50th Anniversary Product

UT-300 Series Automatic Ultra-Thin-Film Analyzer

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Technological development of semiconductor devices including DRAM has been remarkable. Development of new thin film materials, film thinning and multi-layering are essential to such technological development. In semiconductor device production, accurate measurement of the thickness of thin films is regarded as an important factor in improving productivity. Thus, lots of manufacturing processes include a thin film measurement process. This paper explains the UT-300 Automatic Ultra Thin Film Analyzer, that automatically measures optical indices such as the thickness of semiconductor thin films, refractive index, and extinction coefficient. In particular, a chief requirement for thin films is accurate measurement of minute areas. This paper focuses especially on the UT-300H, which because of improvements in the optical system of the original UT-300 can measure minute areas.

Introduction

There are various measurement means of obtaining optical indices such as thin film thickness and refractive index. In thin film measurement techniques, attention has been focused in particular on the spectroscopic ellipsometer, which can accurately and nondestructively calculate thin film thickness and refractive index. UVISEL, a spectroscopic ellipsometer developed by HORIBA Jobin Yvon for research and development, is used by many customers and widely contributes to semiconductor research and development. On a semiconductor production line, it is necessary to set up cassettes in which the wafers to be measured are carried automatically or manually to the cassette station, take out wafers from the cassette and carry out only the procedures for which measuring conditions are preset, then return the wafers to the cassette after the measurement (C to C). In addition, it is necessary to transfer the measurement data to the host computer, manage the data, and thereby improve productivity. HORIBA has cultivated automatic handling systems in semiconductor processes and in-house data communication technology. By integrating the technologies of the HORIBA group, the Automatic Ultra Thin Film Analyzer UT-300 (Figure 1) was developed. In order to improve device productivity, it is necessary to directly measure the actual samples rather than dummy wafers. For this purpose, it is a prime requirement that the UT-300 can measure minute areas.

Figure 1 Fully Automatic Ultra Thin Film Analyzer UT-300

Operating Principles of the Spectroscopic Ellipsometer

A spectroscopic ellipsometer is an instrument that measures variations in polarization states from reflected light. This method has been widely used for evaluation of semiconductors and organic thin films in recent years. It is superior in terms of both precision and sensitivity to the optical interference method that uses two oscillating elements in the same optical path.

The ellipsometer illuminates the sample with p-polarized and s-polarized light and obtains film thickness and optical indices, etc. from the reflected light due to variations in the polarization states. The polarization states are indicated by the superposition of waves that propagate over two straight coordinate axes. As shown in Figure 2, the ellipsometer expresses the polarization states of incident light and reflected light using the p and s polarization coordinates. Incident light is a linear polarization inclined 45 degrees from the p and s polarization coordinates. When incident light illuminates a sample, changes occur in the amplitude and phase contrasts of both the p-polarization and s-polarization, which generally results in elliptically polarized light. The ellipsometer measures two values, Δ (phase contrast of p-polarization and s-polarization) and ψ (amplitude ratio of p-polarization and s-polarization) expressed by angle. When the sample has an ideal structure, refractive index n and extinction coefficient k of the sample can be calculated from Δ and ψ obtained from the ellipsometer. Because the spectroscopic ellipsometer performs multiple-wavelength measurements, relationships $(d, n(\lambda), k(\lambda)) = \mathrm{f}\,(\Delta(\lambda), \psi(\lambda))$ are established. As a result, film thickness d and optical indices n and k can be also obtained at the same time.

