RECENT ADVANCES IN CERIA-BASED SLURRIES FOR STI AND ILD APPLICATIONS

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ABSTRACT

New slurry formulations are described for both Shallow Trench Isolation (STI) and Inner Layer Dielectric (ILD) CMP applications. These formulations use cerium oxide as the abrasive, since the industry requires a higher performance from these slurries for both of these applications at sub-90nm technology nodes, compared to the traditionally used silica-based slurries.

The slurries for STI CMP show high oxide to nitride selectivity, low dishing and exhibit excellent within wafer (WIW) and within die (WID) performance. Slurries are described which exhibit reverse-Prestonian behaviour. The slurries for ILD CMP give very fast step height removal rates (SHRR) and exhibit 'auto-stopping' behaviour. When polishing wafers with a variety of pattern densities and feature sizes, the cerium oxide slurries show lower dependency on pattern density, as compared to silica slurries.

All of the CMP slurries exhibit consistent manufacturability, excellent dispersion characteristics, long shelf life and produce low defectivity.

1. INTRODUCTION

This paper describes the development of ceria-based CMP slurries used in two process steps in the production of sub-90nm technology node integrated circuits. The processes are Shallow Trench Isolation (STI) CMP and Inner Layer Dielectric (ILD) CMP.

The STI process was developed to effectively isolate the active areas that form the transistor gates at the device level and it allows superior scalability and fulfils the planarity requirements for lithography [1], compared to earlier techniques.

One of the greatest challenges for the integration of STI structures in circuits is to develop a well-controlled planarization process using Chemical Mechanical Polishing (CMP). CMP is carried out following the formation of the isolation structures (trenches) by etching and the filling of the trenches with a dielectric material (usually HDP CVD oxide). After the oxide deposition there is usually substantial topography across the structure, the result being that the oxide over the active areas is thicker than that over the field areas (trench). CMP is used to reduce the topography down to the silicon nitride CMP-stop layer deposited on the active areas. An important aspect of the process is that it needs to produce minimal dishing in the trench oxide after an overpolish step to remove the oxide from the active area nitride. The selection of the polishing slurry is therefore critical.

Apart from producing low dishing, other requirements of the slurry are that it must give; fast planarization (step height removal), high selectivity (oxide to nitride) and low defectivity. Traditionally silica-based slurries have been used, but due to the increasingly stringent requirements of the evolving technology, these can no longer provide the required performance. Silica slurries show a much greater pattern dependency than the newer ceria-based slurries. Ceria slurries are becoming dominant for sub-90nm node STI polishing. Other than decreased pattern dependency, ceria slurries show greater oxide to nitride selectivity, which limits the amount of nitride erosion.

The work here describes the development of one-component, high selectivity ceria slurries for sub-90nm technology node device polishing [2]. These are used in one- or two-platen processes giving firstly fast planarization (step height reduction) of topography and secondly low nitride loss, minimal within-die (WID) and within-wafer (WIW) oxide and nitride layers, low oxide dishing and low defectivity. Also described is the mechanism of ‘reverse-Prestonian’ behaviour, which can be observed in some slurries depending on the nature of the additives used in the slurry formulation.

The ILD CMP process is carried out to planarize dielectric layers, to enable multi-layer circuits to be built up with no issues for lithography at each level, due to excessive topography across the die. Standard Inner Layer Dielectric (ILD) polishing utilises an endpoint detection or a fixed time process to determine when to stop polishing. This can create non-uniformities across the oxide surface caused by both within die topography variations and within wafer polishing rate variations [3]. Incorporation of a stopping layer would help, but the standard ILD process does not use any. One way to minimise non-uniformity and also to widen the process window is to formulate an ILD slurry with auto-stopping characteristics.

An auto-stopping slurry is one that shows a moderate to high (>3000 A/min) step height removal rate (SHRR) when polishing topography, but reverts to a low (<300 A/min) removal rate of the oxide after removal of the topography (i.e. the wafer polishes like a blanket wafer). This type of slurry, when used in an optimised process, would result in effective removal of topography to leave a very planar surface. Additionally, the slurry should show very low pattern density dependency across a wide range of feature sizes and densities (up to 1000μm and an active area density range of 10-90%). This paper describes some ceria-based ILD slurries that have been formulated with auto-stopping characteristics, efficient topography removal and low pattern density dependency [4].

2. EXPERIMENTAL

All of the slurries described in this paper were manufactured at the Penn Yan facility of Ferro Electronic Material Systems. The silica slurry SS-12 was obtained from Cabot Corporation.

Oxide and nitride thicknesses were measured using a ThermaWave 3290DUV Optiprobe. Defect inspection was carried out using an Applied Materials WF-736 Orbot tool. Post-CMP cleaning was carried out using an Ontrak double-sided brush scrubber with megasonics.

