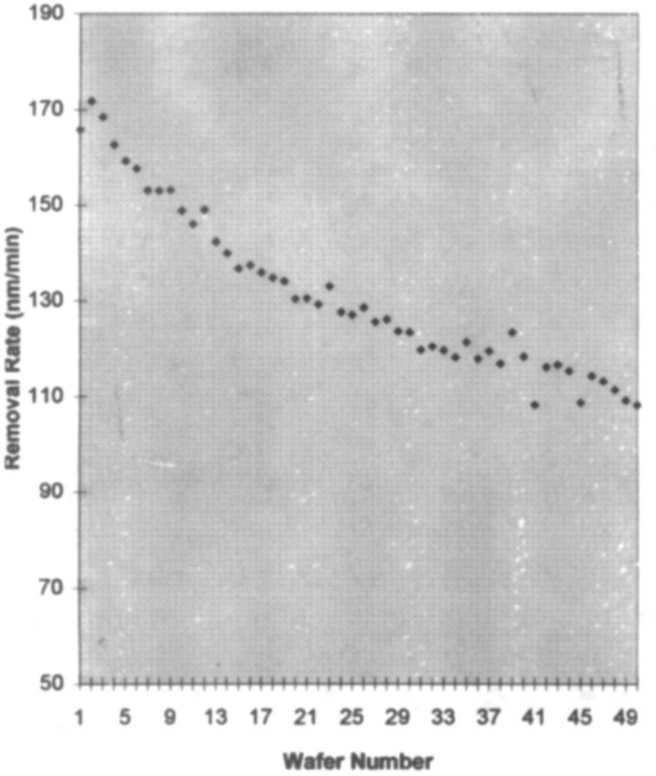


Fig. 1. Rate drop curve with no conditioning done on the pad.

