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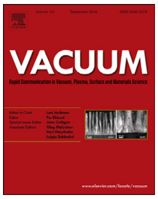

In situ assessment of the roughness of a uniformly eroded cylindrical magnetron target

Muhammad Arif, Thomas Ernstbrunner, C. Eisenmenger-Sittner*

Institute of Solid State Physics, E-138, Vienna University of Technology, Wiedner Hauptstrasse 8-10, Vienna A-1040, Austria

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ABSTRACT

We present an experimental approach for the in situ characterization of the surface roughness of an eroded magnetron target based on the reflectance pattern of a laser beam. The surface of the eroded region was modeled as a random arrangement of tilted plane facets with large surface extensions as compared to the wavelength of the laser. A simple algorithm was used to reconstruct surface profiles form the reflected intensity values from the eroded surface. The surface profiles of Al, Cu and Ti targets were reconstructed under high vacuum conditions without disturbing the processing parameters of the magnetron sputtering plant. From these generated profiles, the roughness parameters, root mean square roughness, correlation length, skewness and kurtosis of different target materials were calculated by this in situ technique. The results measured with this in situ technique are in good agreement with comparable measurements using a mechanical profilometer outside the sputtering system. However, some deviation was observed for surfaces with higher roughness and mean tilt angles. This method can be used for in situ monitoring of sputter targets to extract the surface features which may correlate with thin film properties and may precede dangerous events like target melting or other catastrophic failures.

1. Introduction

Magnetron sputtering is a widely used technique for high quality functional coatings at both laboratory and industrial scale [1]. Cylindrical magnetrons exhibit higher deposition rate, greater stability, low deposition temperatures, and better control of materials composition [1]. During deposition, the material is ejected from the surface of a target (cathode) due to the bombardment with energetic particles. In magnetron sputtering, a magnetic field close to the target confines the motion of secondary electrons near the target surface. This higher plasma density enhances the sputtering process at low inert gas pressure. However, the plasma is generally not uniform over the target surface, and regions of different plasma densities lead to a non-uniform target utilization. Therefore, the monitoring of the target surface during the sputtering process is of great importance.

Optical techniques have great potential for non-contact and online measurement of surface roughness [2]. During the last few decades, different optical techniques have been developed for surface roughness measurement [3–5]. When electromagnetic radiation is incident on a surface, the reflected beam bears useful information about the roughness of the surface. The proportion of specular to diffuse reflection of incident radiation on a rough surface depends on the surface properties, including surface roughness. In a preliminary work, *Clark* [6] suggested the use of a laser beam for the application of real time, non contact surface roughness measurement. *Persson* [7] has demonstrated the in-process measurement of surface roughness of a specimen on a grinding machine using laser scattering. The on-line roughness measurement method proposed by *Wang* [8] is also based on a laser-scattering probe. In most of the previous works the in-process measurement of surface roughness of openly accessible materials has been studied using a laser beam. However, the in situ investigation of a sputtering target, which is enclosed inside a vacuum chamber, has not been demonstrated before. In this work, we present an experimental approach to monitor the surface roughness of an eroded cylindrical sputtering target by reflection of a laser beam. The surface of the eroded region is modeled as a random arrangement of micro facets. This technique for the surface analysis of the target is based on assessing the specular and diffuse patterns of the reflected laser beam from tilted micro facets of a rough surface.

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* Corresponding author.
E-mail address: christoph.eisenmenger@ifp.tuwien.ac.at (C. Eisenmenger-Sittner).

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Previously, different authors have also assumed the rough surface as a combination of mirror-like micro facets with different orientations. *Torrance* and *Sparrow* [9] considered these randomly placed facets as the basic mechanism for both specular and diffuse reflection from a rough surface. By considering the reflection from theses facets, *Oren* and *Nayar* [10] presented a comprehensive model to predict the reflection from a rough surface. On the basis of reflection, these models explain how surface orientations affect the intensity and the shape of the specular and diffuse patterns. They also account for the geometrical effects such as masking, shadowing and inter-reflection between different points. In addition to the information of total radiance which helps to investigate the relationship with the surface roughness, the generation of surface replica directly from the reflected pattern could be a new approach for in situ surface analysis. Our model is based on physical optics and we assume that the size of facets is much larger than the incident wavelength. The surface is hit by a laser beam and the specular and diffuse reflection is captured on a screen. Under certain conditions, the intensity and direction of the reflected beam can be attributed to the orientation and area of these facets. The surface profiles were generated directly from the reflected pattern of the laser beam. The generated surface structure of different sputtering targets was compared with that of mechanical profilometer measurements and found in good agreement. This method can be used to analyze the basic surface parameters of the sputtering target during operation which can influence the thin film properties. It may also be used to identify target melting and end-of-life effects of the target which may be associated to changes in reflectivity.