2.1. STI Slurry Development

Polishing was carried out using a 2-platen process on an Applied Materials Mirra CMP 200mm platform. Blanket TEOS and nitride wafers were used to measure removal rates and SKW3 MIT854 wafers from SKW were used to generate performance and defectivity data. Figure 1 shows the die and measurement site locations on the SKW3 wafer.

Polishing endpoint was determined by time, which had been established in previous experiments. The endpoint for the first step polish was determined to be when approximately 1000 Angstroms of active oxide remained over the 4x4 mm feature and the endpoint for the second step was determined to be when the 4x4mm area active oxide had completely cleared.

The average WID range for each wafer was calculated by determining the range within each individual die (difference between the thinnest and thickest points measured) and then averaging the individual die ranges over 17 die (for oxide) and 10 die (for nitride). The WIW range (average thickness of either oxide or nitride within an individual die) was calculated from all the thickness measurements made within that die. The range was then given as the difference between the highest and lowest average thickness over 17 die (oxide) and 10 die (nitride).

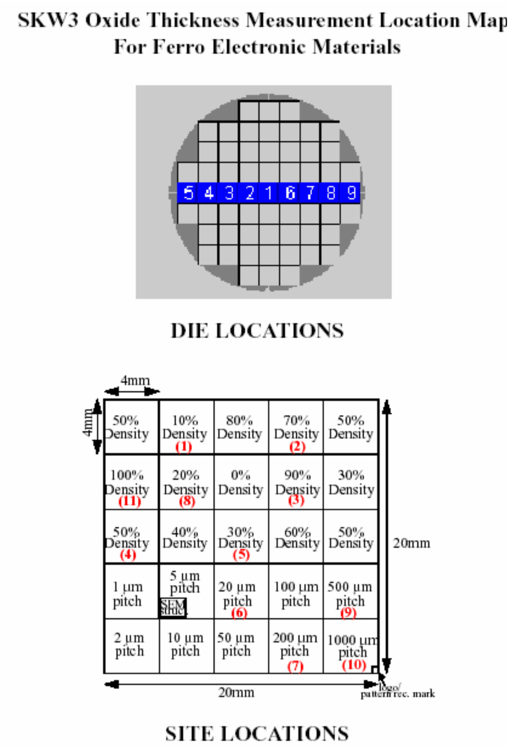

Figure 1: SKW-3 Mask layout

2.2. ILD Slurry Development

Polishing at the Ferro Penn Yan facility was carried out using a Strasbaugh 6EC single platen 200mm platform. Polishing at the customer site was carried out on a Novellus Momentum 200mm platform. Blanket thermal oxide wafers were used to measure removal rates and SKW 7-2 ILD wafers from SKW were used to generate performance and defectivity data in Penn Yan. Figure 2 shows a cross-section of the Up oxide and Down oxide areas on the SKW 7-2 wafer. The polishing endpoint was determined to be when the Up oxide had been polished down to 10,000 Angstroms thickness (on an SKW 7-2 wafer with an initial Up oxide thickness of approximately 20,000 Angstroms). At this point, the topography was less than 500 Angstroms. The customers own wafers (cross-section shown in figure 3) with over 40,000A of Up oxide thickness were used at the customer site.

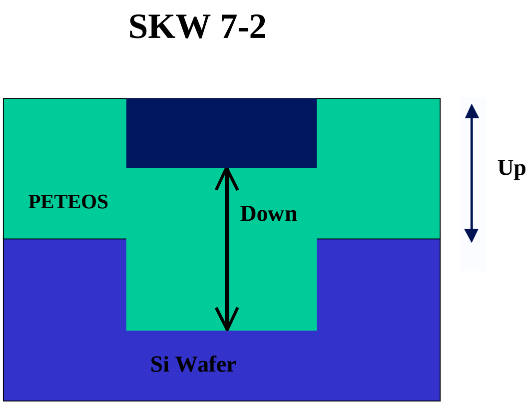

Figure 2: SKW 7-2 ILD mask cross-section (Up ~ 20,000 A)

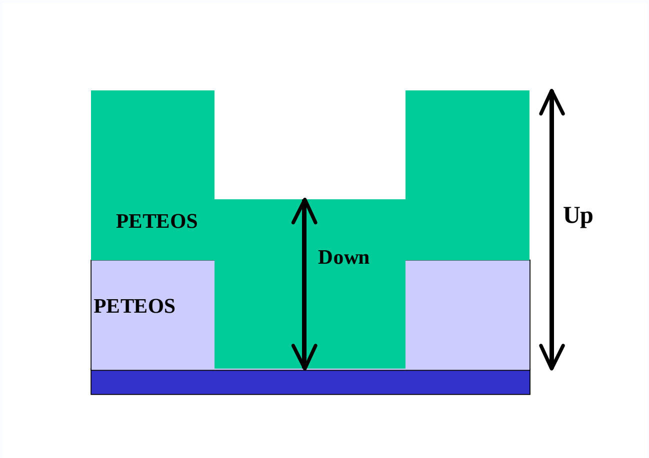

Figure 3: Customer wafer cross-section (Up ~ 43,000 Angstroms)

3. RESULTS AND DISCUSSION: STI CMP SLURRIES

Single-component slurries are described in this section, which can be used in both one- and two-slurry polishing systems. Two-component slurries are also described, along with a description of reverse-Prestonian behaviour, observed in some of these slurries.