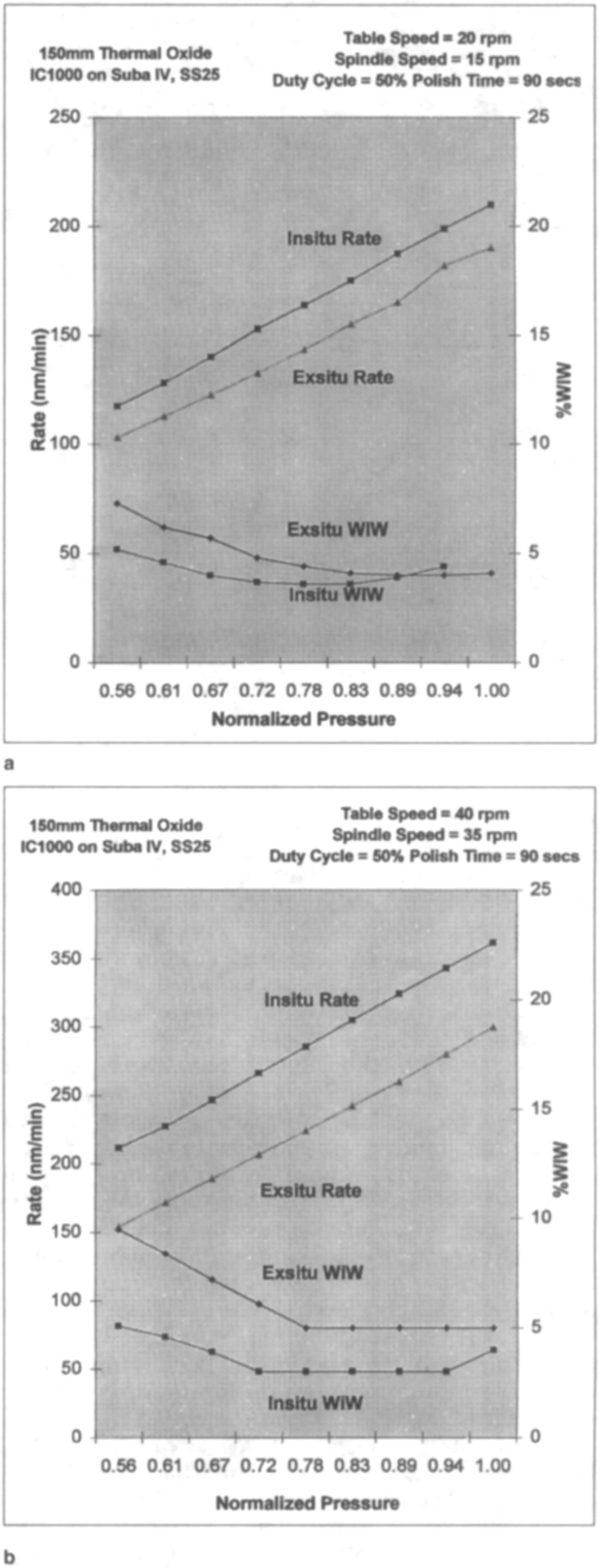


Fig. 2. (a) *Ex situ* vs *in situ* conditioning at low table and high spindle speeds, and (b) *ex situ* vs *in situ* conditioning at high table and spindle speeds.

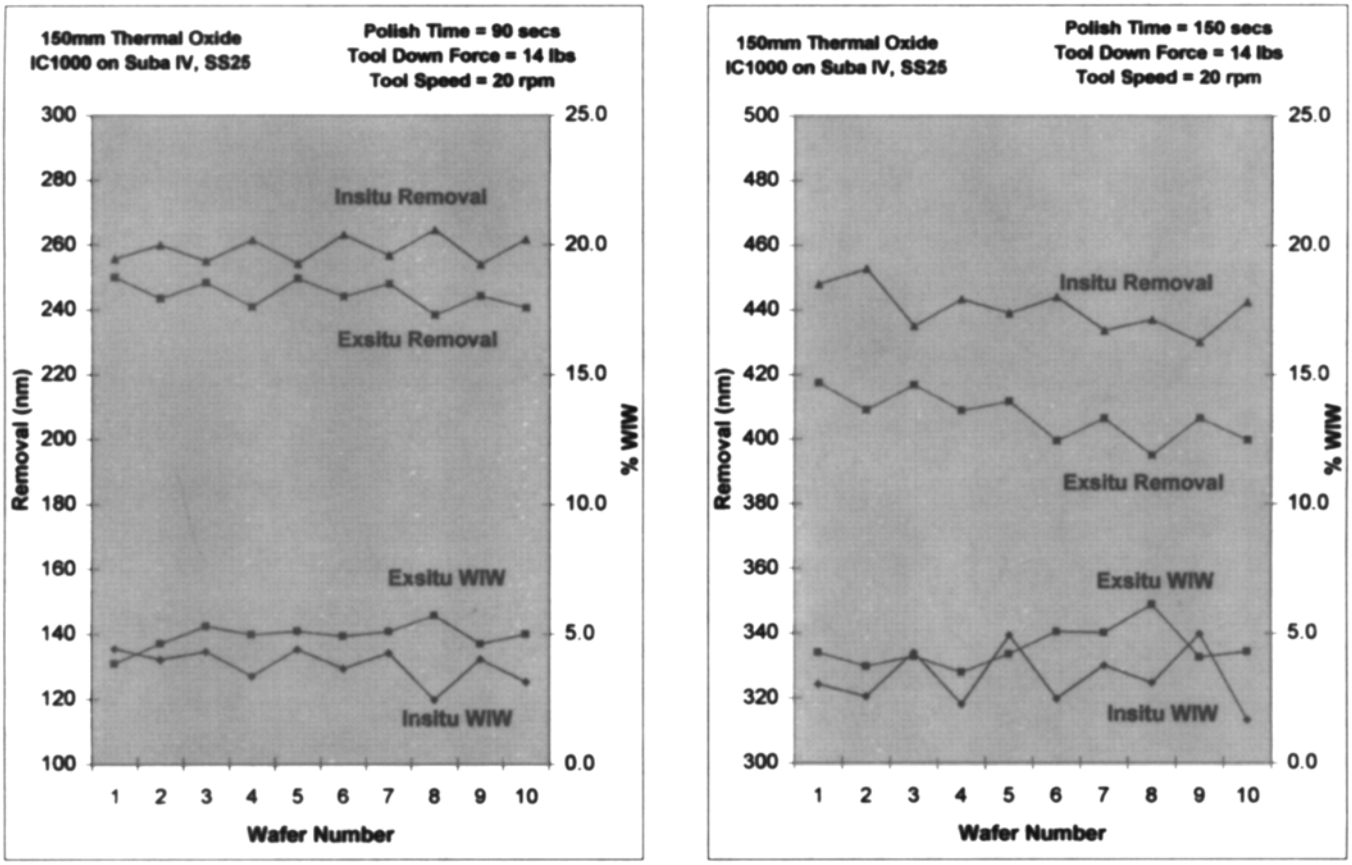
nique to circumvent this effect is to dress the pad with a conditioning tool such as a diamond disc. Typically, the oxide removal rate drops progressively as more wafers are polished with no conditioning done on the pad, as shown in Fig. 1. This drop in the rate makes it difficult to maintain a stable manufacturing process. Continuous or intermittent conditioning is utilized to restore the pad and return the removal rate to a more stable value. There are multiple approaches to pad conditioning. Two approaches are

