Journal of Non-Crystalline Solids 354 (2008) 5504–5508

Contents lists available at ScienceDirect

Journal of Non-Crystalline Solids

journal homepage: www.elsevier.com/locate/jnoncrysol

Characteristics of sputtered amorphous carbon films prepared by a closed-field unbalanced magnetron sputtering method

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ARTICLE INFO

Article history:
Received 25 August 2007
Received in revised form 21 July 2008
Available online 18 September 2008

PACS:
87.64.Je
68.49.Uv
81.15.Cd
81.05.Uw
68.37.Og
62.20.Qp

Keywords:
Raman scattering
UPS/XPS
Sputtering
Carbon
STEM/TEM
Hardness

ABSTRACT

We discuss the tribological performance of sputtered amorphous carbon (a-C) films deposited by closed-field unbalanced magnetron (CFUBM) sputtering with a graphite target using a mixture of helium (He) and argon (Ar) as sputtering gases. We investigated the effects of the graphite target power density on the micro-structural and physical properties. In the Raman spectra, the G-peak position moved to the higher wavenumbers. The I_D/I_G ratio increased with the increase of target power density in the fixed DC bias voltage. This was the result of the structural change in the a-C film that resulted with the increase in sp^2 bonding fraction. Also, the maximum hardness of the a-C film was 23 GPa, the friction coefficient was 0.1, and the critical load was 25.9 N on the Si wafer. In addition, the compressive residual stress of the film increased a little with increasing target power density. Consequently, the various properties of a-C films, with an increase of the target power density, were associated with the increase of cross-linked sp^2 bonding fraction and the cluster size. The tribological properties of a-C film showed clear dependence on the energy of ion bombardment with the increase of plasma density during film growth.

1. Introduction

Amorphous carbon (a-C) and hydrogenated amorphous carbon (a-C:H) films are composed of a network of sp^3 (diamond-like) and sp^2 (graphite-like) co-ordinations. They possess excellent mechanical and tribological properties such as elevated hardness and excellent wear resistance [1]. In addition, they have low friction coefficients and provide protection for the counter parts [2]. Therefore, these films' properties indicate that they have good prospects for use in a wide range of applications not only the typical mechanical applications such as in protective coating, wear resistant coating, corrosion resistant coating, and antireflective coating, but also in optical applications such as in photodiodes, light-emitting diodes, and electroluminescence devices [3,4].

We know that the properties of deposited a-C films depend strongly on the deposition conditions and elaboration methods. We can obtain a-C films with several techniques such as sputtering [2,3,11,14], ion beam deposition [10], CVD [13], and PLD. Sputtering methods are preferred for industrial applications because of these methods' versatility, widespread use, and ease of scaling up. Also, these kinds of techniques allow for good control of the various deposition parameters such as the deposition rate, temperature, and gas composition during the deposition process. In this paper, we report on the effects of target power density on the tribological and structural properties of a-C films synthesized by closed-field unbalanced magnetron (CFUBM) sputtering.

2. Experimental

The a-C films were deposited onto 3 cm × 3 cm p-type (100) silicon and glass substrates by using a closed-field unbalanced magnetron (CFUBM) sputtering system consisting of two targets with 99.99% pure graphite and a diameter of 10.16 cm. The distance from target to substrate was 60 mm. Also, high purity argon (99.99%) and helium (99.99%) were used as the sputtering gases for the growth of the a-C films. The silicon and glass substrates were cleaned successively for 5 min in acetone, methanol, and D.I. water. Then, the silicon substrates were etched in a hydrofluoric acid solution to strip off any native oxide. For the deposition process, the background pressure of the process chamber was evacuated to below 4.3×10^{-4} Pa using diffusion pumps and then the gases

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doi:10.1016/j.jnoncrysol.2008.08.007

Table 1
Deposition conditions of a-C films prepared by CFUBM sputtering

	Deposition parameters					
	Base pressure (Pa)	Ar/He flow rate (sccm)	Ar/He pressure (P_{Ar}/P_{He}) (Pa)	Total pressure (Pa)	Substrate bias voltage (V)	Target power density (kW/cm^2)
Conditions (value)	4.3×10^{-4}	14.2/2.5	0.36/0.04	0.4	−200	1.2, 1.6, 2.0

of Ar and He (14.2:2.5 sccm) were introduced into the chamber and were mixed. The total working pressure for the entire deposition run was 0.4 Pa. We obtained the a-C films at various target power densities from 1.2 to 2.0 W/cm^2 below the fixed negative DC bias voltage. The thicknesses of the deposited all films were approximately 200 nm. We summarize the experimental parameters in Table 1.

