

CMP Characterization Mask Set for STI Processes Mask Documentation

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I. Introduction

The purpose of this documentation is to describe a mask for characterizing and modeling pattern dependent variation in CMP processes, consumables, and tools for shallow trench isolation (STI) processes. While there is considerable research into physical modeling and understanding of pattern sensitivities, this mask was designed to enable methods for the rapid characterization, empirical modeling, and comparison of pattern dependencies as a function of process, consumable, or equipment options. The test mask and measurements can also serve as a source of data for the calibration and validation of physical or semi-empirical modeling efforts.

The characterization mask presented here can be utilized to investigate pattern dependencies (density and pitch) in a variety of CMP process applications, including traditional back-end, trench isolation, and damascene or inlaid metal processes. However, the mask presented here is specifically designed to investigate two pattern dependencies, density and pitch, for STI processes. Typically, an STI process flow begins by depositing a thin pad oxide and nitride layer followed by patterning of trenches into the nitride and underlying silicon. The trenches are filled with an isolation oxide and polished. While there are many module and integration issues in STI, the mask presented here was specifically designed to characterize and explore issues relating to pattern dependent issues associated with planarization by CMP (although some structures have been added to probe pattern dependent gap fill issues). Key pattern dependent issues include both “dishing” of features being polished and “erosion” or regions with lower or higher density of features. Density and pitch were chosen as the primary mask vector since they are believed to be the dominant factors in erosion and dishing.

II. Mask Descriptions

The CMP Characterization Mask for STI processes is designed for rapid CMP consumable, process, and tool characterization and evaluation. While previous work on oxide CMP back-end processes (see the documentation/mask set for oxide CMP for more details) focused on single-factor mask vectors, the new test mask for STI processes combines two main patterns, density and pitch, into one mask and focuses on the rapid evaluation of dishing/erosion phenomenon. The mask supports simplified metrology tools and techniques including optical film thickness and profilometry measurements as well as selected SEM structure measurements. The mask was designed to produce a 20mm x 20mm die, but smaller die can be generated by intelligent scaling of the layout.

The floor plan and the actual layout of STI mask are shown in Figures 1 and 2 respectively. As shown in those two figures, the STI mask is composed of 4mm x 4mm density and pitch structures which divide the 20mm x 20mm die into 5 rows and 5 columns. The structure size of 4mm x 4mm was chosen since the interaction distance for oxide CMP was less than 4mm and since we wanted to decouple the interactions between density and pitch structures. 15 density structures occupy the top 3/5 of the die, and 10 pitch structures occupy the bottom 2/5 of the die.

In the density structures (density defined as the area of trench over the total area), the pattern density is varied systematically from 0% to 100% in increments of 10%. Each structure consists of vertical lines except the two 50% structures which have horizontal lines to see the effect of geometric orientation. The pitch is fixed at 100 μ m, a rather large feature size to facilitate profilometry measurement. The density structures are organized in pseudo-random layout to place high density regions next to low density regions. This is done to characterize pattern dependencies between different density regions in addition to pattern dependencies for specific density regions. In the pitch

structures, the density is fixed at 50% (same trench width and space) and the pitch is varied from 1 μ m to 1000 μ m in a logarithmic fashion formed from vertically oriented lines. To be able to measure optically, 1 μ m, 2 μ m, 5 μ m, 10 μ m, and 20 μ m pitch structures have 20 μ m x 20 μ m spot area (for the active region, not for the trench) since these structures have less than 20 μ m line space.