- *ex situ* mode (conditioning done prior to or after every polish run), and
- *in situ* mode (simultaneous polishing and conditioning).

Both methods are investigated in this study and the results are compared. A pad stack of IC 1000 over Suba IV, a commonly used pad set for oxide polishing, has been used in all the experiments which were performed on a Strasbaugh 6DS-SP (dual spindle) tool.

In Situ vs *Ex Situ* Conditioning Process

To identify the interactions, if any, between different machine and conditioning parameters, a design of experiments[2] (DOE) approach was utilized. A statistical software package (RS/1) was used to generate the sequence of experiments for studying the effect of factors and their interactions on responses. The factors examined were down force, table and spindle speeds, back pressure and the type of conditioning. The response variables that were modeled included removal rates and nonuniformities across



a

b

Fig. 3. (a) *Ex situ* vs *in situ* conditioning at low polish times, and (b) *ex situ* vs *in situ* conditioning at high polish times.

the wafer surface. A set of experiments (generated by RS/1) were performed on Strasbaugh 6DS-SP planarizer first with *ex situ* conditioning. A similar set of experiments were then performed with *in situ* conditioning. The conditioning tool force and the speed of the conditioning wheel (80 grit) were maintained at 14 lbs and 20 rpm, respectively. The responses showed that pressure and table speeds have the maximum influence on the rates. The results are shown in Fig. 2a and 2b. Figure 2a shows the dependence of rates and WIW nonuniformities at low table and spindle speeds over a range of normalized pressures. Figure 2b shows the variation in rates and WIW nonuniformities for different pressures at higher table and spindle speeds. In both cases, Preston equation is satisfied with removal rate varying linearly with applied stress and velocity. The removal rates obtained with *in situ* conditioning were 15 to 20% higher than those obtained with *ex situ* conditioning Also, the WIW nonuniformities were 23 to 45% lower for *in situ* conditioning.

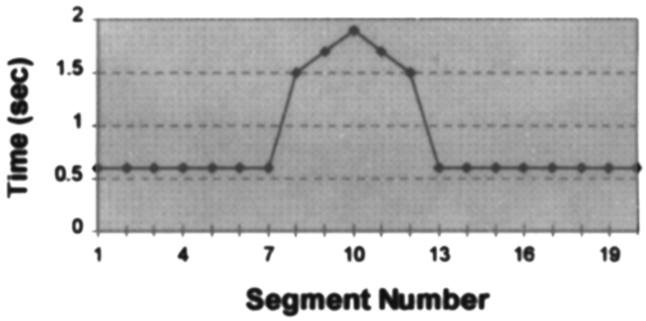


Fig. 4. Conditioning sweep profile.

