Measurement of Aluminum Thin Film Thickness by Fizeau Interferometer Technique

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ABSTRACT

Thickness measurement of thin film coated on a substrate is very important since properties of the film depend largely on its thickness. Several methods are available for the measurement; however, most of them require destruction or modification to the measurement surface. In addition, some nondestructive methods such as X-ray fluorescence technique are complicated and expensive. Therefore, the main objective of this work is to study a less expensive nondestructive technique for thin film thickness measurement using an optical technique called Fizeau interferometer. In this method, thickness of thin film is determined as a difference of measured position of interference fringe patterns. An experiment was setup to examine its performance by comparing with a stylus profiler technique. Results showed that the approach could be used to measure Aluminum thin film of thickness between 0.11-0.39 µm with a comparable accuracy to the stylus profiler.

Keywords: Aluminium thin film, Thin film measurement, Fizeau interferometer

1. INTRODUCTION

Thin film technology is nowadays used in many industries to improve quality of their products. The deposition of thin films on a glass substrate can change physical properties of the specimen. One important factor that has a principal effect on the characteristic of a workpiece is the thickness of the coated film. Film thickness has a direct effect on physical properties of the specimen such as optical transmission, reflection and electrical resistance.

Film thickness is defined as the perpendicular distance from any point on a surface to the other end of the film. There are several methods [1] for thin-film thickness measurement, for instance, weighing, X-ray fluorescence and stylus profiler techniques. Each technique has difference benefits and drawbacks. Normally, the selection is based on the type of the film, range, resolution and accuracy of the measurement.

This paper presents a Fizeau interferometric technique to measure the thickness of Aluminum thin film coated by sputtering technique on a grass substrate. The technique is a nondestructive method which uses an optical arrangement together with interferometric principle. The result from this approach is compared to that from stylus technique [2] to determine its performance.

This paper is organized as follows. The next section provides theory of thin film thickness measurement using Fizeau Interferometer and stylus profiler. Sections 3 and 4 describe experimental setup and results respectively. Conclusions and discussion are presented in Section 5.

2. THEORY

2.1 Interferometric Technique

Fizeau Interferometer (FI) is normally used for testing surface flatness, etc. In this work, this technique is used for measuring thin film thickness. The principle of FI is based on a separated amplitude interference [3,4].

When a light wave incidents on a glass substrate coated by a metallic film, it will separate into two rays: transmitted and reflected waves. The two will have lower amplitudes than the original and if the path difference between the two is within a coherence length, a fringe interference pattern will appear.

\[ \text{OPD (}\Delta\text{)} = \frac{2ncos\phi'}{n-1} \]

where \(n\) is the refractive index of the film, \(d\) and \(\phi'\) are the film thickness and refractive angle of the light respectively.

Fig. 1: An Optical Path Difference of radiation

The above principle can be applied to thin-film measurement as shown in Fig 1. As light incidents on one surface of a parallel thin film, one ray will be reflected while the other will pass through the surface of the thin film and get reflected at the interface between the film and the substrate. The two rays will combine at one point. Since they travel by different paths, there will be a phase difference between the two. This phase difference will generate interference and the thickness measurement can be computed from the Optical Path Difference (OPD) as follows.
Since reflection on the surface between A and B is a reflection from high density medium, the reflection ray will experience a phase change of $\pi$ radian. The interference can be expressed as follows equations.

For stimulate interference pattern
\[2nd \cos \phi' = \left( m + \frac{1}{2} \right) \lambda \]  \hspace{1cm} (2)

For destroy interference pattern
\[2nd \cos \phi' = m \lambda \]  \hspace{1cm} (3)

where $\lambda$ is the wavelength of the light and $m=1,2,\ldots$.

### 2.2 Fizeau Interferometer

If the surface planes of film are not parallel, the contours arise from this non-uniform film are called Fizeau fringes. Form the principle of Fizeau fringe when the observer looks from vertical angle ($\phi=\phi'=0$), the equations (2) and (3) become as follows.

For stimulate interference pattern
\[2nd = \left( m + \frac{1}{2} \right) \lambda \]  \hspace{1cm} (4)

For destroy interference pattern
\[2nd = m \lambda \]  \hspace{1cm} (5)

![Fig. 2: Picture of interference fringe patterns](image)

If we add a partially transparent thin-film plate of the same type on top of the specimen and manage to have a thin wedge arrangement of a small angle as illustrated in Fig 2, an air film will be formed between the two plates. Using refractive index of air $n=1$, the thickness difference, $\Delta d$ between interference fringe patterns follows the equation
\[\Delta d = \frac{\lambda}{2n} \]  \hspace{1cm} (6)

The film thickness, $t$ can be calculated from the fringe patterns shown in Fig 2 using
\[t = \frac{\Delta d \Delta S}{S} \]  \hspace{1cm} (7)

or
\[t = \frac{\Delta S \lambda}{2S} \]  \hspace{1cm} (8)

where $\Delta S$ and $S$ are the shift between interference fringes and the fringe width respectively.

### 2.3 Stylus Technique

Surface measurement using a stylus profiler is the most widely used technique for surface characterization [2]. Typically the method provides surface roughness parameters; however, it can be applied for the measurement of thin film thickness.

The stylus profiler consists of a diamond-tip pin probe connected to a magnetic pickup coil. The signal obtained from the profiler is the vertical displacement of the probe along the horizontal path as the probe is moved. The application of the instrument to thin film thickness measurement can be done by preparing a step of metallic film coated on the testing substrate. The probe is then run across the step edge as shown in Fig 3.