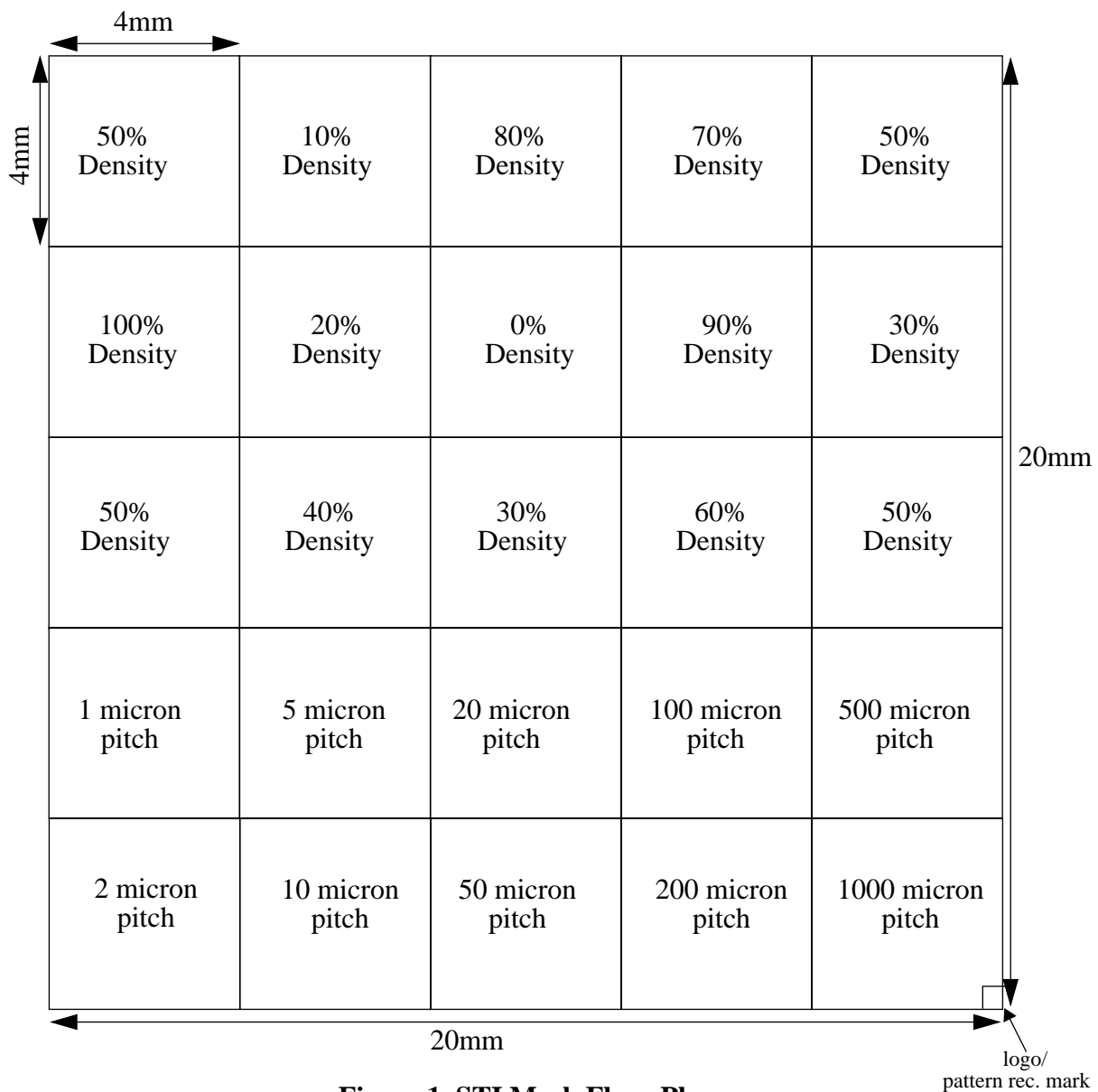


Figure 1. STI Mask Floor Plan

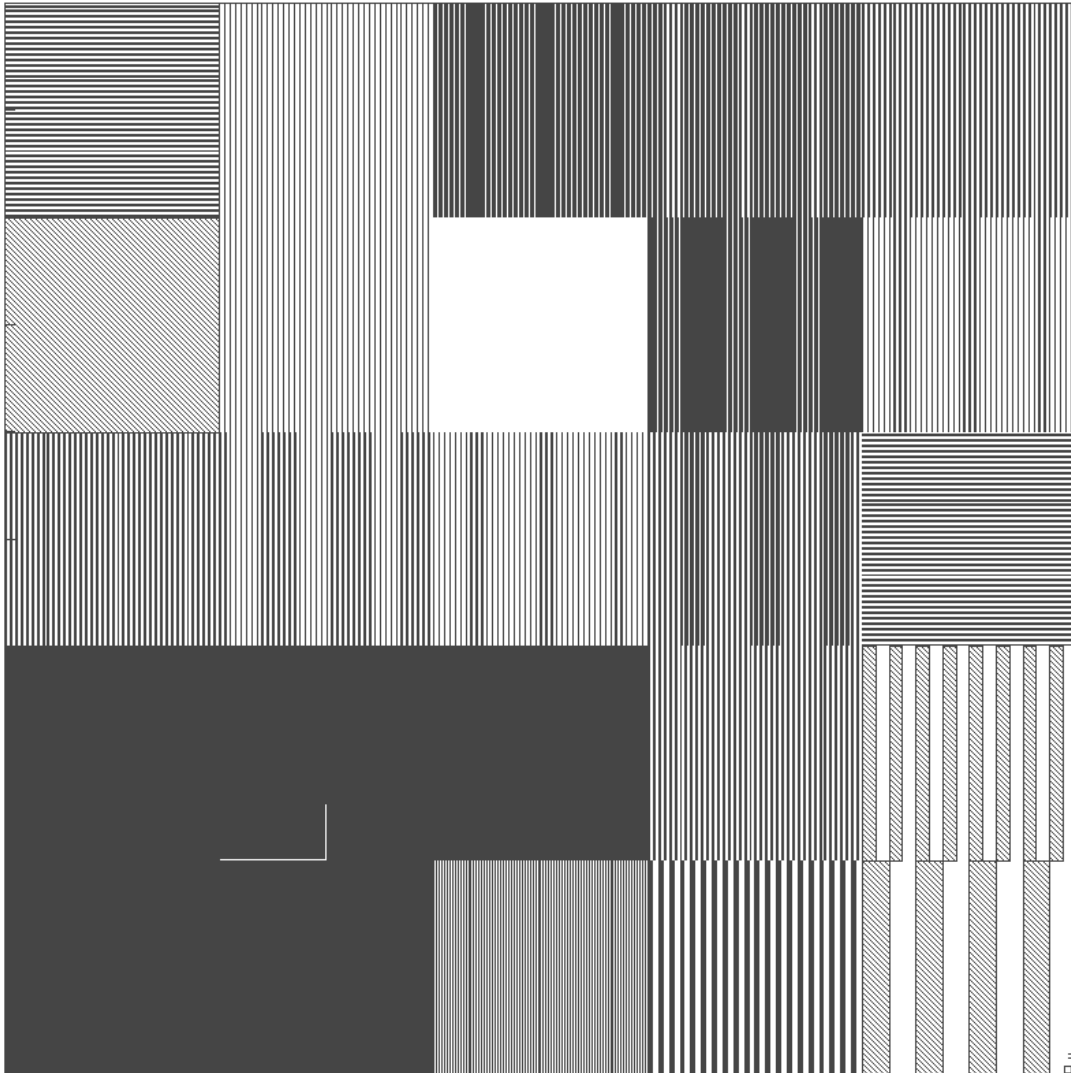


Figure 2. STI Mask Layout

In both density and pitch structures, vertical/horizontal lines, instead of other geometric shapes, were used to get good profilometry measurement results.

III. Metrology

In this section, the application of several metrology tools and techniques is discussed. Specifically, particular attention is directed towards optical interferometry and profilometry techniques as well as Atomic Force Microscopy (AFM) and SEM (Scanning Electron Microscopy).

Optical interferometry is a commonly used technique for directly measuring film thicknesses. It offers reasonably high throughput as well as an absolute thickness measurement assuming the tool is properly calibrated. For the characterization masks, either five die, nine die, or full wafer sampling schemes are useful. In a five die strategy, five dies near the center of the wafer (which is typically more uniform than elsewhere on the wafer) are measured. This is useful for quick analysis and initial model development, but does not provide any information about edge or spatial effects across the wafer. In a nine die sampling scheme, one die at each edge of the wafer (top, left, right, and bottom) are sampled in addition to five die from the center of the wafer. This technique can provide some information about edge effects. Finally, a full-wafer scenario can be used in which every die is sampled on the wafer. While the throughput of this technique is quite low, more powerful analytic techniques can then be used. Also, automated optical metrology is limited to structures with linewidths greater than 10 μm . For smaller structures (down to about 4 μm), optical metrology can still be used but only in manual model and with less reliable results.

