Abstract—The purpose of this paper is to elucidate other applications where the low frequency component of background signal (haze) level of a wafer inspection tool can be used to qualitatively analyze different processes. During initial epitaxial development cycles a fast method of qualifying the growth runs is required. While SEM inspections can sub-sample the wafer, a semi-quantitative way of qualifying growth can be immensely helpful in speeding up the process. In this paper we monitor the epitaxial growth of III/V materials by two different methods: 1) strain relaxed buffers (SRB approach); and, 2) selective epitaxial growth (SEG approach) by using the haze.

Keywords—Light scattering, haze, III-V materials, process control

I. INTRODUCTION

The semiconductor industry is constantly looking for new ways to improve device performance while keeping Moore’s law alive. Heterogeneous integration of III-V high mobility materials on a Si substrate in a 3D-architecture such as a FinFET is one of the most likely methods of achieving performance improvement while keeping the law alive in the coming decade. For N-channel devices, indium gallium arsenide with high indium concentration is one of the more preferred candidates due to its superior electron mobility, high saturation velocity and good optical band-gap [1]. The main challenge in growing these ternary compounds on a Si substrate is to grow it without too many defects such as threading dislocations, twins, stacking faults and anti-phase boundaries. The task of growing such films with an acceptable number of these aforementioned defects is extremely difficult due to the large lattice mismatch between Si and III-V materials. Several options have been considered to obtain high quality single crystal III-V compounds on Si with low defect density: strain relaxed buffers, epitaxial lateral overgrowth, rapid melt growth, and the defect confinement technique [2], [3], [4]. Further improvements are still required to reduce the too high defect density in the III-V layers.

As technology nodes become more aggressive, the lower detection limit for the size of defects on bare silicon wafers keeps decreasing. Light scattering is often the method of choice for the detection of surface defects on un-patterned wafers. Fig. 1 shows how scattering intensity in laser-based dark-field inspection is used to detect light point defects (LPD) as well as understand the surface roughness. As shown in Fig. 2, the detectable defect size depends on the background signal level. This method has a couple of limitations. First, if there are a very large number of defects on the wafer, the tool will reach its saturation limit and not report all defects. Second, if there are small and large defects, it will not be possible to detect them using the same measurement recipe [5]. Using multiple recipes requires multiple scans resulting in increased fabrication cycle time and multiple calculations to arrive at a defect size histogram. Instead of detecting and monitoring LPDs, the inspection can be used to monitor the haze level (the low frequency component of the background signal of the tool), often with a single recipe, thus avoiding any issues associated with the quantity or sizing of defects.

![Diagram showing typical scattering signals from a wafer surface.](image1)

In Fig. 2, we show a typical PMT signal. By setting the “correct” threshold of intensity we can detect the particles.
Setting the intensity threshold too low can lead to false detections while setting the threshold too high can prevent the smaller defects from being detected.

II. EXPERIMENTAL

In this technique the wafer surface is scanned with a laser beam. Surface imperfections or defects such as roughness, particles and scratches scatter the laser light. The scattered light can be detected by means of a dedicated optical set-up. In our case, we use the Surfscan SP3 platform from KLA-Tencor. The presence of a defect is linked to the geometrical point on the wafer surface generating the scattering event. This allows construction of a map showing the distribution of defects over the wafer surface. Moreover, the intensity of the scattered light can be used to size the defects via specific calibration data.

Two angles of incidence of the light source are available: oblique and normal to the wafer surface. Scattered light is collected in two different channels, wide and narrow, which collect different ranges of the angle of scattered light.

In our study, we evaluated the haze variations for both strain relaxed buffer (SRB) wafers and selective epitaxial growth (SEG) wafers as a function of different growth conditions.

III. RESULTS AND DISCUSSION

We analyze two sets of wafers for our purpose. The first of wafers are SRB layers grown directly on Si and the second set of wafers are actually III/V wafers grown by the aspect ratio trapping method (ART).

A. Strain Relaxed Buffer wafers

For the SRB layers we show that by monitoring the haze of the wafer, an estimate of the surface quality of the epitaxial layer can be obtained. This is the first study that demonstrates that haze can be a good correlation factor for the number of crystal facets. In order to do so we apply a standard edge detection algorithm developed by Canny et al. Fig. 3(a) shows an example of a SEM image and its corresponding edges as detected by the algorithm. After the edges are detected (Fig. 3(b)) we count the total number of white pixels in the latter. This can now be easily converted to total crystal facet length since we know the size of the SEM image and the field of view (FOV). It is imperative to mention here the importance of the SEM imaging conditions. Changes in the imaging condition (e.g. landing energy, beam current) can lead to differences in the edge contrast of the acquired image. The problems are similar to CD–SEM analysis [1].

Fig. 3. (a) SEM image of an SRB wafer from the center. (b) Standard edge detection algorithms applied to the SEM image to extract the edges of the crystal facets.