The thickness of the a-C films was measured using FE-SEM [Jeol, JSM6700F] and the internal structure of the films was characterized by Raman spectrometry [Jasco, MRS-300], X-ray photoelectron spectroscopy [VG MICROTECH, ESCA-2000], and high resolution transmission electron microscopy (HRTEM) [JEOL, JEOL 300 kV]. The surface morphology of the films was observed using atomic force microscopy [Seiko, SPA-400] and the value of the root-mean-square (RMS) roughness was obtained over an image area of 2 μm^2. The residual stress of a-C films was measured using stress tester [J&L Tech, JLCST022]. And also, the hardness and elastic modulus were measured using a commercial nano-indentation instrument [Nano-indenter XP] having a continuous stiffness method (CSM) option. Continuous loading–unloading indentations were applied up to a maximum load of 30 mN. Also, the friction coefficients of the a-C films with an increase of the target power density were analyzed using a ball-on disk (BOD) tribometer in normal dry ambient air against a polished AISI 52100 steel ball with a diameter of 4.72 mm. The sliding speed of the steel ball was maintained at a constant value of 60 rpm. Also the adhesion value of a-C films was measured using a nanoscratch tester [J&L Tech. JLST022]. A diamond tip of nominal radius was used to scratch the film surfaces and the normal load was increased to 35 N. Also, the scratch speed v and scratch distance were kept to values of 0.2 mm/s and 10 mm.

3. Results

Raman spectroscopy is an effective method for the characterization of carbon materials [1,6]. Raman spectra of the a-C films deposited at various target power densities are shown in Fig. 1(a). The I_D/I_G ratio and the G-peaks position, which were deconvoluted into two Gaussian curve fits, in order to obtain quantitative information on the sp^3 content in the film, are shown in Fig. 1(b) for the various target power densities. From these figures, we observed that the G- and D-bands, corresponding to the gra-

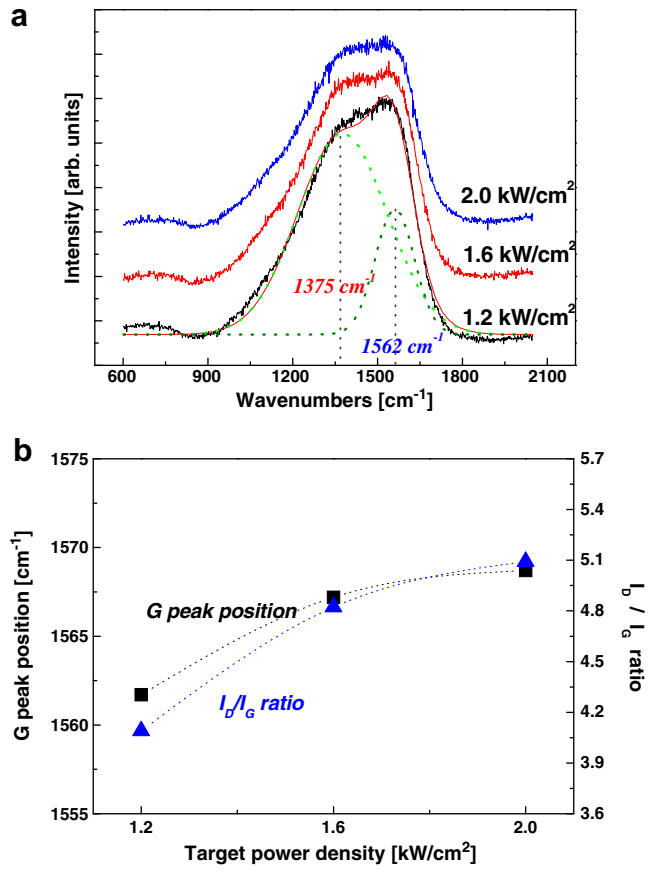

Fig. 1. Raman spectra (a) and the variation of the G-peak position and I_D/I_G ratio (b) of a-C films prepared at various target power densities.

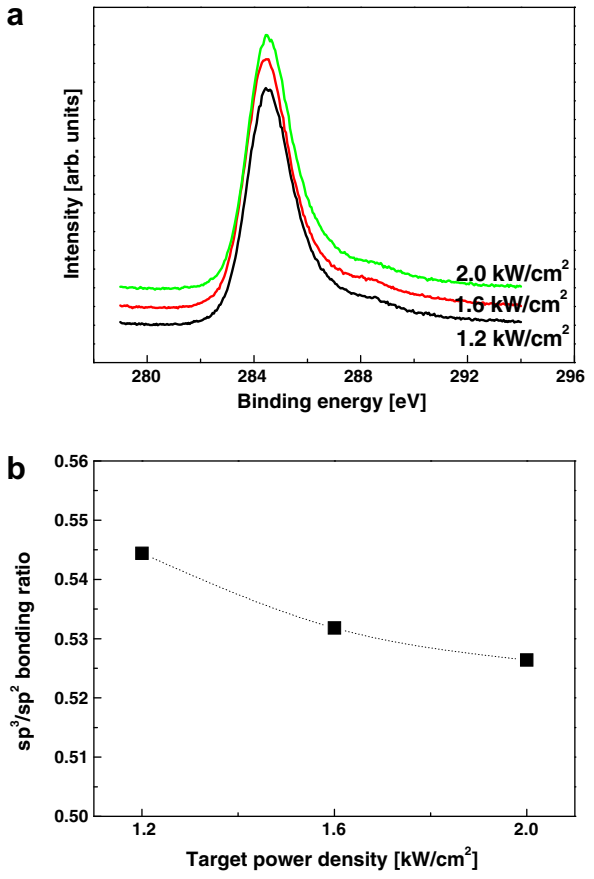

Fig. 2. Carbon 1s XPS spectra (a) and the variation of sp^3/sp^2 bonding ratio of a-C films prepared at various target power densities (b).