Thin-film Characterization by SNOM

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Abstract

This paper presents a near-field ellipsometry method for ultra-thin thin film characterization in nano-scale resolution. The method is based on the fusion of the topographic and ellipsometric optical measurements that are simultaneously obtained by a scanning near-field optical microscopy (SNOM). Experimental investigation has shown that the proposed near-field ellipsometry method can attain nano-scale lateral resolution and artifact correction in characterization of ultra-thin thin film.

1 Introduction

Nowadays ultra-thin thin film has been widely used in many applications such as sensors [1] and optical waveguides [2]. Unfortunately, imperfections are inevitable in practical fabrication of thin film. Hence, thin film characterization is necessary, which is basically to measure the thickness and the refractive index of each thin film layer. The traditional characterization methods include the ones based on surface plasmon resonance [3] and the ones based on optical ellipsometry [4]. However, the lateral resolution of the traditional characterization methods is limited by the optical diffraction limit which is about half the wavelength of the optical light used. Moreover, since the optical ellipsometric measurements are related to the thickness and the refractive indexes by complex coupled equations, numerical solution of the equations gives rise to erroneous results and in turn results in the artifacts. Therefore, it is imperative to have high resolution and reliable thin film characterization methods.

In this paper, a near-field ellipsometry method is proposed. Like traditional ellipsometry methods, the proposed method still uses light polarization to establish the ellipsometric equations of the thickness and the refractive index of all thin-film layers. However, unlike the traditional ellipsometry methods, the proposed method uses two unique features of an aperture SNOM. The first feature is that SNOM can achieve nano-scale lateral resolution going beyond the diffraction limit. The second feature is that SNOM can measure simultaneously the optical and the topographic characteristics at the top layer of the thin-film. These characteristics allow us to construct an extra constraint that helps correct errors in numerical solutions of ellipsometric equations. Thus, the artifacts can be removed in characterization.

2 Theoretical formulation of near-field ellipsometry

In the proposed near-field ellipsometry method, a polarized light is incident through a prism on the bottom surface of the thin film under characterization, as shown in Figure 1. A SNOM probe is placed above the upper surface of the thin film to collect the evanescent wave generated by the polarized light.

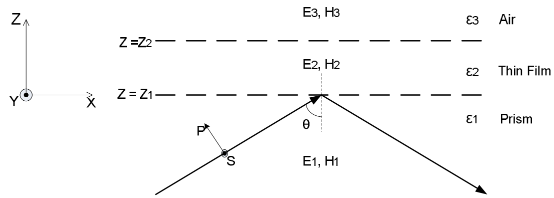

Figure 1: A single layer thin film on a prism. E_i, H_i and ε_i denote respectively the electric field, the magnetic field and dielectric constant of i-th layer. P- and s-polarized light represent the electric fields parallel and perpendicular to the incident plane, respectively.

For s-polarized light, the electric field only vibrates along y direction, but for p-polarized light, the electric field has two components: one along x direction and the other along z direction. Using the conclusion of [5], only the transverse field (*i.e.*, the x component) can be coupled into the fiber probe and measured by SNOM. Applying this knowledge together with Maxwell equations and boundary conditions, the ellipsometric equations are obtained by the ratios between the transmission coefficients of the x and y components. They are given by:

$$\rho = \frac{k_{z_1}[(\varepsilon_2 k_{z_1} + \varepsilon_1 k_{z_2})(\varepsilon_3 k_{z_2} + \varepsilon_2 k_{z_3}) + (\varepsilon_2 k_{z_1} - \varepsilon_1 k_{z_2})(\varepsilon_3 k_{z_2} - \varepsilon_2 k_{z_3})e^{2jk_{z_2}d}]}{\varepsilon_2 \varepsilon_3 k_{z_3}[(k_{z_1} + k_{z_2})(k_{z_2} + k_{z_3}) + (k_{z_1} - k_{z_2})(k_{z_2} - k_{z_3})e^{2jk_{z_2}d}]}, \quad (1)$$

