Step Height Comparison by Non Contact Optical Profiler, AFM and Stylus Methods

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Abstract : Tremendous progress in research and development for nanotechnology has resulted in demand for reliability of various measurements at nano level. For example performance and design of MEMS requires measurement of the dimensional parameters, similarly thin films grown for various nanotechnology applications e.g. Solar Cell etc. are measured for their thickness using optical/stylus profilers, AFMs etc. Metrological traceability to these measurements is established using calibrated step height standards. Optical methods are increasingly used for measurement of step height, particularly because of these being non-contact measurements. Optical methods based on interferometry have the advantage that they can be traced directly to SI unit metre. The route of traceability comes through the use of interferometers. The frequency of laser heads used in interferometers is calibrated by comparing its frequency to a primary optical frequency standard. In this paper, we highlight optical methods used in optical profiler, describe some of their characteristics as well as compare measurements of step height standard obtained with three techniques viz. optical profiler, stylus profiler and AFM. For comparative study, measurements have been carried out using Veeco Wyko – NT9800 optical profiler which is equipped with reference laser interferometer for scanner and is traceable to SI unit metre, Ambios Technology XP-200 stylus profiler & Veeco AFM on step heights of about 50 to 500 nm.

Keywords: *Step Height, Optical. Profiler, Stylus Profiler, Atomic Force Microscope (AFM)*

1. INTRODUCTION

Dimensional metrology is one of the key capabilities that underpin the development of micro and nanotechnologies. [1] Measurements of step height at the micro/ nanoscope are vital in the research and development phases for new products and also crucial for monitoring the performance of the device. Traceable calibration of step height is necessary, as it is used as standard for calibration of AFM, microscopes etc. AFM, Stylus Profiler and Optical Profiler are used for step height measurements in a large range of applications including semiconductors, MEMS, biomedical devices, automobile parts, thin film coatings.

Optical Profiler is based on the principle of short coherence length white light interferometry. It can handle a variety of surfaces such as rough, smooth, transparent, opaque, etc. It offers non-contact operation and hence it is non-destructive. This has made it widely employed as tool to metrology tasks. It has an advantage that a large size of specimen can be analyzed with high sub-nanometer vertical resolution and it can be traced directly to SI unit metre definition through calibrated frequency of the laser. However, its magnification is less and it has lower lateral resolution relative to AFM's. AFM offers excellent resolution and magnification. It is independent of materials phase and reflection differences but it is a

slower technique and there is a limitation on the sample size. Stylus Profiler applies scanning with a stylus for the measurement of step height. It does line by line profiling. It is directly sensitive to surface height. It is mostly used in the field of engineering sciences. But it has a disadvantage that being the contact method the stylus may cause deterioration to soft and delicate materials. Thus all the three methods mentioned above have their pros and cons and these are applied to various fields depending on the requirements as discussed above. Since all the three methods measure step height, it is essential to establish the comparability of these. In this paper, the comparison of step height measurements by optical profiler, AFM & stylus profiler has been made.

2. EXPERIMENTAL

The sample for the comparison of measurement was a VLSI [2] step height standard of 46.3 nm and width 100 µm. It was etched in quartz (chrome-coated). It was measured using a three-dimensional optical profiler Veeco Wyko NT 9800 with Vision 32 [3] software. Fig.1 shows the schematic of optical profiler with a Mirau interferometric objective used for the measurement. It is also equipped with a laser (He-Ne 633nm) interferometer for in-situ correction of z scan with traceability to SI unit meter by calibrating laser with respect to the primary standard. The nonlinearity errors are minimized by the use of laser interferometer, resulting in significant increase in measurement accuracy [4].

For the present study, the sample has been measured at magnification of 20X with Mirau interferometer objectives using

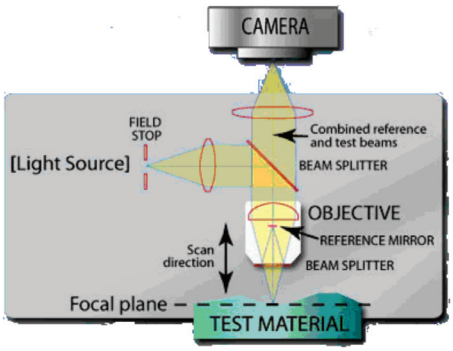

Fig.1 Schematic of Optical Profiler

phase shift interferometry (PSI). During the measurement, a piezoelectric transducer linearly moves the reference surface a small, known amount to cause a phase shift between the test and reference beams. The system records the intensity of the resulting interference pattern at many different relative phase shifts and then converts the intensity to phase data by integrating the intensity data. The phase data are processed by Vision 32 software to remove phase ambiguities between adjacent pixels and the step height is calculated from the phase data[5]. The profiler's data was also processed using ISO 5436 [6] specified method with SPIP software.

