FEATURE ARTICLE

Full Automatic Spectroscopic Ellipsometer UT-300

Part 2 : Basic Principles of Spctroscopic Ellipsometry and Photo-Elastic Modulator

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Abstract

Recent advances in thin film technology, especially in semiconductor one, are providing new opportunities and challenges for the development and application of spectroscopic ellipsometry in thin film metrology. Nowadays precise determination of film thicknesses, optical properties and surface morphology are extremely important to produce high quality devices .

JY's spectroscopic ellipsometer is based on the use of a PEM modulator, which allows fast and accurate measurements. The optical system combines with a powerful numerical data acquisition system, that enables real time multiple wavelength computing. We compare JY's technology with other systems, such as rotating polarizer type of ellipsometer. As detailed in another paper from this serie, PEM ellipsometer proves to be the most sensitive and precise technique for ultra thin films measurements.

1 Introduction

Thin film materials pervade our everyday life. We are familiar with transparent conductors in LCD watches and computer displays, antireflection coatings, glass coatings for both color and energy efficiency, a large variety of microelectronic and optoelectronic devices, hard coating... Without thin film technology our way of life would not be the same.

Only about 25 years ago the variety of deposition and etching techniques for preparing thin films based devices was relatively limited. Now a certain level of process sophistication and system integration has been achieved and, consequently, more and more precise characterization of the thin films used is required in order to produce quality devices.

The sensitivity of ellipsometry to thin films and surfaces has been well known for over a century. However, it is only in the last two decades that this non-destructive technique has become an automated, fast, sensitive and highly reliable tool for thin film structures characterization.

2 Spectroscopic Ellipsometry : Theory and Data Analysis

Spectroscopic ellipsometry measures the change in the polarization state of probing light, introduced by its interaction (through reflection or, more rarely, transmission) with the sample under study, and as a function of wavelength. This change is usually described by two angles (Ψ) and (Δ), which express the ratio ρ of the complex reflection coefficients Rp and Rs of the sample (the indices « p » and « s » stand for light polarized parallel (p) and perpendicular (s) to the plane of incidence (Fig.1).

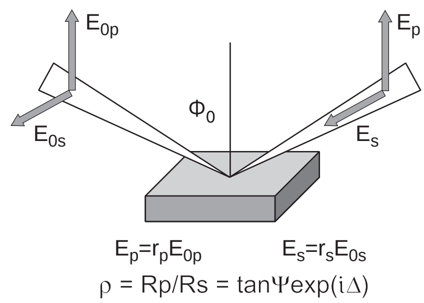

Fig.1 Polarization of Reflected Light

The reflection coefficients are determined by the optical properties and composition of the substrate and the overlying layers, by their thicknesses and morphology, and by surface roughness. In order to deduce the unknown parameters of the sample under investigation, a model which optically describes the sample structure is built. This model contains initial estimates of the parameters sought. The parameters are then varied to generate a set of calculated Ψ_{calc} and Δ_{calc} that fits best the measured data.

Data fitting consists in minimizing the mean-square deviation χ^2 between calculated and measured ellipsometric parameters (Ψ and Δ):

$$\chi^2 = \Sigma_{i=1..N}\Sigma_{j=1..M}[\{\Psi_{calc}(\lambda_i,\varphi_j)-\Psi_{measure}(\lambda_i,\varphi_j)\}^2 + \{\Delta_{calc}(\lambda_i,\varphi_j)-\Delta_{measure}(\lambda_i,\varphi_j)\}^2]/(2N-P-1)$$

where the sum is taken over all measured wavelengths λ_i and angles of incidence φ_j; P is the number of unknown material parameters and N, the number of experimental data points . The values of the varied parameters obtained after a χ^2 minimum has been achieved are then taken to be the best statistical estimates of the material parameters descibing the sample properties.

3 Spectroscopic Phase-Modulated Ellipsometry (SPME): Principle of Operation and Instrumentation

The optical set-up of SPME in the UV-visible range is displayed in Fig.2. The excitation head consists of a light source, a polarizer and a photoelastic modulator. After reflection on the sample the emerging light beam goes through an analyzer and a monochromator before being detected by the detector. The last three optical elements form the detection head.

The photoelastic modulator consists of a fused silica block glued to a piezoelectric crystal quartz bar oscillating at the frequency of 50 kHz. This generates a periodic phase shift $\delta(t) = A \sin(\omega t)$ between two orthogonal amplitude components of the transmitted beam.

The detected intensity takes the general form :

$$I(t) = Io + Is \sin \omega t + Ic \cos 2\omega t$$

Where Is and Ic are function of (Ψ , Δ) .

In the UVISEL system , the Fourier analysis of the signal is carried out by a Digital Signal Processor. This fast microprocessor system (cycle time < 100ns) is specially dedicated to fast fourier transform computation. Finally the DC and the first two harmonics of the signal are continuously transmitted to a PC. The intensity ratios then directly yield the ellipsometric parameters Ψ and Δ characterizing the sample under study. Fig.2 shows the schematic diagram of the spectroscopic phase modulated ellipsometer.