3.1. One-Slurry Systems

The main focus of development has concentrated on formulating one-component slurries, which show efficient planarization, low dishing and high selectivity between oxide and nitride, leading to low nitride loss. Such one-component systems, an example being SRS-

970, are much easier to handle than two-component systems and do not suffer from very short pot-life. SRS-970 Is used at 4% ceria and pH=4. It has a Dmean of 140nm and a Do (top-size) of <600nm. Figures 4 and 5 concern SRS-970 performance data from the Optiprobe, showing endpoint and 20% overpolish data respectively, for the Field Oxide (Fox). Typical performance data shows excellent planarization, low WID values and low nitride loss. Figure 6 shows typical nitride loss after 20% overpolish, across the range of features on the SKW mask.

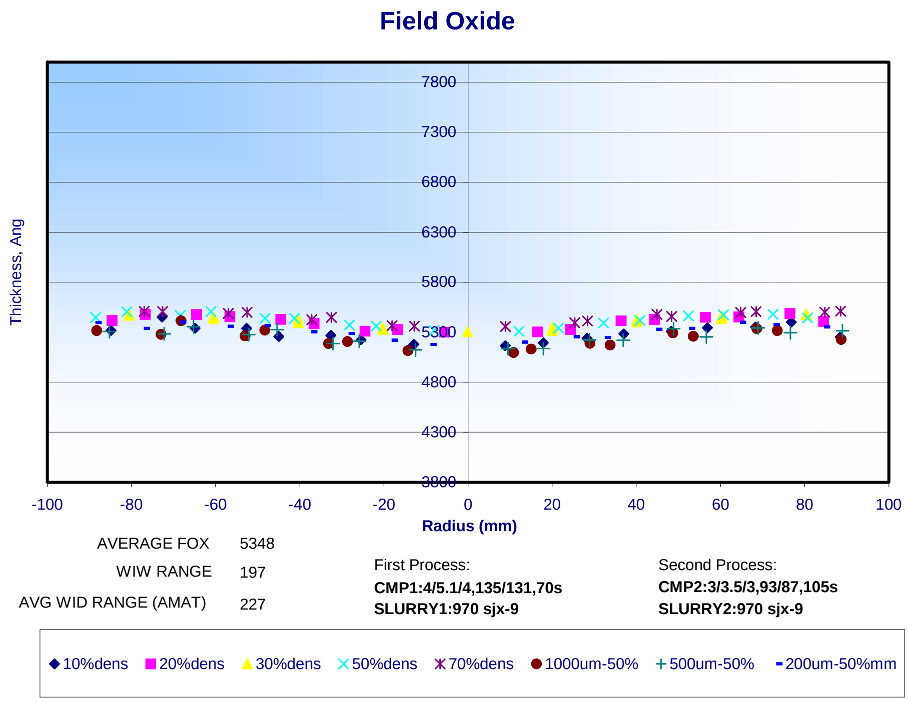

Figure 4: SRS-970 - polishing endpoint on Field Oxide (Fox)

3.2. Two-Slurry Systems

Two-platen processes using two different slurries on each platen are also available, with optimised formulations for planarization and finishing (stopping on nitride). This is less desirable than the single-slurry system, with respect to slurry handling, but increased flexibility can be realised here to produce faster planarization and less dishing. In fact, polishing with the 2-slurry system leads to dishing of less than 25nm on Fox.

3.3. Reverse-Prestonian Mechanism

Usually, slurries for STI behave in a normal, Prestonian way, that is the polishing rate increases in direct proportion to an increase in downforce pressure and speed [3]. A phenomenon observed with some of the ceria-based slurries is reverse-Prestonian behaviour. As the downforce pressure is increased, the oxide removal rate decreases. It has been found

