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High efficiency surface roughness measuring system for hard thin films deposited by cathodic arc evaporation

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ABSTRACT

Zirconium carbon nitride (ZrCN) hard films own lower friction coefficient, high hardness, higher wear and corrosion resistance. Investigations on the surface roughness of ZrCN hard thin films become an important issue because the surface roughness of ZrCN hard thin films is widely believed to be related to its characteristics of wear and corrosion resistances. A new optical measuring system is developed to measure surface roughness of ZrCN hard thin films deposited by cathodic arc evaporation. A fixture of photodetector is designed and implemented for reducing the modulation time during optical measurements. The incident angle of 20° is found to be a good candidate for predicting the surface roughness of ZrCN hard thin films. Surface roughness of ZrCN hard thin films can be determined rapidly from the average value of the reflected direct current voltage recorded by the optical measuring system using the trend equation. The maximum measurement error of the optical measuring system developed is less than 12.37%. The savings in measurement time of the surface roughness of ZrCN hard thin films is up to 93.33%.

1. Introduction

The recent advances in modern manufacturing technologies demand coating solution with high mechanical hardness, wear resistance and corrosion resistance [1–3]. It is well known that zirconium carbon nitride (ZrCN) hard thin films own some advantages including low friction coefficient, low wear rate and high corrosion resistance [4]. Characteristics of wear and corrosion resistance were significantly affected by the surface roughness of ZrCN hard thin films. Thus, understanding the surface roughness value of ZrCN hard thin films after coating is an important issue. Generally, the most widely used methods to measure surface roughness of ZrCN hard thin films include atomic force microscopy (AFM) [5], high-resolution transmission electron microscopy (HR-TEM) [6], field-emission scanning electron microscopy (FE-SEM) [7], and white-light interferometry (WLI) [8]. In general, AFM is widely accepted as the international standard to characterize the surface roughness of the thin films due to the high spatial resolution of measurement. Although these methods usually provide reliable results for measuring surface roughness of ZrCN hard thin films, the cost of the hardware is expensive. Therefore, development of a low-cost on-line optical diagnostic technique for rapid measuring surface roughness of ZrCN hard thin films is required. It is well known that light scattering method has the main advantage of simplicity and reliability [9]. To solve this problem, an optical measuring system based on light scattering method [10] for rapid surface roughness measurement of ZrCN hard thin films is developed in this study. The effects of incident angle on the measurement accuracy of surface roughness of ZrCN hard thin films were discussed. Trend equation for predicting the surface roughness of ZrCN hard thin films was investigated. The applicability of the surface roughness value obtained using the optical measuring system developed was investigated and compared with WLI. The percent error of the measurement using the optical measuring system was also discussed.

2. Experiment

The ZrCN thin films were deposited on a (1 0 0)-oriented crystalline silicon wafer using cathodic arc evaporation. Reactive arc deposition from zirconium targets in an Ar and N_2 atmosphere with an addition of C_2H_2 reactive gas was used. The chamber was evacuated to a base pressure of 1.19×10^{-2} Pa and then the substrates were heated up to about 150 °C. DC substrate bias voltage was 100 V, working pressure during deposition of the order was 8.09×10^{-1} Pa. A Cr interlayer was deposited for better adhesion. Nine test samples were prepared by varying the C_2H_2 flow rate in this work. The deposition rate was about 21.42 nm/min. The deposition parameters are listed in Table 1.

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Table 1
Deposition parameters for preparing different ZrCN thin films.

Sample No.	1	2	3	4	5	6	7	8	9
N_2:C_2H_2 ratio	110:5	112:7.5	120:10	111:12.5	114:15	115:17.5	114:20	112:25	120:30
Holder rotation speed (rpm)	2								
Arc current (A)	90								
Bias voltage (V)	100								
Base pressure (Pa)	1.19×10^{-2}								
Working pressure (Pa)	8.09×10^{-1}								
Substrate temperature (°C)	150								
Deposition time (min)	21								