Ex situ conditioning is inappropriate for long polish times. Since glazing of the pad can occur before completion of polishing and initiation of conditioning, there is an overall drop in the rate. However, *in situ* conditioning, is not subject to this limitation over long polish runs. A comparison of results from both modes of conditioning for 90 and 150 s polishes are shown in Fig. 3a and Fig. 3b. An average difference of ~14 nm in removal and about 4% WIW nonuniformities were observed for 90 s polish over five runs (i.e. ten wafers). On increasing the polish time to 150 s, the average difference in the removal increased to about 40 nm (Fig. 3b). The average WIW nonuniformities averaged between 3 and 4%.

PAD DEFORMATION

Pad deformation is known to be detrimental to process stability. Two main factors causing pad deformation, and thereby limiting the pad life of the CMP process, are pad compression and pad wear. Some of our preliminary experiments indicated that pad deformation results from pad wear caused by conditioning rather than pad compression from polishing. In other words, the contribution to pad deformation by

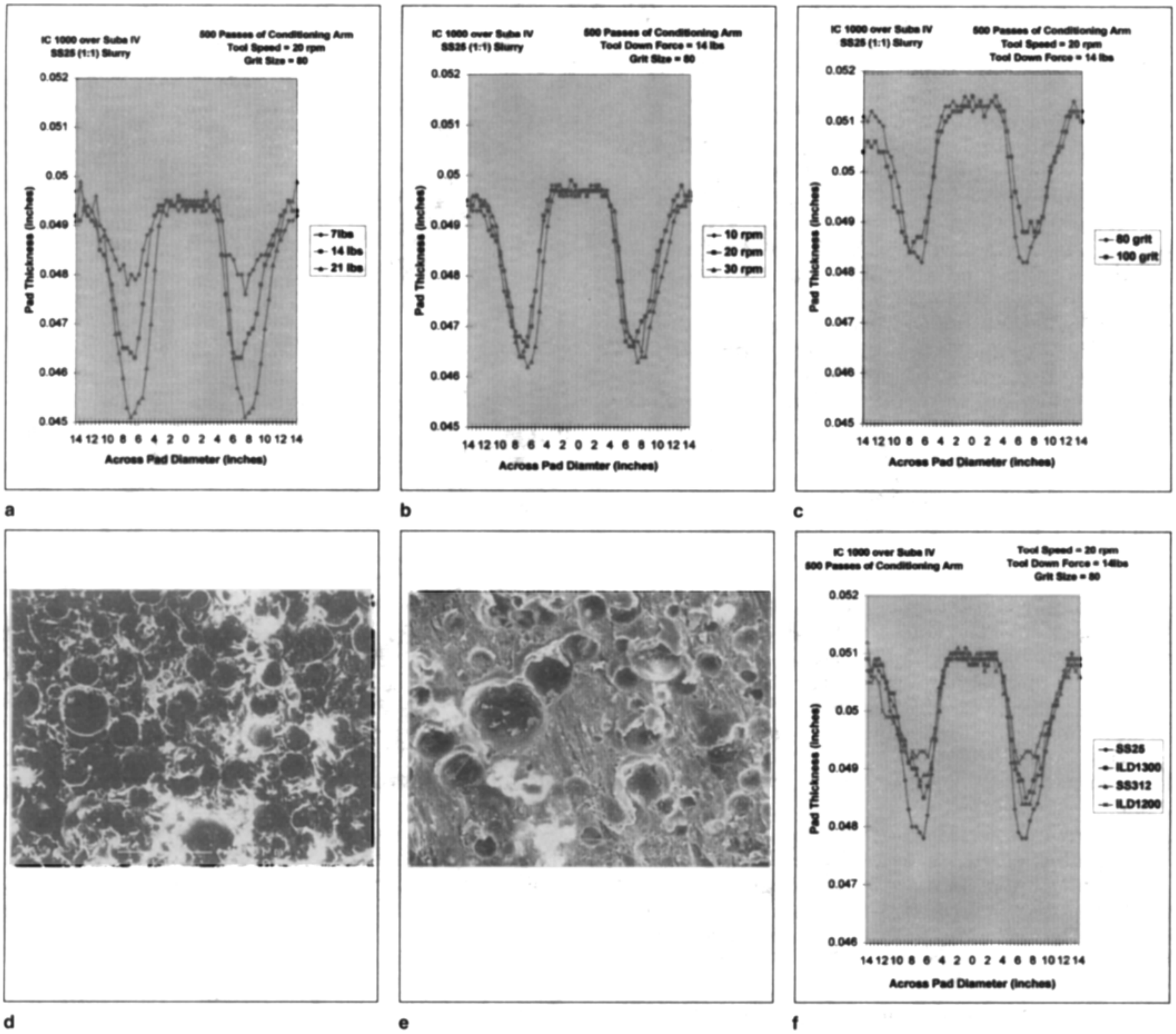


Fig. 5. (a) Pad profiles with varying conditioning down forces, (b) pad profiles with varying conditioning tool speeds, (c) pad profiles with varying conditioning tool grit sizes, (d) post polish pad conditioned with spiral diamond disc, (e) post polish pad conditioned with perforated diamond disc, and (f) pad profiles with different polish slurries.

compression was small when compared to the wear caused by conditioning. The pad conditioning profile used to characterize the extent of wear is shown in Fig. 4. This model conditioning profile is "center biased" (more conditioning at the center of the wafer track, with the dwell time near the center being approximately 2 s while the dwell time near the edges is 0.6 s). This profile was chosen so that the results of both aggressive and mild conditioning can be observed simultaneously on the same pad. There are 20 segments in this profile. The conditioning down force and the dwell time can be varied at each of these segments. For all the experiments, the down force was set to a particular value in all segments. With the table rotating, the conditioning arm sweeps the 20 segments from near the center of the pad to the edge of the pad. A 4″ spiral diamond disc (80 grit) was used as the conditioning tool. The