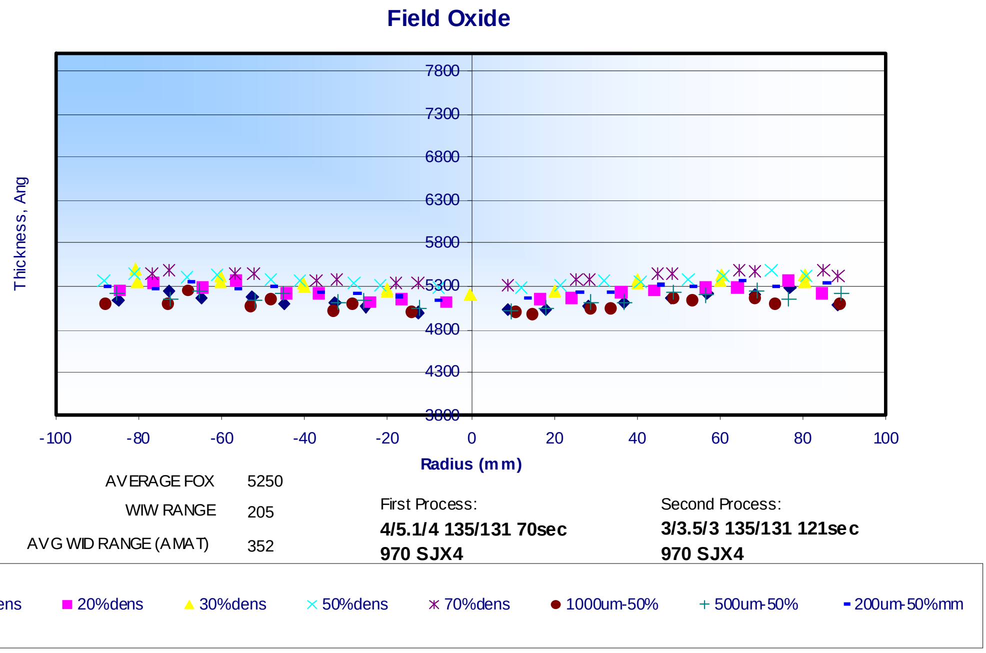

Figure 5: SRS-970 – 20% overpolish on Field Oxide (Fox)

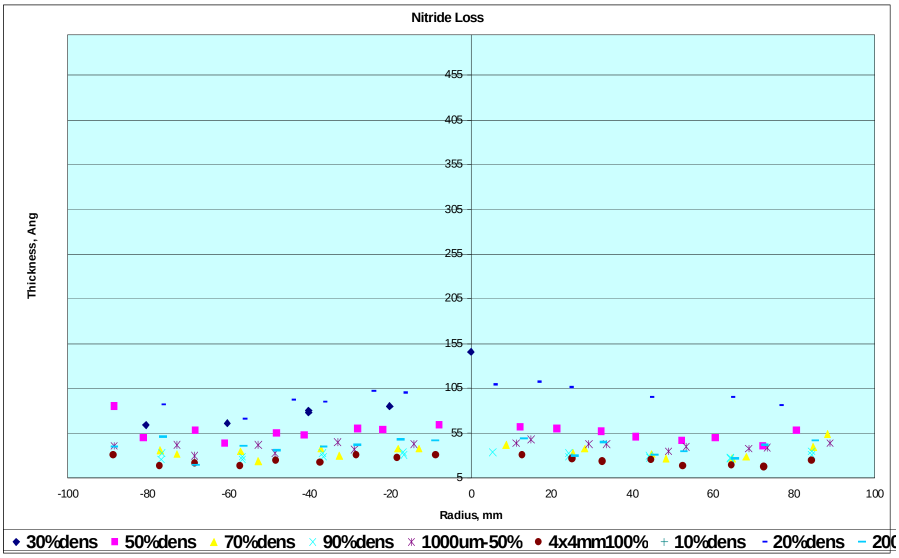

Figure 6: SRS-970 – Nitride loss after 20% overpolish

that the presence of certain additives is critical, depending on whether Prestonian or reverse-Prestonian characteristics are observed.

It seems that certain film-forming additives impart very effective protection over the oxide surface and this protective effect is more efficient at higher downforce pressures, leading to lower removal of material by the abrasive. As the downforce pressure decreases, the film becomes less protecting and the removal rate increases due to the abrasive action of the ceria. However, at pressures below 3psi, the film no longer has any protective qualities, but the pressure is too low for the removal rate from the abrasive action alone to be higher than that at 3psi. Figure 7 shows a typical plot of removal rate vs downforce pressure for a reverse-Prestonian slurry, showing the trends described above.