In Fig. 4 we show that the haze follows the total crystal facet length acquired from the SEM graphs. This was done by fitting a standard edge detection algorithm on the SEM image taken on the different wafers and then extracting the total number of “white pixels” from the edge detection map. Since we know the pixel size of the image, we can calculate back the total amount of edges or total facet length. Plotting “average haze” versus the total crystal facet length results in almost a one-to-one correlation. In our case we did the analysis on the SEM post the “coalescence stage”, which is after the “nucleation stage” but before the onset of “3D growth”. The same method can also be used to judge nucleation, but in that case we need to take into account the nucleation density.
case that we would need to calculate the total scatter area of each “island”.

Across wafer non-uniformities can also be flagged by setting up different rule based bins (RBB’s). One such example would be to monitor the haze variation across a wafer with an artificial die grid over the wafer (Fig. 5). Center to edge variations can be easily tracked by such a system. The purpose of the grid would be to account for the percentage of die meeting the epitaxy (or other process) criteria. Furthermore, in initial development stages the haze line analysis algorithms can be used to show big crystal dislocations and CMP scratches when a LPD mode inspection would not be possible. With 50μm haze resolution on the latest inspectors, epitaxial development can be greatly accelerated by using a haze-based analysis. This is shown in the following figure. Within wafer non uniformity based on haze can be mapped out (Fig. 5(a)) and the different areas can be extracted (Fig. 5(b)). This was further verified by doing SEM inspections in the two zones flagged by the grid.

B. Selective Epitaxial Growth

Selective epitaxial growth is often used to grow high quality III/V materials in trenches. This method of defect confinement has recently attracted great interest due to the possibility of obtaining high quality III-V based active regions using nanometer scale trenches with high aspect ratio (>2). The benefit of using this method versus the SRB method is that it is possible to to eliminate (111)-oriented defects (such as threading dislocations, twins, or stacking faults) on the sidewalls. Optimizing such a growth process is extremely important and difficult before device quality III/V materials can be integrated. Most often TEM can only give an indication of the quality within the trenches but this extremely local. Excluding process and tool issues from true epitaxial limitations is important during the early phases of development. The exact steps of this method of growing III/V materials are depicted in Fig. 6.

For the selective epitaxial growth wafers, the haze of the wafers were measured after steps a, b, and c of Fig. 6. Haze measured post STI patterning gives us the absolute pattern signal because the number of defects should be minimal at this stage. Now in order to monitor the III/V material growth we measure the haze of the wafer after the Ge and InP had been grown inside the trenches. It is important to state here, that for this method to be sensitive to defects the signal from the defects should be larger than that coming from the pattern edges only.

The haze of the wafers were measured after the trench etch and then after the Ge/InP growth. Fig. 7 shows the haze map of a typical patterned wafer post Ge seed in the trenches. A closer look on the pattern shows that the haze is actually a very good indicator of the pattern density variation. In Fig. 8 we show the die layout. There are 4 repetitive blocks in the reticle. Each one of the 4 blocks has a specific width of
trenches. This clearly shows that haze can pick up the minor pattern differences from cell to cell.

Next, we try to analyze the haze variation of a certain pattern (cell), across the wafer, within the die as recorded by the Surfscan SP3 wafer inspector after the Ge seed layer deposition. In the example in Fig. 9, we take a 600 X 600 micron cell which has only 150 X 1000 nm lines and plot the average haze value of this cell across the wafer. Each such cell has 12 X 12 = 144 pixels in the SURFimage plot. Average of these 144 pixels gives us the average haze value for each cell. Next, we plotted the average haze of a particular cell which had a specific pattern across the wafer. This gives us valuable insight into the growth behavior of the III/V material inside different aspect ratio trenches across the wafer. A center-to-edge variation, as shown for this case, for a particular pattern (cell), can quickly highlight a center-to-edge defect excursion. This was further validated by patterned wafer inspection tools and SEM review. It was noticed that a lot of the larger defects were in fact towards the edge of the wafer. In theory, if the pattern is same across the wafer the scatter signal intensity should be same. Any change, across the wafer should be picked up by the haze signal. So, haze can be used to monitor pattern deviations when they are above a certain size and density. When the density of defects is high, higher than the signal from the patterns, it can flag process excursions. This is re-iterated by the SEM graphs taken for the same pattern both at center and at edge. We would like to point out at this stage that the method can also be used to monitor pattern density variations. For example the same pattern (cells) should show the same haze value for all dies if everything else is constant.

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IV. CONCLUSIONS

These studies show that haze can be used for more than just bare wafer roughness measurements. Haze can be used for monitoring epitaxial growth and can in principle give early indications of wafer surface variations. For SRB layer it was found to correlate well with the number of crystal facets. If analyzed, more information can be derived from haze data, and, in certain cases, defect density trends on patterned wafers can also be analyzed. Also pattern density variations can be evaluated across a wafer.

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REFERENCES