conditioning tool was allowed to sweep 500 passes across the pad simulating a 500 wafer run. Figure 5a shows the resulting measured variation in pad wear using SS25 slurry for three different conditioning down forces. The lowest down force caused the least amount of wear. A maximum reduction in the pad thickness of 4, 6, and 10% was measured with 7, 14, and 21 lbs down force, respectively. This is consistent with the hypothesis that pad deformation is directly proportional to the applied stress.[3] Figure 5b shows the change in wear for different tool speeds. The pad profiles show smaller variations (~6% maximum) with differing table speeds.

The effect of changing the diamond particle size on pad wear was also investigated. Two different sizes, namely 80 grit (mean particle size ~175 μm) and 100 grit (mean particle size ~147 μm), spiral discs were used. Figure 5c shows the decrease in pad thickness for both discs. The wear caused by an 80 grit disc was slightly higher (~6%) than that caused by the 100 grit conditioning disc (~4%). Apart from the grit sizes, the embossed patterns on the diamond discs also affect the deformation of the pad. The scanning electron microscopy photographs of the pads conditioned by a spiral diamond disc (with 175 µm diamond particles) and a perforated (or honeycomb) disc of the same particle size are shown in Fig. 5d and 5e. The perforated disc left behind a significant blockage of polish pad pores, possibly due to under conditioning. However, the pad conditioned with the spiral disc showed no visible blockage of the pores. Thus, the particles sizes and the embossed patterns have significant effects on the resulting pad conditions (i.e. pore blockage and pad wear).

Oxide polishing is sensitive to the type of solubilizing ions present in the slurry. The removal rate is about 10% higher with SS25 (potassium based slurry) when compared ILD 1300 (ammonia based slurry). Two different potassium based and two different ammonia based slurries were examined to gauge the dependence of the extent of wear on the solubilizing ions (Fig. 5f). All the four slurries tested had similar pH, mean particle size, and solids content. SS25 caused the highest amount of wear (6%) followed by ILD1300 and SS312 (~5%) with ILD1200 causing the least wear (~3%). Interestingly both ammonia based slurries yielded the same extent of wear, while the potassium based slurries differed in the percentages of wear.