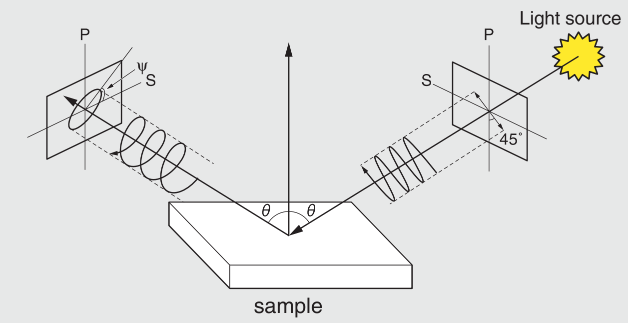


Figure 2 Operating Principles of the Ellipsometer

Consideration of Incident Angle θ and Solid Angle α

One of the important stipulations for thin film measurement is measurement of minute areas. In order to obtain precise measurement results from the spectroscopic ellipsometer, the angle at which incident light illuminates the sample (hereinafter referred to as the incident angle θ) and the solid angle of the focused beam on the sample (hereinafter referred to as solid angle α) are optically important as shown in Figure 2. In general, a Brewster angle[*1] is set up for the incident angle in the spectroscopic ellipsometer's measurements. We set up the Brewster angle of semiconductor device base-material silicon wafers at 76.1 degrees and the incident angle θ at 75 degrees in consideration of various sample analyses. However, beams must be narrowed down up to a quarter to obtain the target spot size, because the 75-degree incident angle of light flux increases the spot size on the sample by 4 times in the major axis direction. Beams on the sample are generally narrowed down by increasing solid angle α. In the spectroscopic ellipsometer's measurements, however, incident angle θ is also an important factor for the analysis. Consequently, increasing solid angle α makes it difficult to perform accurate measurements, because information on the incident angle θ becomes less accurate. Therefore, we conducted studies of an optical system that can reduce the spot on a sample efficiently while keeping incident angle θ at 75 degrees and solid angle α at 1.6 degrees.

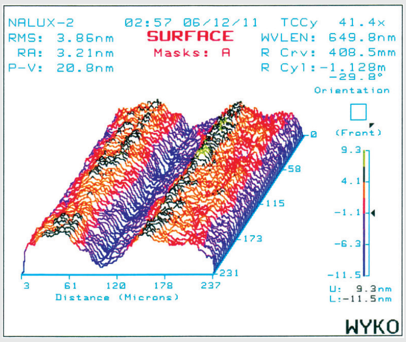
[*1] Incident angle at which the reflection coefficient against p-polarization is reduced to zero when light reflects on the sample surface.

Optical Design

In general, a parabolic mirror is used to narrow down spots more. Needless to say, the manufactured accuracy of the parabolic mirror affects the spot size. We focused on either machining or grinding as possible mirror manufacturing methods, finally electing to use the machining method, because grinding produces poorer accuracy of form. However, the machined mirror exhibited grating-like tool marks on its surface (Figure 3(a)), which resulted in light diffraction making several spots on a sample as shown in Figure 3(b). In order to reduce this influence as far as possible, we took the machining methods and materials into consideration and selected the mirror accordingly.

Furthermore, a polarizing prism must be placed between the collection mirror and sample because the spectroscopic ellipsometer that measures variations of polarization states needs to illuminate the sample with linear polarized light. This caused chromatic aberration, which then became a beam-narrowing issue. Because it is impossible to make a polarizing prism into a lens shape (and so remove chromatic aberration) due to its structure, the spot size must be evaluated while considering chromatic aberration.

(a) Mirror surface



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NALUX-2            02:57 06/12/11   TCCy   41.4x
RMS:  3.86nm       SURFACE        WVLEN:  649.8nm
 RA:  3.21nm       Masks: A       R Crv:  408.5mm
P-V:  20.8nm                      R Cyl:-1.128m
                                        -29.8°
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(b) Diffracted light due to tool marks