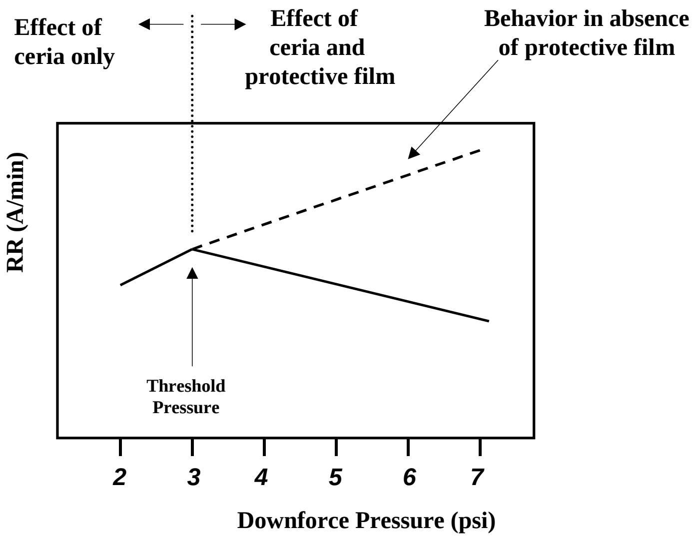

Figure 7: RR vs Pressure for a reverse-Prestonian slurry

4. RESULTS AND DISCUSSION: ILD CMP SLURRIES

Single component slurries, formulated at 1% ceria are described in this section. Examples are shown in Figure 8. Performance data for two product types are shown in more detail, the first for auto-stopping slurries (SRS-977) and the second for high step height removal rate slurries (SRS-985).

Product	Dmean (nm)	Do (nm)	Blanket TOX RR (A/min)	SHRR (A/min)
SRS-977	140	<600	700-1300	2500-3000
SRS-985	190	<1000	2000-2500	7000-8000
SRS-1023	140	<600	300-500	4500-6000

Figure 8: Ferro ILD slurries

4.1. Auto-Stopping Slurry Development

For silica slurries, the relation between the polishing rate and pressure is linear, in accordance with Prestons equation [3]. However, in the case of some formulated ceria slurries the relation is non-linear and a threshold exists [5]. The auto-stopping behaviour can be explained as follows. When the polishing rate is below the threshold, additives in the formulation act to protect the oxide surface, resulting in low removal rates. When the polishing rate is greater than the threshold, the protective characteristics become weaker and the polishing rate increases. During polishing, different topographies polish at different rates, with the high points being subjected to pressures greater than the threshold and therefore polishing faster, whereas the low lying areas are subject to lower pressures and the removal rate is low (the protective additive is not as easily removed). As the surface becomes planar, the pressure drops below the threshold across the wafer and the removal rate drops.

The SRS-977 slurry was formulated to give moderate SHRR (2500-3000 A/min, depending on process conditions) and a low thermal oxide blanket rate (700-1300 A/min). This product has been shown to exhibit auto-stopping behaviour, resulting in a highly planarized surface after polishing.

The self-stopping behaviour is shown in Figure 9, using wafers shown in figure 3. Here the remaining Up oxide is plotted against polishing time and it is seen that the curves level off after 400 seconds polishing, at most downforce pressures. Figure 10 shows Down oxide removal vs Up oxide removal. Even when the wafer is planarized (around 20,000A of Up oxide removed), less than 2000A of Down oxide has been removed and therefore, the planarization efficiency is high. This behaviour has been further optimised in another formulation, SRS-1023, which shows a lower blanket removal rate and a higher SHRR compared to SRS-977 (see figure 8).

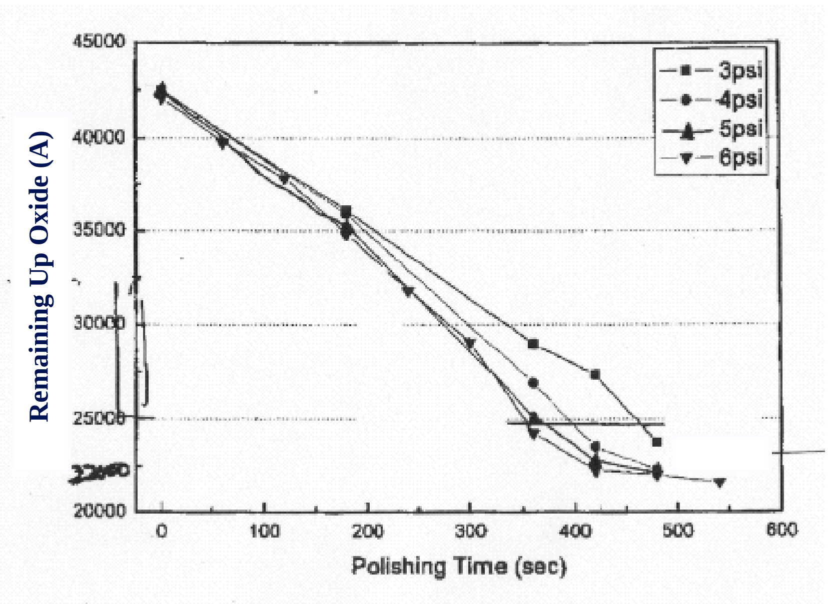

Figure 9: Remaining Up oxide vs polishing time, showing auto-stopping behaviour (SRS-977)

