Accurate Depth Targeting for High Aspect Ratio Deep Trench Etches

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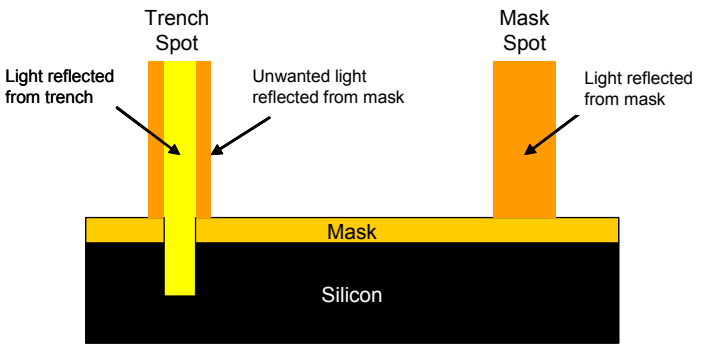
The TDM-200 performs in-situ real-time trench depth measurement during a plasma etch. It therefore can stop the etch at any required depth, no etch stop layer is necessary. The TDM-200 can be mounted on any etch tool with a top viewport over the wafer. It generates two laser beams which interfere with each other. One beam strikes the bottom of the investigated feature, while the other strikes the mask surface, serving as a height reference. The system measures the difference between the optical paths taken by the two beams and exploits the changing polarization state to extract the trench depth continuously during the etch process.

The TDM-200 has previously been available for etches of large features where the laser spot is completely within the feature. However the capabilities of the TDM-200 have now been extended to allow accurate trench depth measurement of small features down to 5 μm (for unidimensional features such as a line). This is achieved by the release of new software which integrates a new patented "Fine Feature" algorithm. In addition to an approximate etch rate this algorithm only requires the etch and passivation times of the Bosch® process.
When the laser spot size is similar in size, or larger than the etched feature some of the light which is nominally reflected from the trench actually comes from the surrounding mask, see diagram below. Initially this is a small effect, but as the etch progresses the trench reflectivity often decreases, as it becomes rough, whereas the mask reflectivity tends to remain constant, therefore this can become significant during the etch. This limits the maximum useable depth of the standard algorithm (the exact limiting depth is process and wafer dependent). However the Fine Feature algorithm overcomes this, using highly optimized real-time data analysis and correction, to extract the relevant information from the acquisition data. This allows the TDM-200 performance to be greatly enhanced for this type of feature.



This application note details the ability of the TDM-200 to accurately monitor a series of 200 μm wide trenches when using the Fine Feature algorithm.

Experimental

The measurements were performed at ADIXEN using a DRIE ICP etching tool model AMS 100 «I-Speeder».
SEM picture and data are provided with the courtesy of ADIXEN.

Test wafers

The samples used to carry out the experiments were silicon wafers with 200 μm line features. Various mask material were used: photo resist, silicon oxide, a bilayer of resist with silicon oxide on top and a bilayer stack of resist and aluminium.

Optical set-up and feature description

Figure 1 shows the top view and a post etch SEM cross section of the 200 μm line feature. The TDM-200 provides a real-time digital CCD image of the wafer surface from its integrated frame grabber (top view image). This allows the accurate positioning of the two laser beams, the top one on the 200 μm wide trench and the other on the mask.

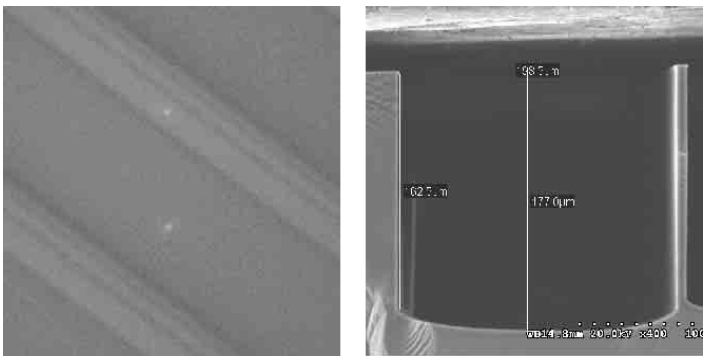


Figure 1. On the left : top view of the feature. On the right : SEM cross section of the 200 µm line (Courtesy of Adixen).