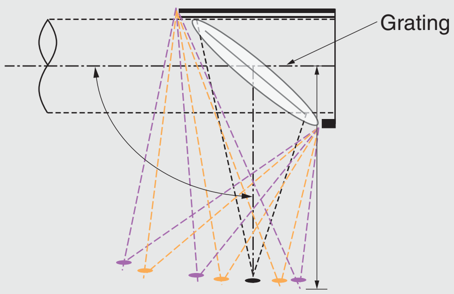
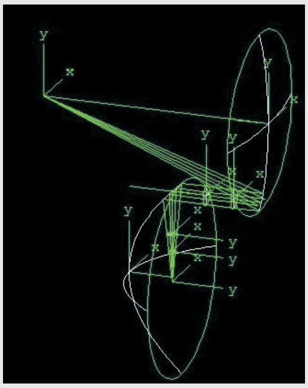


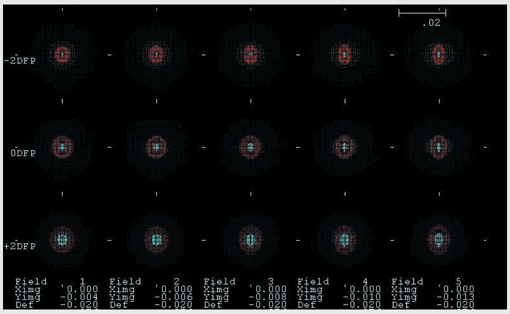
Figure 3 Mirror Surface and Diffracted Light due to Tool Marks

While undertaking various tasks, we conducted an optical simulation (Figure 4(a)) for narrowing down beams more efficiently and examined an optical layout that can narrow down beams efficiently. During simulation, we collectively calculated the spot diagram (Figure 4(b)) and point spread (Figure 4(c)), and estimated that the image size becomes approximately 30 μm without using a polarizing prism. It is estimated that the size at the major axis side then becomes approximately 120 μm as a result of 75-degree incident angle. We considered that the target size, 200 μm × 400 μm can be achieved even if tool marks and chromatic aberration were taken into account, and went ahead with the design.

(a) Consideration of optical layout



(b) Spot diagram



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Field       1   Field       2   Field       3   Field       4   Field       5
Ximg    0.000   Ximg    0.000   Ximg    0.000   Ximg    0.000   Ximg    0.000
Yimg   -0.004   Yimg   -0.006   Yimg   -0.008   Yimg   -0.010   Yimg   -0.013
Def    -0.020   Def    -0.020   Def    -0.020   Def    -0.020   Def    -0.020
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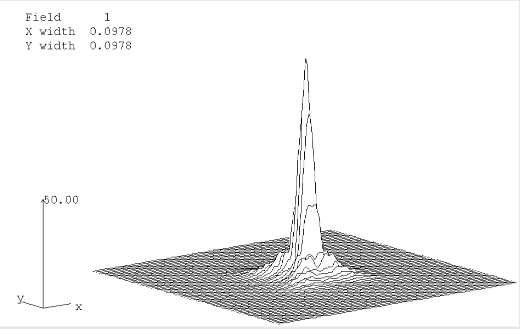
(c) Point spread of light



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Field      1
X width  0.0978
Y width  0.0978
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Figure 4 Optical Simulation

Evaluation of Microspots

After completion of the optical design and parts selection, microspot size evaluation became an important issue after all. Even if the light beam is narrowed efficiently, it is difficult to narrow it down completely. Also, as mentioned above, the spectroscopic ellipsometer is an instrument that analyzes optical properties according to variations of polarization detected from a sample. Thus, if materials outside the measurement area have a large influence on the polarization states, even a small amount of light affects the measurement result a great deal. Considering light intensity distribution, generally the intensity in the central section is strong and gradually weakens away from the center (Gaussian distribution) and the spot diameter is defined as $1/e^2$ (approx. 13%) of the maximum of the portion where the light intensity is highest. However, accurate measurement becomes difficult when other material information (approx. 13%) is present. Hence, we evaluated the spot size using a step test, which is an evaluation method closer to measurement results.