The same sample was also measured using AFM (CP2, Veecco) at Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. As the AFM's scan range was limited, the full width of step could not be measured in one scan. Hence this double – sided step was measured as single – sided step on left side and right side. The double sided step height was estimated from the average of these measurements. For the sake of comparison, similar single sided step height measurements were done on the images obtained from optical profiler by line profiling method using SPIP software.

The sample was also measured using Ambios Technology XP-200 Stylus Profilometer [7]. The measurement was evaluated using XP Plus software. [7] The step calculation from the profile was done in a manner similar to the Vision software i.e. neglecting the transition zones. Seven line profiles spaced equally were scanned. Average step height value was calculated from these. The certified step height value and uncertainty of the measurement provided by VLSI for step height standard had also been measured using stylus profiler traceable to National Institute of Standards and Technology (NIST). The expanded uncertainty was measured at 95% confidence level, as defined by the ISO Guide to the Expression of Uncertainty in Measurement.

3. RESULTS AND DISCUSSION

3.1 Results from optical profiler : Fig. 2 shows the 3D view of the step at 20X in PSI

mode and Fig. 3 shows the 2D profile of the step as obtained from optical profiler using Vision software.

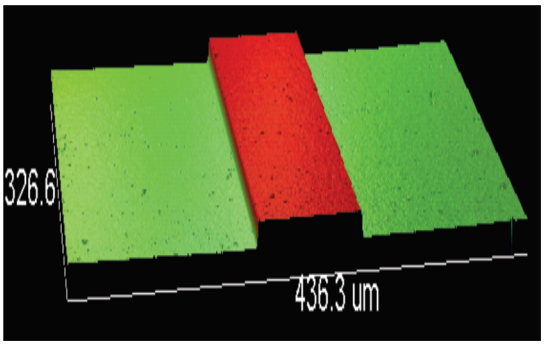

Fig.2 3D views of the step at 20X

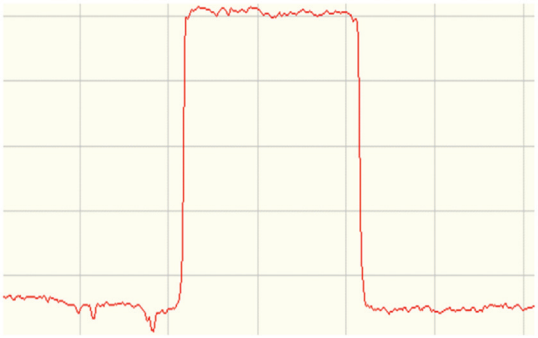

Fig. 3 2D profiles of the step at 20X

In the Vision software algorithm, for the measurement of step height, two lines are fitted – on the top and on the bottom of the profile data neglecting the transition zones.

The measurement of step height was also evaluated using SPIP software. A line-profiling method & the method given in specification standard ISO 5436 [7] were used to get a quantitative value of the step height.

In the line profiling method, the cursor was placed at the left bottom and top height and their difference was given as value for left side step. The measurement was repeated 50 times and their average step height value was calculated. The same procedure was repeated 50 times for right side step and their average step height value was calculated. The values are shown in Table 1.