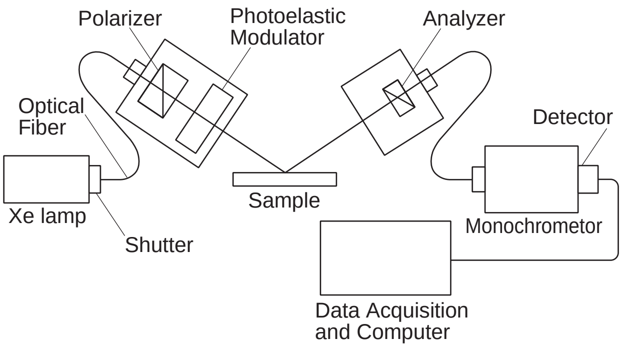

Fig.2 Schematic Diagram of the Spectroscopic Phase Modulated Ellipsometer

3.1 Rotating Polarizer / Rotating Analyzer Types : Simple, but Slow and Inaccurate

Rotating a polarizer at constant speed is a simple technique : it does not need additional elements, and modulation is the same for all wavelengths. However, measurements are relatively slow, limited by mechanical rotation speed (few 10 or 100 Hertz). In addition, such modulation frequencies fall within noise range from other mechanical devices, that can perturb data acquisition. Also, such systems are affected by source or detector residual polarisation sensitivity, or by polarizer inhomogeneities over the beam rotation. Such imperfections can partially be reduced by a calibration, but they can drift with time, thus introducing errors.

Signal equations from a rotating type ellipsometer provide functions of $\tan(\Psi)$ and $\cos(\Delta)$: Δ precision is low, in the regions where $\Delta = 0$ (180°). As it turns out that Δ is the most sensitive parameter to small changes, such as from ultra thin films, Δ precision is extremely important to determine ultra thin films.

3.2 PEM : Fast and Accurate

JY's PEM ellipsometer combines two key elements : phase modulation and an entirely numerical data acquisition and processing system. These features allow for a robust design with no mechanically moving parts, and for rapid and precise measurements.

The PEM is a transparent quartz bar (Fig.3), to which is applied a sinusoidal vibration, though piezo-electric elements : an electrical signal is applied to piezo electric transducers that induces mechanical strain and is transfered from the piezzo to the quartz bar. This mechanical strain induces a periodical birefringence into the quartz bar. When polarized light is going through the modulator, it is affected by the modulated birefringence, and as a result the two components undergo a modulated phase shift : an input linearly polarized beam becomes elliptically polarized at the output of the modulator, and the size of the ellipse is modulated at the frequency of modulation. This modulation is performed without any mechanical movement, resulting in improved signal stability and accuracy. Signal equations provide tan(Δ) and cos(2Ψ) : Δ precision is thus excellent over the whole range.

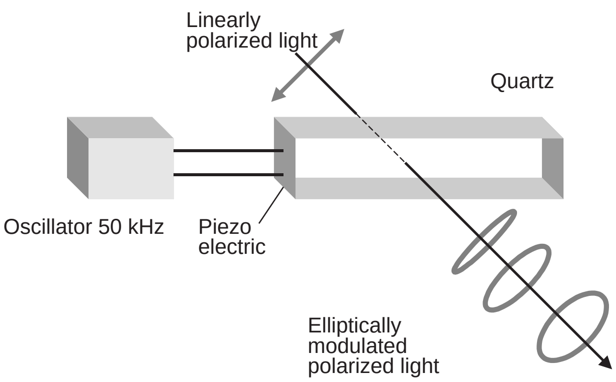

Fig.3 Principle of Photo-Elastic Modulator

The PEM high frequency modulation (50kHz) allows fast measurement, with minimum 5ms acquisition time. The fast electronic acquisition filters out noise due to low frequency vibrations which results in higher signal to noise ratio than Rotating Polarizer modulation. Because it results from a sustained oscillation, each PEM frequency is fixed by the bar length and thus extremely stable (less than few Hertz jitter). In addition, our new real time multichannel data acquisition system can perform simultaneous measurements over multiple wavelengths, without increasing integration time.

PEM requires a more careful control that a rotating polarizer, but Jobin-Yvon has acquired this knowledge, as PEM are used in JY's dichrographs for more than 20 years. The amplitude of modulation is calibrated from fabrication versus electrical signal, and versus wavelength. Modulation is internally controlled, so as to provide easy and extremely stable measurements. This requires in particular, a good PEM thermal stability.

4 Conclusion

Spectroscopic phase-modulated ellipsometry, being a non-desctuctive, fast, precise and easy-to-use optical technique is on the way of becoming an invaluable tool for the thin film materials characterization. The application fields cited above are only a part of a whole list of various actual and potential applications of SPME to microelectronics or elsewhere. With the increasing complexity and lowering the size of the samples SPME has an ensured future owing to its high instrumentational sensitivity and accuracy, and advanced modeling software capabilities.

References

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