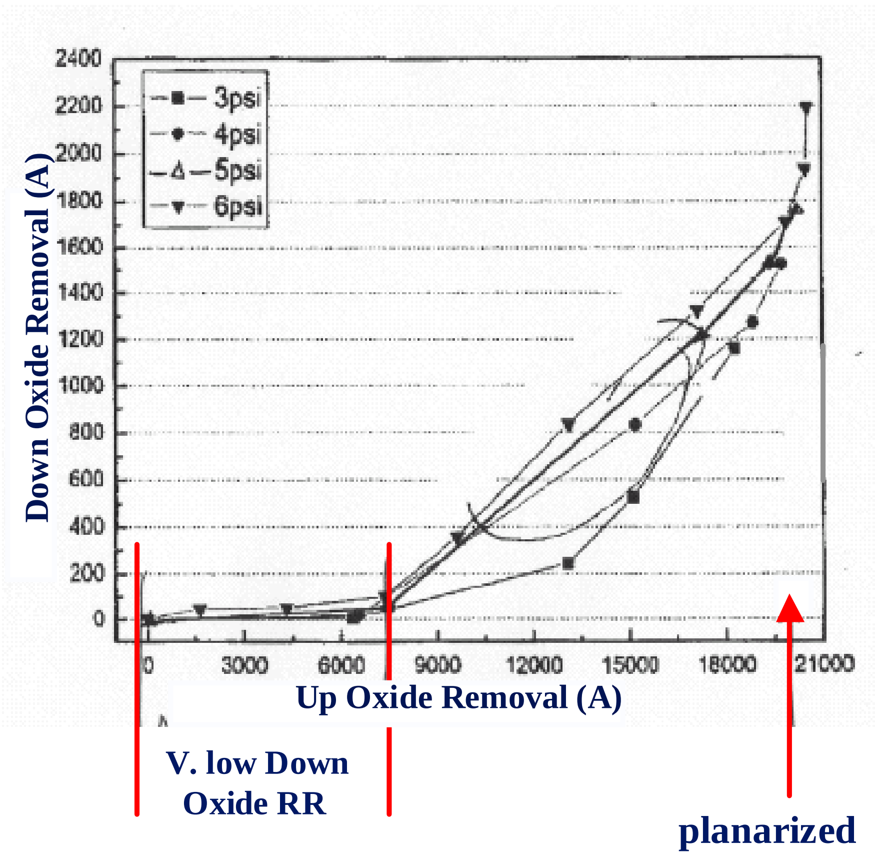

Figure 10: Down oxide vs Up oxide removal, showing High planarization efficiency (SRS-977)

4.2. Fast Step Height Removal Rate (SHRR) Slurry

SRS-985 is a slurry that was formulated to give a fast SHRR and a low pattern dependency. This slurry removed 20,000A of topography on a customer wafer (figure 3) in 180 seconds, with minimal Down oxide removal, to produce a highly planar surface (figures 11 and 12 show the post-polish Up oxide and Down oxide profiles respectively). On a SKW 7-2 wafer, 8000A of topography was removed in 60 seconds. This slurry was shown to be excellent for fast topography removal, however the blanket removal rate (>1500A/min on TEOS) was too high for it to exhibit true self-stopping behaviour.

One excellent feature of the SRS-985 slurry is that it shows almost no pattern dependency and this can be seen in figures 13 and 14, for Up and Down oxide respectively. Here the pattern dependency of SRS-985 is compared with SRS-977 and a commercial silica slurry (SS-12). SKW 7-2 wafers, with densities in the 10-90% (active nitride) range were used here. The silica slurry is very pattern dependant and this is one reason why silica slurries are coming to the end of their useful life as options for the next generation of ILD polishing.