![Fig. 3: The application of stylus profiler to thin-film thickness measurement](image)

### 3. EXPERIMENTAL SETUP

In our experiments, Aluminum (Al) was deposited as a thin film onto a glass substrate by sputtering method. The film was grown up with pressure of $4.0 \times 10^{-3}$ mbars, input voltage of 450 volts, and input current of 200 mA. The thickness of the film is relative to the coating time [5,6]. The glass substrate is of size 2.5 x 7.5 cm². The coating was done on a partially covered specimen to produce a step edge for the stylus measurement. Fig 4 (a) shows the testing specimen and the film to measure. One important point is that Al was coated again for additional reflection of the film as shown Fig.4 (b).

The Fizeau interferometer was set up as shown Fig.5. A He-Ne laser with a wavelength of 632.8 nm was employed as the source of radiation for the Fizeau interferometer. Interference fringes obtained from the interferometer were captured by a telescope.

Fig 5 shows the operation of the Fizeau interferometer. The light from the He-Ne source is passed through a collimator lens set which combine and generate collimated light to a beam-splitter. The beam-splitter then separates the light into two rays: reflected and refracted. The reflected ray will incident to the reference plate and the glass substrate. It is then reflected back passing the beam-splitter and combine with the refracted ray. In this process, interference fringe patterns are appeared on the
telescope. The patterns are then recorded and used to compute the thickness of the thin film.

![Diagram of Fizeau interferometer used for the measurement of thin film thickness.](image)

**Fig. 4:** The preparation of testing specimen, (a) A step edge of Al coating on a glass substrate, (b) A specimen with another layer of Al for additional reflection.

**Fig. 5:** Diagram of Fizeau interferometer used for the measurement of thin film thickness.

### 4. EXPERIMENTAL RESULTS

Six specimens were prepared by the method mentioned in the previous section. Each of the specimens underwent thickness measurement by both Fizeau interferometer and stylus profiler. An example of the result from the Fizeau interferometer is displayed in Fig. 6. The parameters $\Delta S$ and $S$ were measured from the fringes and used to calculate the thickness of the film.

Table 1 displays the results from all six specimens. The fringe patterns obtained from the specimen which was coated for three minutes produced indistinguishable patterns; therefore its thickness cannot be determined.

Comparison of the results of thickness measurement from Fizeau interferometric and Stylus profiler techniques is shown in Table 2. It can be seen that the maximum difference is 8.33% which may be caused by the accuracy of the position measurement of the interference patterns.

![Picture of interference patterns](image)

**Fig. 6:** Pictures of interference patterns.

**Table 1:** The results from the measurement of thin film thickness by Fizeau interferometer

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>coating Time (minute)</th>
<th>$S$ (mm)</th>
<th>$\Delta S$ (mm)</th>
<th>Thickness ($\mu m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₁</td>
<td>3</td>
<td>indistinguishable</td>
<td>indistinguishable</td>
<td>N/A</td>
</tr>
<tr>
<td>Al₂</td>
<td>5</td>
<td>0.020</td>
<td>0.007</td>
<td>0.11</td>
</tr>
<tr>
<td>Al₃</td>
<td>9</td>
<td>0.025</td>
<td>0.013</td>
<td>0.17</td>
</tr>
<tr>
<td>Al₄</td>
<td>13</td>
<td>0.024</td>
<td>0.016</td>
<td>0.21</td>
</tr>
<tr>
<td>Al₅</td>
<td>18</td>
<td>0.021</td>
<td>0.021</td>
<td>0.32</td>
</tr>
<tr>
<td>Al₆</td>
<td>22</td>
<td>0.023</td>
<td>0.029</td>
<td>0.39</td>
</tr>
</tbody>
</table>

**Table 2:** Comparison of the results of thickness measurement from Fizeau interferometric and Stylus profiler techniques

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Thickness of thin film ($\mu m$)</th>
<th>Stylus ($\mu m$)</th>
<th>FI ($\mu m$)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₁</td>
<td>0.08</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Al₂</td>
<td>0.12</td>
<td>0.11</td>
<td>0.11</td>
<td>8.33%</td>
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<tr>
<td>Al₃</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.00%</td>
</tr>
<tr>
<td>Al₄</td>
<td>0.20</td>
<td>0.21</td>
<td>0.21</td>
<td>5.00%</td>
</tr>
<tr>
<td>Al₅</td>
<td>0.34</td>
<td>0.32</td>
<td>0.32</td>
<td>5.88%</td>
</tr>
<tr>
<td>Al₆</td>
<td>0.40</td>
<td>0.39</td>
<td>0.39</td>
<td>2.50%</td>
</tr>
</tbody>
</table>

### 5. CONCLUSIONS AND DISCUSSIONS

Measurement of thin film thickness by Fizeau interferometric technique is proposed in this paper. It is a nondestructive technique based on optical interference. An experiment was set up to investigate the performance of the approach. Specimens were prepared by growing up thin films of different thickness on glass substrates through a high vacuum deposition system. A special step edge was also
created in each specimen to allow the application of stylus profile measurement. Results of the thickness measurement were compared to those obtained from the stylus profile measurement. It was found that the approach could measure thin film thickness between 0.11-0.39 µm. The thickness, which is lower 0.11 µm, can not be determined by the method due to indistinguishable fringe patterns. The results from the Fizeau interferometer are comparable to those from the profiler. To sum up, this method provides accurate measurement of thin film thickness without any modification to the measurement surface. However, resolution and accuracy of this technique is dependent directly on the position measurement of the interference patterns.

6. REFERENCES