In each case, the center of each pitch structure above the oxide is measured for all pitch structures greater than about 20 μm . This measurement will provide information on dishing of features. The same method can be applied to the density structures to gather information on erosion. This method provides partial information such as selected absolute thickness measurements but does not result in full surface maps; thus profilometry is necessary to fully understand and characterize the behavior of STI CMP processes.

In profilometry, a sharp stylus is dragged across the surface of interest and deviations in the stylus are measured. In addition, the surface can also be nondestructive scanned optically. Profilometry can be used in 3-D mode to generate an entire die map with high throughput or 2-D traces can be used to generate planarization information over cm scale distances. In profilometry, measurements are susceptible to stage tilt and bias as well as wafer bow and warp. This problem can be compensated by using a combined optical/profilometry technique: several points are selected on the die which are measured using both optical interferometry and profilometry measurements. The surface formed by the measurements from profilometry is forced to match the surface formed by the optically measured values; the difference between these two surfaces is called the correction surface. The efficacy of this technique is dictated by the number of measurements which make up the correction surface: using only five measurement sites to form the correction surface enables correction for linear deviations.

For rapid characterization of the STI mask using profilometry, five scans across the middle of each “row” of structures are recommended. At the center of the left edge of the die for each row, there is a small horizontal mark so that a profilometer can be placed in the middle of the structures of interest. The profilometry scan is performed for all five rows, and with optical interferometry measurements for calibration to absolute values, complete surface maps of all the structures can be generated.

AFM and SEM are also useful metrology tools for use with the characterization masks. In each case, very detailed information about planarization including the profile shape can be obtained, and small structures which cannot be measured using optical interferometry can also be examined. SEM measurements are also very useful for gap-fill characterization in the SEM structures mentioned in the previous section. Since the effective throughput of these techniques is

extremely low, the application of these tools is limited to only a few key measurements. An additional drawback of SEM techniques is that they are destructive.

Finally, a simple but effective approach should not be neglected: visual inspection and interpretation of fabricated wafers. In certain circumstances, differences between structures and wafers can be discerned visually by looking for subtle color variations between each case, and a color chart can also be used to roughly quantify the differences. Although simple, this technique can be quite useful in identifying gross differences associated with particular consumable, process, and tool choices during rapid evaluation or optimization.

Also note that in addition to a name plate on the lower right corner of each die, there are two structures with a small box inside of a box (see Figure 4). These structures have been included for use in pattern recognition alignment and targeting on metrology tools.

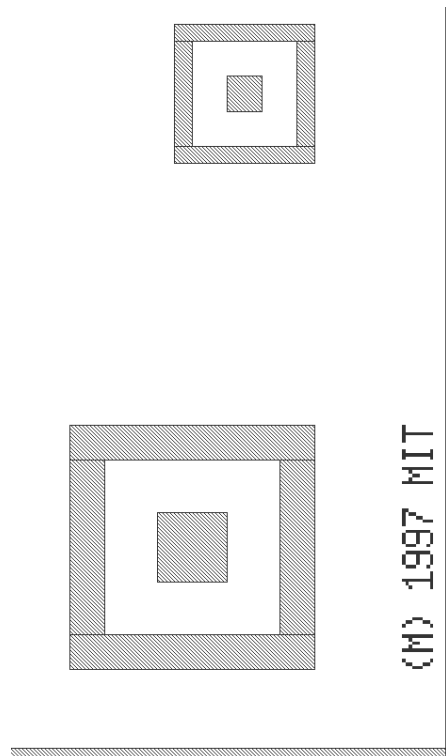


Figure 4. Name Plate and Pattern Recognition/Alignment Target