2. Experimental setup

Fig. 1 shows a schematic diagram depicting our experimental setup for recording the reflected images of different target materials. The experiment was carried out in a turbo molecular pumped magnetron sputtering plant (Adixen ATP-150, base pressure 10^{-5} Pa), with a cylindrical cathode of 44 mm diameter and 100 mm exposed length to the plasma. A rotating magnet assembly, cooled by water was fixed inside the cathode tube. The cylindrical cathode/target and the screen positioned inside the high vacuum chamber of the magnetron sputtering unit is shown in Fig. 1(a). A green laser beam, type 3R with 3 mm diameter, 5 mW power and of 532 nm wavelength was used. A sealed Quartz window was used to permit the laser beam to hit the target surface from outside the vacuum chamber. The laser was incident upon the sputtering target covering a cross sectional area of a diameter of approximately 3 mm. A circular screen, diameter approximately 100 mm (PET film, Kimoto 100-PBU) was fixed within the chamber to get the images of the scattered laser beam from the target surface. A rotatable cylindrical shutter was developed to protect the screen from exposure to sputtered material (not shown in the figure). A small hole of 1 cm diameter was used in the shutter to incident the laser beam on the sputtering target through the Quartz window. Another circular hole of 10 cm in diameter in the shutter to expose the screen to the laser beam reflected from the target surface. During the sputtering process, the circular shutter was rotated in such a position that screen and the laser beam were not exposed to the sputtered material. After the sputtering cycle, the cylindrical shutter was again rotated to get the reflected beam on the screen. Using this arrangement the screen was completely safe from the sputtered material as was shown by checking for deposits on the screen after several hours of cathode operation. A transparent window of poly methyl methacrylate (PMMA) was fixed to see the laser scattered image on the screen from outside the vacuum chamber. Argon (Ar) was used as working gas during non-reactive magnetron sputtering. Aluminum (Al), Copper (Cu) and Titanium (Ti) targets were sputtered at a constant 5 A DC discharge current for different durations. Digital images of reflected light from these targets were photographed using a digital camera (Canon EOS 1200D), after each sputtering run. The path between the PMMA window and the camera was covered with a black sheet to avoid the exposure of the screen to external light. The erosion rate of the target was considered as constant over the entire cylindrical surface due to the rotation of the magnetic system. Finally, the images of the target surface were analyzed by using the MATLAB computer software. Moreover, this experimental arrangement allows us to monitor the eroded surface under high vacuum conditions without removing the target from the sputtering chamber. Nonetheless, it has to be noted that the discharge has to be switched off to allow the assessment of the reflection without disturbance of light emitted from the plasma.

The cylindrical magnetron target was considered as uniformly eroded in a given region as shown by a grey zone in Fig. 1(b). The target was hit by a laser beam in a way that the incident beam and its specular reflection enclose an angle of 90°. The specular and diffuse reflection of the laser is captured on a screen. If the beam has a finite diameter, for simplicities sake it can be assumed that the intensity of the beam is constant throughout the beam and zero

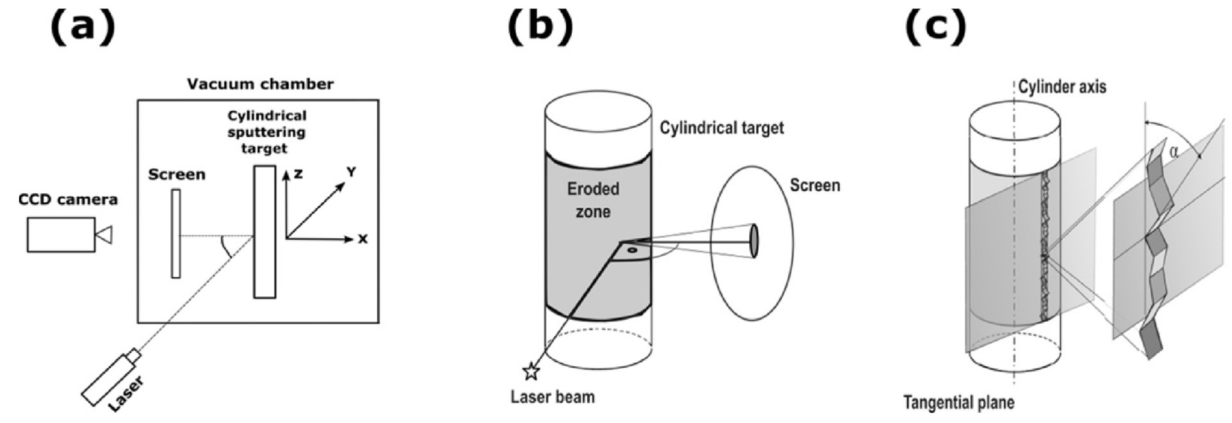

Fig. 1. Schematic diagram depicting the experimental setup to capture the specular and diffuse reflection pattern of a laser beam reflected from the eroded cylindrical sputtering target on the screen. (a) Arrangement of sputtering target, screen, laser and camera. (b) A laser beam hits the surface of the target within the erosion zone and its diffuse reflection is captured on the screen. (c) Representation of a rough surface within the width of the incident laser beam. The magnified section represents the zone where the laser hits the surface. The surface consists of facets tilted by an angle α relative to the tangential plane.

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