In a step test, two kinds of samples are prepared on which films made of totally different materials are formed. They are moved onto the stage by a minute step feed, and then variations of the spectrum are obtained by the spectroscopic ellipsometer. Because variations for respective wavelengths can be measured simultaneously, the spot size differences between wavelengths caused by chromatic aberration can be observed. Further, it is possible to include evaluations of the effects of experimental influence, because the spectrum measured by the ellipsometer is directly evaluated (Figure 5). In the step test, we regarded ±2% of the mean spectrum as the threshold and the amount of stage movement required for the signal change from that point as the spot size. The spot size obtained from our step test was 115 μm × 150 μm (Figure 6), and it was verified that precise measurements can be achieved within the target area, 200 μm × 400 μm.

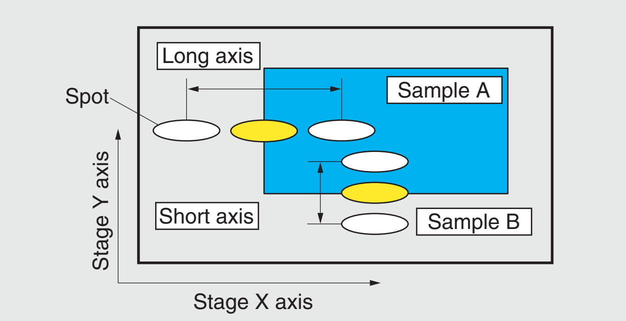
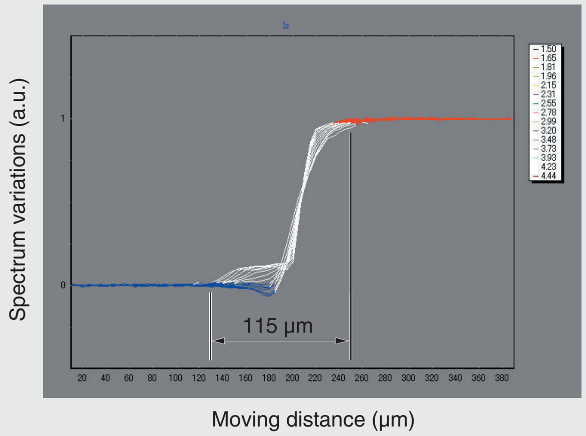


Figure 5 Schematic Diagram of Step Test

(a) Short axis



(b) Long axis

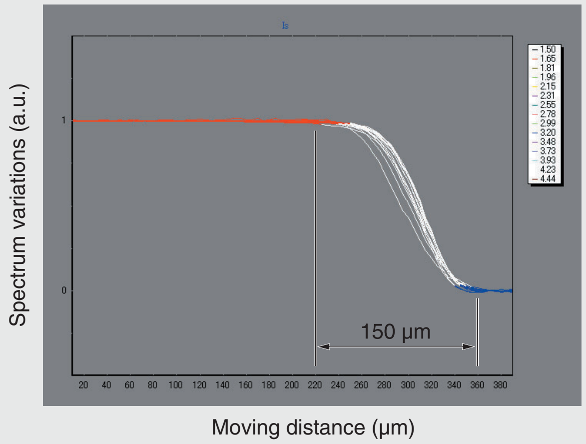


Figure 6 Result of Step Test

Conclusion

It is considered that semiconductor device technologies will continue to develop and the need for fully automatic measurements will expand further. As the requirements increase for smaller and smaller minute-area measurement, so we are studying the possibilities for fulfilling them. At present, we have completed a demonstration instrument for measuring more minute areas. At the same time, we are working toward improvement of quality and performance. We would like to develop instruments in response to customer needs by making full use of various measurement techniques of the HORIBA group and integrating them with the full automation techniques cultivated in the UT-300.

Reference

[1] Y. Nagai, M. Magari, R. Benferhat, S. Hirakawa, N. Nabatova-Gabain, Y. Wasai, H. Iida, Full Automatic Spectroscopic Ellipsometer UT-300, *Readout English Edition*, **5**, 11-23 (2003).

[2] Hiroyuki Fujiwara, Spectroscopic Ellipsometry (2003, MARUZEN).