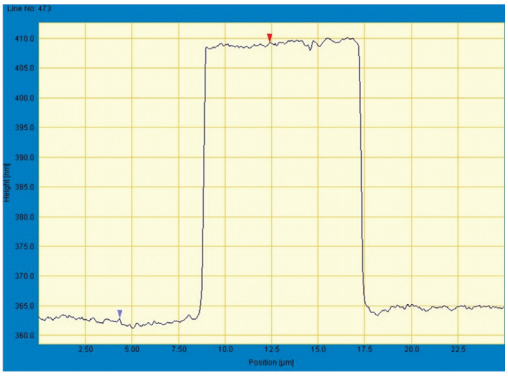

Fig. 4 Line Profiling Method applied to optical profiler image

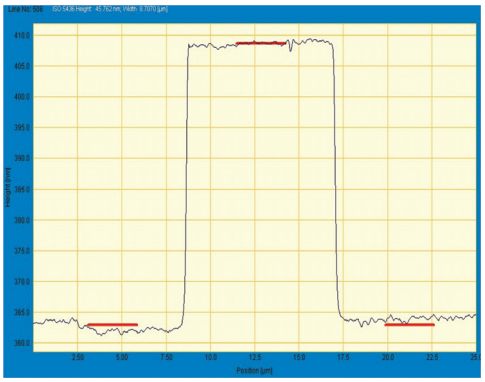

Fig. 5 ISO 5436 Method applied to optical profiler image

In ISO method, first the edges of the step were identified and this was done by searching for the maximum slope of the profile. For a single-sided step, a single edge was found. For a double-sided step, two edges were found. The transition zones were then removed from the data and only top and bottom where slope is nearly zero was considered. After the edge transition points have been found, two parallel lines were fitted, using a least square algorithm, to the profile data over specified portions at the top and the bottom of the step, and the step height was given by the separation of the two lines. The measurement was repeated 50 times & their average step height value is shown in Table 1.

3.2 Results Obtained by AFM: Fig.6 shows the image as obtained by AFM. The

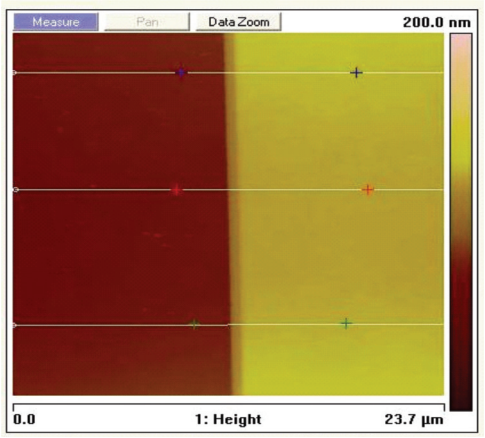

Fig. 6 AFM image o the step

Table 1 Step height measured by stylus profiler, optical profiler and AFM

Double Sided Step					Average of two single sided step	
	Cert Value	Stylus method	Optical profiler with vision software	Optical profiler with ISO 5436	SPIP+ Profiler	AFM
Step height value (nm)	46.3	46.19	45.58	45.69	45.87	45.38
Standard deviation (nm)	U=1.3 at k=2	0.45	0.1	0.13	0.23	+0.48
Deviation from certified value (nm)		0.11	-0.58	-0.61	-0.44	-0.92

estimated step height given in Table 1 is average of six measurements.

Images for left side and for right side of step were obtained and the distance between highest and lowest point following a plane fit to the area was calculated to represent step height.

3.3 Result Obtained by Stylus Profiler: Step measurements as obtained by stylus profiler are shown in Fig.7 and Table 1

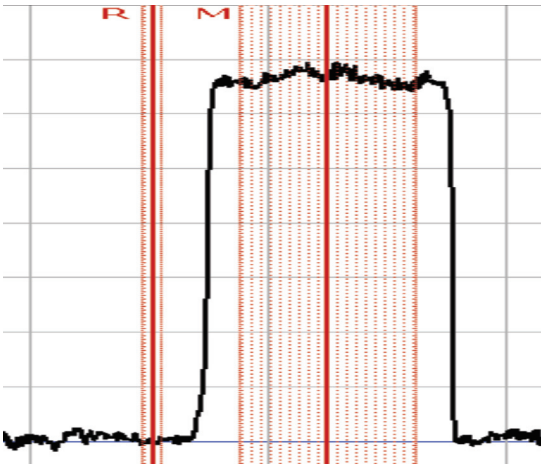

Fig. 7. Profile obtained by stylus measurements

A comparison of average step height obtained by optical profiler and AFM is shown in Table 1

4. CONCLUSION

It can be seen from the results that the values obtained by stylus profiler and optical

profiler matches within the uncertainty of measurements. However on a closer observation, one observes that match between the two stylus profiler values is better (< 0.12 nm) than the optical profiler. Also double-sided step measurement by vision software algorithm and ISO 5436 algorithm agree well. Thus it can be concluded that the effect of algorithm change is negligible.

The difference from the certified value is largest in case of AFM measurements. AFM measurements differs from the certified value by 0.92 nm whereas the uncertainty of certified value is ±1.3 nm at k =2. It may be attributed to the fact that the certified value is a double sided step measurement carried out on whole step and evaluated by ISO method on a wider area of step as compared to the area scanned by AFM.

Thus for the step height in question the measured values by three methods agree well. However a more detailed study for various ranges of step heights is required further.

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