The previous sections have addressed influence of conditioning down forces and speeds, the type of slurry, and diamond discs on pad degradation. The next step was to investigate the stability of polish process. Data from an extended run done over 25 runs (or 50 wafers) are shown in Fig. 6 The machine parameters were so chosen to yield relatively high rates (greater than 250 nm/min). A potassium based slurry (SS25) was used for polishing while an 80 grit spiral diamond conditioning disc was used for *in situ* conditioning with the profile shown in Fig. 4. The conditioning down force was maintained at 14 lbs and the tool speed at 20 rpm (corresponding to the center points of the respective ranges for the data shown in Figs. 5a and 5b). The average rate over the whole run was 299 nm/min with an average within wafer nonuniformity of 3% (1 sigma) and wafer to wafer nonuniformity of 2%. These results indicate that, indeed, a stable oxide process can be achieved.

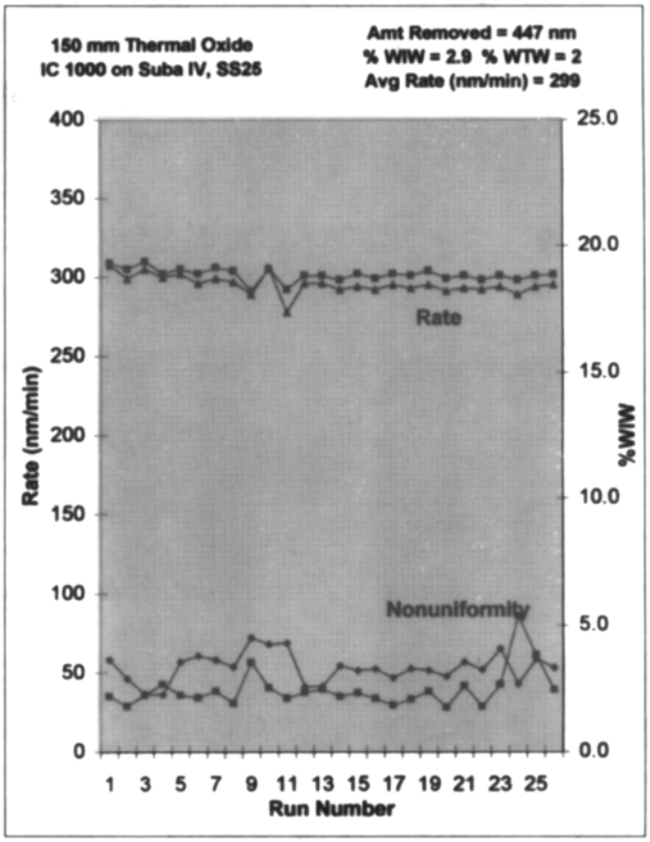


Fig. 6. Fifty wafer run.

CONCLUSION

Conditioning of the polish pad is quite critical to oxide polishing processes. Two methods of conditioning the pad, namely *in situ* and *ex situ*, were compared. The removal rates with the *in situ* technique are about 15 to 20% higher than those with the *ex situ* conditioning. The WIW nonuniformities were also about 23 to 45% lower with *in situ* conditioning. Both *in situ* and *ex situ* conditioning can be utilized effectively for short polish cycles. However, *in situ* conditioning yields higher stable rates for longer polish runs when compared to *ex situ* conditioning. Apart from conditioning, pad deformation plays a dominant role in stabilizing the polish process. The extent of pad wear with different conditioning parameters was examined. The conditioning down force, the diamond particle size, the pattern on the conditioning tool, and the type of slurry used effect the extent of polish pad wear. A combination of these variables was used to identify an optimal oxide removal process for the Strasbaugh 6DS-SP tool.

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