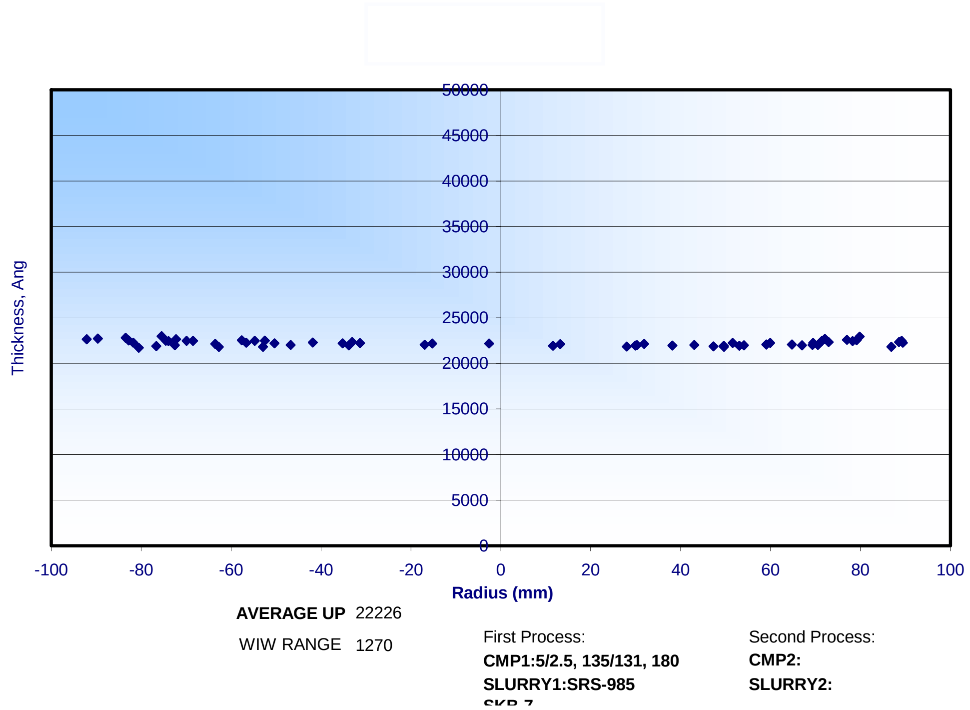

Figure 11: SRS-985 – Up oxide profile (post-polish)

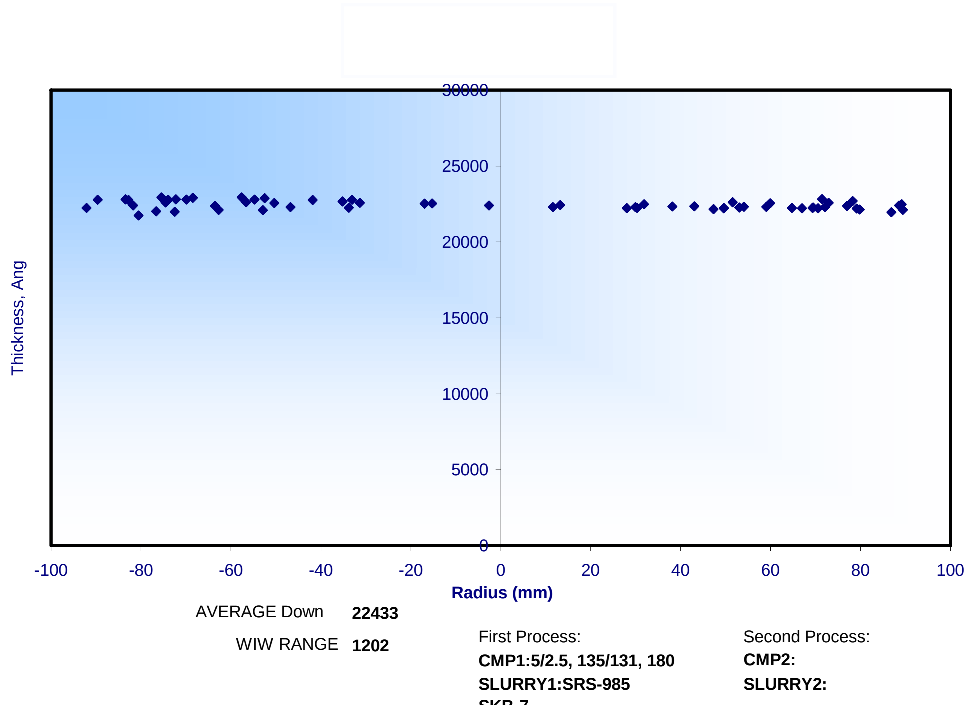

Figure 12: SRS-985 – Down oxide profile (post-polish)