In the equation, ε_2 and d are the dielectric constant and the thickness of the thin film respectively. They are the unknowns to be solved. In addition to the ellipsometric equations, one more equation of the two unknowns can be established by virtue of the topographic information that is obtained simultaneously with the near-field optical signals in the SNOM. When the SNOM is operating in a constant separation mode, we can conjure a virtual straight line A along the probe's scanning direction. Further assuming that the sample has a flat bottom line, we can define a constant d_0. As shown in Fig. 2, d_0 is related to the topographic reading d_A and the sample thickness d by

$$d_0 = d + d_A \cdot \qquad (2)$$

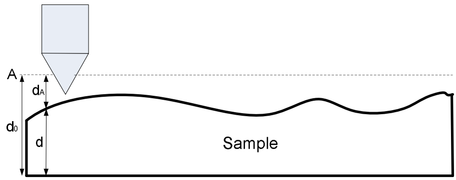

Figure 2: Schematic of the AFM and ellipsometric SNOM relationship.

The two unknowns can be determined by solving (1) and (2). This is the principle of the proposed near-field ellipsometry method. Since the equations are transcendental, numerical algorithms like Newton-Raphson algorithm are usually used. It is noted from this theoretical formulation that the proposed near-field ellipsometry is not limited to characterize single layer thin film, and it can also be extended to characterize multi-layer thin film structures by using the topographic relation as an extra constraint to multiple unknowns.

3 Experiment results

The performance of the proposed near-field ellipsometry method is investigated by experiments. The thin film sample is prepared by coating 50nm-thick gold on the surface of a glass plate, and the plate is placed on a BK7 glass prism with refractive index matching oil filled in between the glass plate and the prism. The light source used is a He-Ne laser with wavelength of 632.8 nm, and the polarization of the light is controlled by a polarizer and quarter-wave plate. An area of 0.8 μm×0.8 μm of the thin film is scanned by a homemade SNOM.

We first calculate the thickness and the refractive index distribution by using the near-field ellipsometry given in (1) and (2). The results are shown in Fig. 3(a) and Fig. 3(b), respectively. Their counterpart results obtained by using only (1) are given respectively in Fig. 3(c) and Fig. 3(d). Since we are using single layer thin film, the refractive index distribution should follow the same pattern as in the topographic image. Thus, the results in Fig 3(c) are clearly artifacts. This shows that the proposed near-field ellipsometry method can attain characterization artifacts correction in addition to the nano-scale lateral resolution. This advantage is leveraging on the fusion of topographic and optical characteristics which are available simultaneous in a SNOM system.

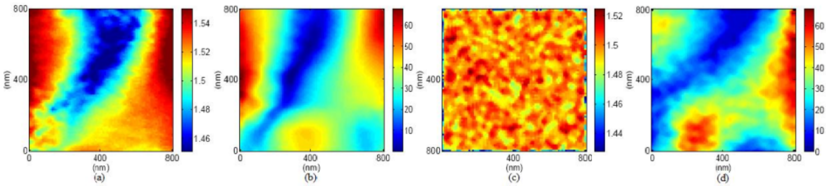

Figure 3: Experimental characterization results of a single layer thin film: (a) Refractive index calculated with Eq. (1) and (2); (b) Thickness calculated with Eq. (1) and (2); (c) Refractive index calculated with Eq. (1) only; (d) Thickness calculated with Eq. (1) only.

3 Conclusion

In this paper, we proposed a near-field ellipsometry method for thin film characterization. The method has demonstrated nano-scale lateral resolution by leveraging the capability of SNOM in overcoming the diffraction limit. By fusing the topographic information with the ellipsometric optical signal, the method is capable of correcting artifacts. Thus, the proposed method is expected to be a promising technique for high resolution and reliable thin film characterization.

References:

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