



# Correlation study of structural, optical and electrical properties of amorphous carbon thin films prepared by ion beam sputtering deposition technique

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## ABSTRACT

The correlation of structural, optical and electrical properties of amorphous carbon thin films deposited by ion beam sputtering technique on the glass substrate was investigated. The film thickness varied over a wide range from 57 to 408 nm by controlling the deposition time. Raman spectra and X-ray photoelectron spectroscopy showed that the size of the graphite crystallites with  $sp^2$  bonds (La) and the  $sp^3/sp^2$  fraction are smaller than 1.5 nm and 1.4, respectively. The values of  $I_D/I_G$  ratio, the 'G' peak position, and surface roughness depend on the film thickness; all of them increased by increasing film thickness up to 360 nm, and then decreased by increasing time and thickness. Furthermore, the resistivity followed similar trends of these structural properties. According to Tauc equation the optical band gap of these films was in the range of 3.2–3.9 eV. A broad emission peak at around 2.94 eV was observed on a photoluminescence spectrum of amorphous carbon film with highest resistivity.

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## 1. Introduction

The amorphous carbon (a-C) films exhibit a lot of excellent properties such as high mechanical hardness, chemical inertness, optical transparency in the visible and IR region, high resistivity and tunable band gap, which had been led to extensive study in this area [1–6]. Therefore, a-C thin films not only have been applied to carry out typical functions such as protective coating, wear resistant coating, corrosion resistant coating, and antireflective coating but also to produce a number of optical devices such as photodiodes, light-emitting diodes, and electroluminescence devices [7].

Various physical and chemical methods such as sputtering [8], pulsed laser deposition [9], plasma-enhanced chemical vapor deposition [6], filtered vacuum arc [10] and ion beam deposition (IBD) [1,3,4] have been employed to synthesize a-C films. Among them, the ion beam deposition method has been widely used to produce amorphous carbon thin films, because of the ability to control independently the ion energy and the ion current density [4]. In addition, IBD compared with other methods is a low temperature process and can form a coating with good adhesion to a substrate because the coating is formed by simultaneous deposition with

ion implantation [11]. The first films that can be classified in this category were deposited by Aisenberg and Chabot [3]. After their research work, ion beam deposition of amorphous carbon thin films has continuously advanced as a consequence of the development and innovation of ion sources [4].

A large number of the previous research results have indicated that the structure and properties of the amorphous carbon films strongly depend on the deposition process parameters, for instance, deposition temperature, kinetic energy of the atoms, deposition pressure, and so on [5]. In addition, the film thickness is an effective parameter on the structural and physical properties which controlled by deposition condition. However, several studies have been done in this context, most of them designed to evaluate the effect of the film thickness (less than 10 nm) on the mechanical and tribological properties of ultra-thin films [8,10,11] or to understand the atomic bond structure of a-C films by the molecular dynamics simulation (MD) technique [8,10]. These layers usually deposited by plasma assisted chemical vapor deposition, filtered cathodic vacuum arc and sputtering techniques [6,8,10].

In this research work, we studied the effect of the variation of film thickness in a wide range of 57–408 nm on the structural, optical and electrical properties of a-C thin films deposited by IBD technique on the glass substrate and found the correlations among them.

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## 2. Experiment

a-C thin films were deposited on the glass slides substrates by ion beam sputtering deposition technique. The substrates were cleaned ultrasonically with acetone and ethanol, respectively, prior to amorphous carbon deposition. The carbon source was a high purity graphite plate (12 cm × 15 cm). The specific angle between the target and substrate was about 45°. The chamber was evacuated to a base pressure of  $1\text{--}2 \times 10^{-5}$  Torr and depositions were performed at room temperature. During the deposition process, the pressure was kept constant at  $0.4\text{--}1 \times 10^{-4}$  Torr by introducing a high purity argon gas. The accelerator voltage and the ion current were 2200 V and 25 mA, respectively. Six sets of a-C films were obtained by variation of deposition time from 15 to 75 min while the other parameters were kept constant. Deposition repeated three times in each condition in order to examine reproducibility. After the deposition, the samples were cooled down to room temperature in argon atmosphere.

The thickness and morphology of the films were determined by using atomic force microscope (AFM) working in a tapping mode (DS 95; Denmark) with a scan rate of approximately 3 Hz and 0.1 nN force in the typical scan area equal to  $1 \times 1 \mu\text{m}^2$ . The Raman spectra were measured using the 532 nm excitation wavelength of Nd-YAG laser with a power of 1 mW. The samples for the X-ray photoelectron spectroscopy (XPS) measurements were prepared in a multi chamber UHV evaporation tool (Bestec, Germany) having a base pressure of  $0.75 \times 10^{-10}$  Torr. A monochromatic Al K $\alpha$  X-rays (1486.6 eV) were employed as the excitation source operated at 10 KV. The optical properties were investigated from the reflectance and transmittance data using a UV/visible spectrophotometer (Cary 500). The photoluminescence measurements were carried out by (Varian Cary Eclipse) Fluorescence Spectrophotometer with the excitation energy of 3.7 eV. A four point probe technique (FPP 5000) was applied to measure the sheet resistivity of carbon films at room temperature.