Fig. 1 shows a schematic illustration of the experimental set-up for rapid measuring the surface roughness of ZrCN hard thin films. The optical measuring system consists of a He–Ne laser, an aperture [11], two focusing lenses, a rotary stage, a photo-detector and a digital multimeter (DMM) [12]. He–Ne laser (NT61-337; JSD Uniphase, Inc.) emitting at a wavelength of 632.8 nm with a power of 0.8 mW was used as a probe laser. The dynamic range of 316.4 nm is sufficient for surface roughness measurement of ZrCN hard thin films because its surface roughness is normally less than 5 nm. A laser beam was directed to the sample with an incident angle, Θ, which was measured from the sample surface normal and finally traveled to the photo-detector (DET210; Thorlabs, Inc.). The samples were mounted on a precision rotary stage. To ensure consistency of the measurement, the measured points were set at the same place for both the optical measurement and WLI measurement (7502; Chroma, Inc.). The reflected direct current (DC) voltage recorded by DMM from the ZrCN hard thin films were measured using a photo-detector and a DMM (34405 A; Agilent, Inc.) connected to a computer. The measured time for each sample was fixed at 15 s. The minimum incident angle cannot be below 10° and the maximum incident angle cannot exceed 70° due to limitations of the experimental apparatus. Thus, six different incident angles (20°, 30°,45°, 60°, 65°, 70° [13–16], were selected to measure the surface roughness of ZrCN hard thin films. The surface roughness of ZrCN hard thin films was measured using a WLI. To obtain accurate surface roughness value of ZrCN hard thin films using the optical measuring system developed, a focusing lens (SLB-50.8-200P; Sigma Koki, Inc.) was used to reduce the spot size of probe laser beam [17,18]. The focal spot size of a probe laser beam was approximately 250 μm. The measurement area of WLI was set of 250 μm × 250 μm based on the spot size of a probe laser beam. The correlation between the reflected DC voltage and surface roughness of ZrCN hard thin films was first determined by WLI for calibration using five test samples of pre-determined surface roughnesses of ZrCN hard thin films measured. Linear trend equations for predicting surface roughness of ZrCN hard thin films was estimated using the least square method. An optimal trend equation for assessing the surface roughnesses of ZrCN hard thin films was determined by the square of the correlation coefficient, R^2, with the largest value. Thus, surface roughnesses of ZrCN hard thin films can be straightforward quantitative determined from the average value of DC voltage recorded by DMM through the optimal trend equation. Subsequently, four test samples of ZrCN hard thin films were employed to investigate the measurement accuracy of the optical measuring system. To reduce the modulation time of the photodetector, a fixture of photodetector was designed and implemented in this work. Fig. 2 shows a designed fixture of photodetector with given angles and dimensions. Polymethylmethacrylate was used as material for fabricating fixture by laser cutting machine (13090; Taiwan 3 Axle Technology, Inc.).

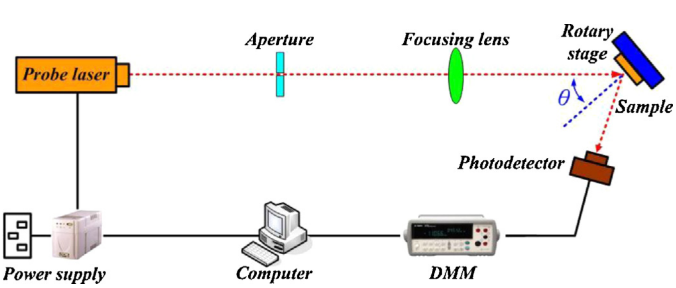

Fig. 1. Schematic illustration of the experimental setup for rapid measuring the surface roughness of ZrCN hard thin films. Θ represents the incident angle of the probe laser.

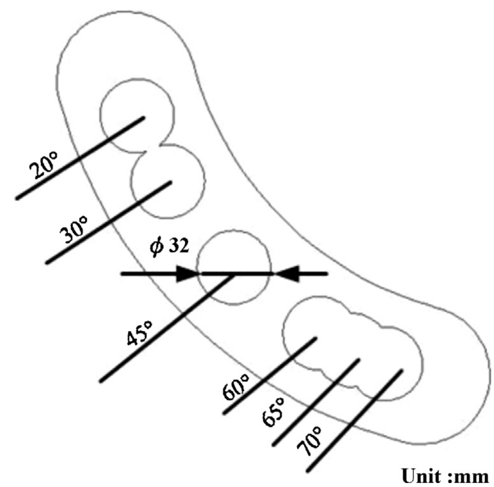

Fig. 2. Designed fixture of photodetector with given angles and dimensions.

3. Results and discussion

Fig. 3 shows the optical measuring system with a photodetector fixture. In general, the modulation time of the photodetector for a new measurement angle is about 5 min. However, the modulation

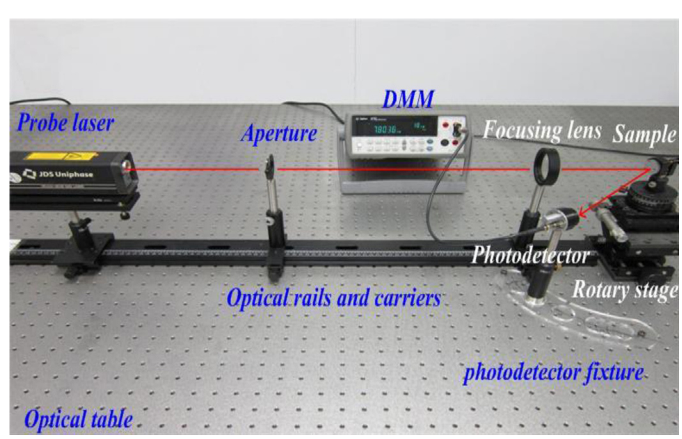

Fig. 3. Optical measuring system with a photodetector fixture.