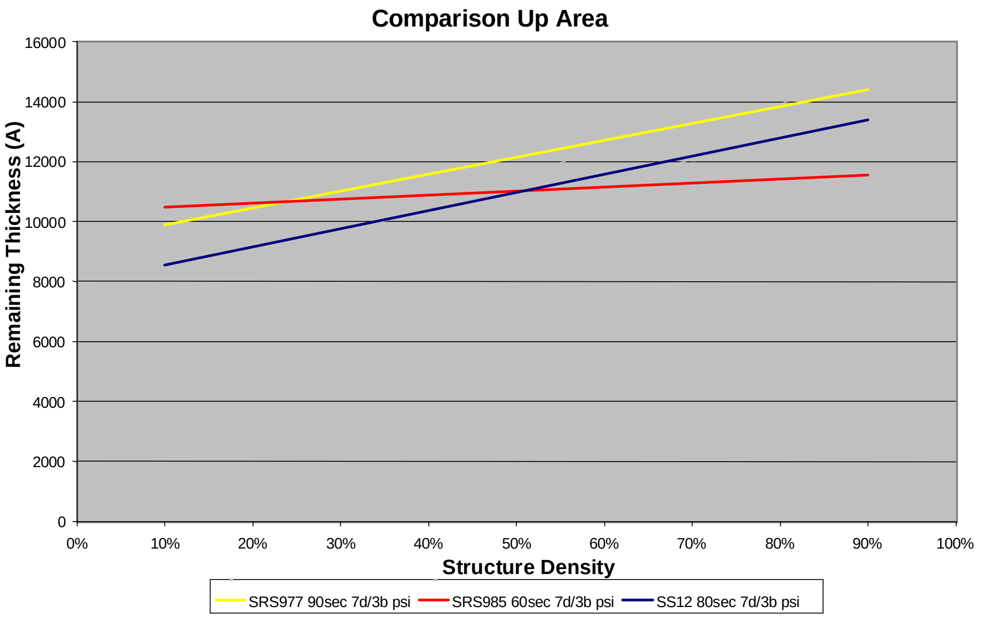

Figure 13: Pattern Dependency (SRS-985 vs SRS-977 vs SS-12)

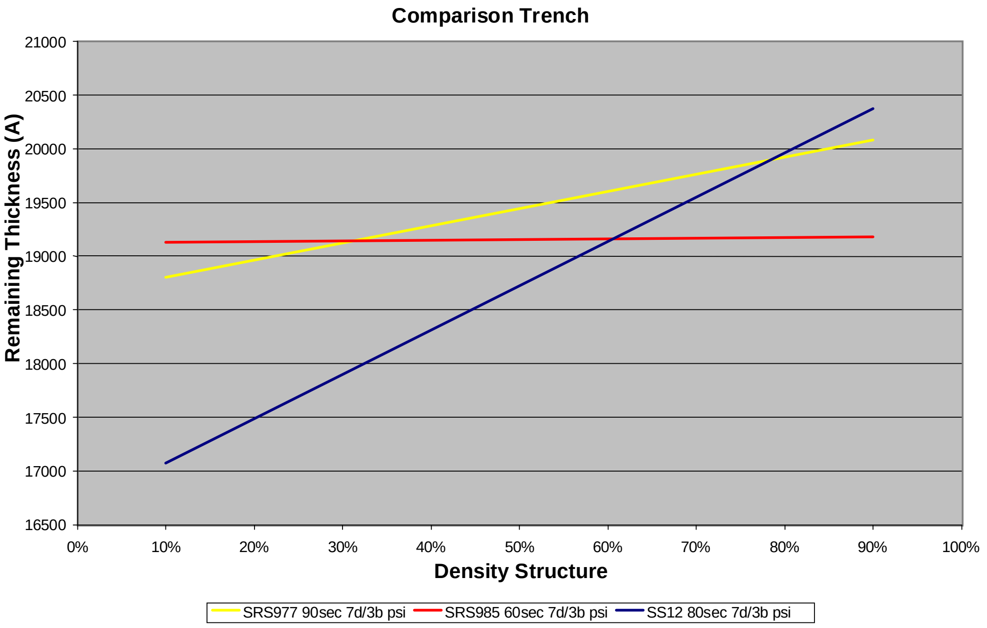

Figure 14: Pattern Dependency (SRS-985 vs SRS-977 vs SS-12)

5. SLURRY MANUFACTURE AND DEFECTIVITY

The capability to control the manufacture of the abrasive particle in-house is critical to the production of a consistent product. Ferro have the capability to completely control both the abrasive manufacturing process and the final product formulation. In this way, large defect-generating particles can be eliminated, whilst still retaining the particle size distribution required for optimum oxide polishing.

Typically, both total defects (including particles) and CMP-induced defects are fewer than those from a commercial silica slurry (up to three times less). CMP-induced defects include scratches, micro-scratches and pullouts.

The one- and two-component slurries described in this paper give high stability, with a shelf-life of over 12 months.

6. CONCLUSIONS

New ceria-based slurries for STI and ILD CMP have been developed that meet the extremely rigorous objectives necessary for the production of sub-90nm devices. The slurries are both single- and double-component products with long shelf- and pot-lives. Control of both the ceria particle manufacture (solid state or solution grown) and the slurry formulation in-house is critical for the production of consistent product, to minimise lot-to-lot variability.

Advanced STI slurries have been described that lead to efficient planarization, low dishing, low nitride loss and minimal defects. These slurries can be used in both one- and two-slurry polishing schemes. A mechanism for the reverse-Prestonian behaviour seen with some of these slurries is discussed. Advanced ILD slurries have also been described, which show auto-stopping behaviour and high SHRR. Auto-stopping characteristics enable a wide process window to be realised and a mechanism for this effect is discussed.

Ferro Electronic Material Systems continues to carry out development work towards further improving the performance of both STI and ILD slurries.

7. REFERENCES

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