## 3. Results and discussion

In order to study the evolution of structural, optical and electrical properties of a-C film deposited on the glass substrate during IBSD deposition process, the film thickness was controlled by the deposition time.

Fig. 1 shows the thickness growth rate of a-C films which can be categorized in to fast ( $15 < t \text{ (min)} < 45$ ) and slow ( $45 < t < 75$ ) increase regimes. Since the deposition rate of carbon atoms was kept constant by controlling the deposition parameters, the growth rate reduction observed in the slow region could be related to density enhancement of the deposited films. This process probably related to increasing atomic motions due to trapping the ion bombardment energy during accumulation that lead to the reduction of free volume and an increase in density [12].

The surface roughness values of a-C films have been reported in Table 1 show the evolution of roughness during the growth process of a-C film as a function of the deposition time. The corresponding typical AFM topography images ( $1 \times 1 \mu\text{m}$ ) are given in Fig. 2(a) and (b).

Fig. 2(c) shows the trend of surface roughness during the deposition from the initial stage. The film surface roughness decreased first and then increased with increasing thickness up to a maximum in 360 nm film thickness and subsequently decreased again. The island growth model was proposed by Zhong et al. can be used to explain the phenomenon [13]. The initial island nucleation was attributed to the preferred growth of the valley [13,14]. The next roughening stage as the island grows bigger and the peak to valley

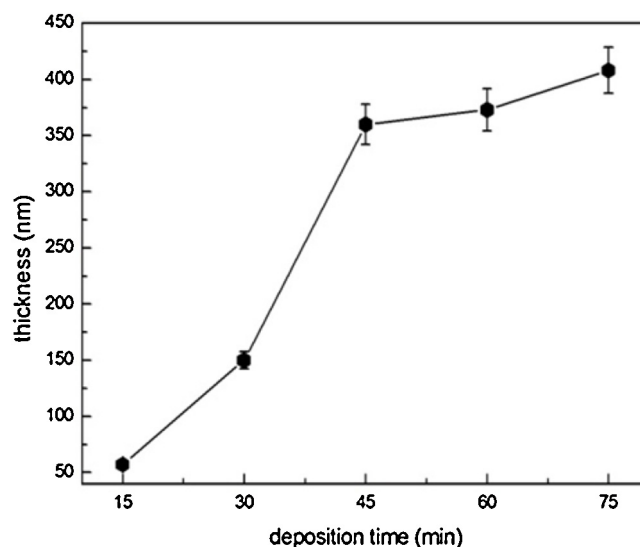


Fig. 1. Variation of film thickness as a function of deposition time.

distance gets larger. With the gradually growth of the islands, the islands get coalesced. Consequently, at the final smoothing stage of the growth, the surface roughness decreases and the surface becomes smoother again.

Raman spectroscopy is one of the most popular non-destructive tools to characterize the structure and the bonding nature of amorphous carbon thin film. The Raman spectra of the carbon film are mainly composed of two broad peaks: the G-peak places in the range  $1555\text{--}1570 \text{ cm}^{-1}$ , as it does in aromatic (rings) and olefinic (chains) molecules and the D peak around  $1370 \text{ cm}^{-1}$  is a breathing mode. This mode is forbidden in perfect graphite and only becomes active in the presence of disorder and its intensity is strictly connected to the presence of sixfold aromatic ring, so, the  $I_D/I_G$  ratio falls as the number of rings per cluster reduces and the fraction of chain groups elevates [1,15,16].

Fig. 3(a) and (b) shows the typical Raman spectra of two amorphous carbon films with two different thicknesses on the glass substrate. In order to extract the information from Raman spectra and determine the values of the  $I_D/I_G$  ratio, D, and G peak positions the spectra were deconvoluted with Gaussian function. D and G peaks are clearly highlighted with dashed line peaks shown in Fig. 3.

The data extracted from deconvolution of the Raman spectrum of the samples with different thickness are reported in Table 1. The size of the graphite cluster ( $L_a$ ) depends on the intensity ratio of the D band on the G band ( $I_D/I_G$ ) according to the following relation [1,17]:

$$\frac{I_D}{I_G} = cL_a^2$$

where  $c$  is equal to  $\sim 0.0055$  (for  $L_a$  in Angstrom) [17–19].

According to the reported results in Table 1, the G peak position moves from  $\sim 1552 \text{ cm}^{-1}$  to  $\sim 1571 \text{ cm}^{-1}$  by increasing the deposition time up to 45 min. By this enhancement, the values of the  $I_D/I_G$  ratio and the graphite cluster size also increase with increasing the film thickness up to 360 nm. At the higher deposition times, the G peak position moves back to  $\sim 1556 \text{ cm}^{-1}$  and the other two parameters reduce with increasing the film thickness. Since the Raman results depend only on the ordering of the  $\text{sp}^2$  sites and cluster size [16], this is due to a little change of  $\text{sp}^2$  content within the measured thickness range.

In the Raman spectra of carbon based materials, the G-peak position, move to higher wave number due to two processes: First,

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