Process Variables

Various Bosch® process parameters such as: the etch time, the passivation time, and the etch rate were investigated.

Ex-situ metrology

The TDM-200's measurements were confirmed after the etch using a scanning electron microscope (SEM). The uncertainty of these measurements is estimated to be ±5%.

Results

Ten wafers were etched during this study and they all gave broadly similar results. The detailed results presented below are from wafer 8.

The trace shown in figure 2 was acquired from a process with an etch rate of 6.0 µm/min. The wafer was coated with a bi-layer of resist and oxide and the process time was 30 minutes. During the process the resist layer was totally removed and the oxide layer started to be etched after around 15 minutes. The resist has a selectivity around 100:1 and an initial thickness of approximately 1 µm. The TDM-200 recorded a depth of 182 µm, while the SEM reported a depth of 177 µm.

The Figure 2 also illustrates the direct improvement provided by the Fine Feature algorithm. It is able to extract the etch depth correctly throughout the process. Notice the etch depth trace is slightly curved indicating that the etch rate decreases as the etch becomes deeper. This effect is commonly seen in this type of etch and it explains why the determination of the correct process time by extrapolation of measurements at different depths is difficult. It also illustrates the added benefit of the TDM-200 to monitor etch rate in real-time. This greatly enhances the information available to the process engineer during process development.

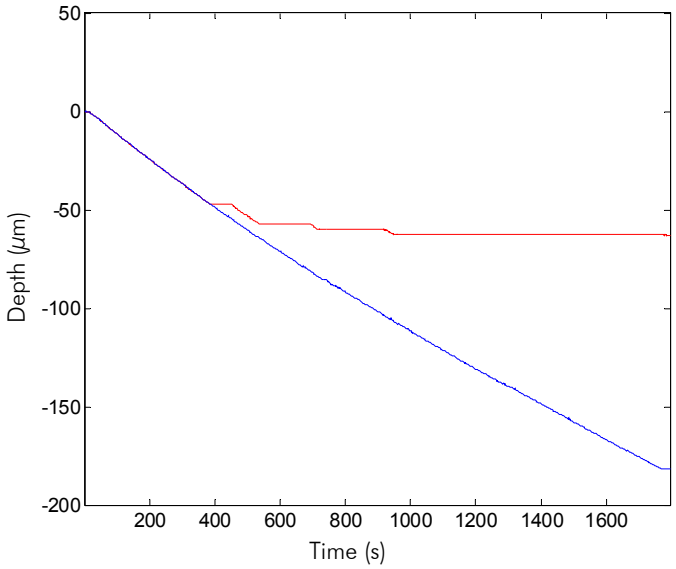


Figure 2. Reprocessed etch depth as calculated by standard algorithm (red) and Fine Feature algorithm (blue).

The following table summarizes the different experiments and their results.

Wafer	Mask	Total Process Time (min)	Etch Rate (µm)	TDM-200 (µm)	SEM (µm)
1	resist	10	2.7	24	23.6
2	resist	6	7.5	46	43.6
3	resist	9	8.9	80.5	79.2
4	resist	15	7.3	107	105.3
5	resist	17	6.7	114	119.6
6	resist	16.5	8.9	147	152.8
7	resist Al	20.5	8.3	171	177.6
8	resist oxide	30	6.0	182	177
9	resist oxide	45	5.0	221	222.1
10	resist oxide	95	5.2	496	505

Table 1. Comparison between the TDM-200 and SEM for a series of measurements on 200 µm lines. Uncertainty of SEM measurements is ±5%.

Conclusion

These results demonstrate the capability of the TDM-200, using its patented Fine Feature algorithm, to monitor in real-time etch depths up to 500 µm on 200 µm line features. The agreement between the SEM and TDM-200 depths is essentially within the 5% uncertainty of the SEM measurements. Additionally the performance of the TDM-200 has been shown to be independent of various mask materials including silicon oxide, photo resist and aluminium. Accurate real-time control of these types of processes is now available, this reduces the etch depth tolerance and makes expensive and time consuming ex-situ metrology redundant.

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