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# Synthesis of Ag and Au nanoparticles embedded in carbon film: Optical, crystalline and topography analysis

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ABSTRACT

Atomic force microscopy (AFM) images give valuable information about surface roughness of thin films based on the results of power spectral density (PSD) through the fast Fourier transform (FFT) algorithms. In the present work, AFM data are studied for silver and gold nanoparticles (Ag NPs a-C: H and Au NPs a-C: H) embedded in amorphous hydrogenated carbon films and co-deposited on glass substrate via of RF-Sputtering and RF-Plasma Enhanced Chemical Vapor Deposition methods. Here, the working gas is acetylene and the targets are Ag and Au. While time and power are constant, the only variable parameter in this study is initial pressure. In addition, the crystalline structure of Ag NPs a-C: H and Au NPs a-C: H are studied using X-ray diffraction (XRD). UV–visible spectrophotometry will also investigate optical properties and localized surface plasmon resonance (LSPR) of samples.

## Introduction

Diamond-like Carbon (DLC) films are amorphous carbon (a-C) or hydrogenated amorphous carbon (a-C: H) with special SP hybridization ($SP^2$ and $SP^3$) where the ratio of $SP^2/SP^3$ will affect their properties [1–4]. Optical transparency, high resistivity, high hardness, and chemical stability are only some of their properties that make them unique in sputtering process [5–8]. Despite all mentioned advantages of DLC films, high residual stress and low adhesion will restrict their applications. Embedding monometallic nanoparticles such as Ag, Au and Cu, and bimetallic nanoparticles such as Ag-Au into DLC films will develop their properties and dispel all limitations. The achieved films are widely used in catalysis, optical sensors, and plasmonic devices due to their strong localized surface plasmon resonance [9,10]. Some of the important methods for growing Metal-DLC films are chemical vapor deposition, laser ablation, DC magnetron sputtering, and hybrid deposition system composed of an end-Hall-type hydrocarbon ion gun and metal DC magnetron sputter source.

The effect of nature and substrate structure on physical and chemical properties of microstructure and surface morphology are significant [11–15]. Due to high vertical and spatial resolution, atomic force microscopy (AFM) is an improved tool for micro roughness characterization of a thin film surface via three important factors: Root mean square (RMS) roughness, average roughness, and peak to valley roughness. From spectroscopic aspect, another considerable method for characterizing surface morphology is its frequency distribution which is presented as power spectral density (PSD) technique [7,16–19].

In this work, Ag and Au targets are used independently for preparing Ag-DLC and Au-DLC thin films by co-deposition of RF-sputtering and RF-PECVD method. Reactive gas in plasma RF system is acetylene and deposition process is carried out at room temperature in 60 s with the constant power. The only variable parameter is gas initial pressure. Analyzing the images of the atomic force microscopy (AFM), yields us information about statistical parameters of Ag-DLC and Au-DLC. Moreover, a power spectral density (PSD) plot provides valuable information on spatial frequencies of height distribution.

## Experimental details

Ag-DLC and Au-DLC thin films were synthesized by co-deposition of RF-sputtering and RF-PECVD methods with RF power of 100 W. There were two electrodes with different areas which were located 5 cm apart in the chamber. While the smaller electrode with 7.5 cm diameter was applied as a powered electrode, the larger one as anode and the ultra-clean glass placed on it as

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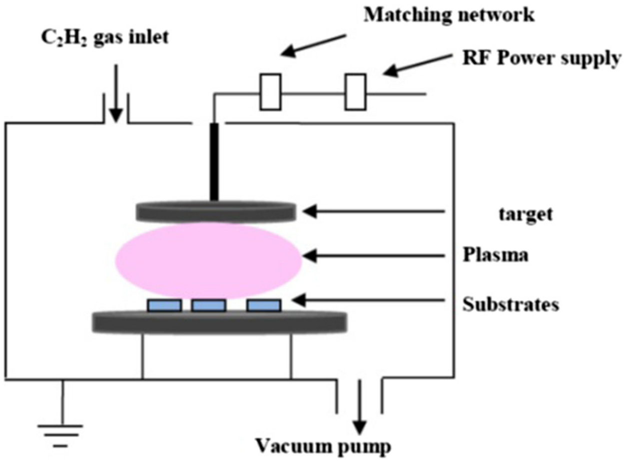

**Fig. 1.** The schematic of experimental set up.

the substrate. The 60 s deposition process was took place at room temperature. Fig. 1 represents the schematic of the system set up.

Table 1 summarizes the deposition conditions of group A and B with Ag and Au targets respectively, each were synthesized at different initial pressures.

Optical properties of the samples were compared by using UV–vis spectrometer (Stellar-Net, EPP2000). In addition, atomic force microscopy (AFM) with DMC DS 95 series in non-contact mode was used to evaluate feature and topography of the films.

## Results and discussion

In order to study the effect of pressure, the power regime was set to be constant (100 W) during 60 s deposition process. Fig. 2 shows the diagram of time deposition (s) versus the initial pressure (pa). It is observed that in the first 20 s, due to high deposition rate of carbon, the pressure dropped dramatically to the critical pressure from 1.75 Pa to 1.90 Pa. Afterwards, the pressure increased slightly and the sputtering process of Ag and Au began. The slow increase of the pressure may be the result of simultaneous deposition of hydrocarbon film, Ag and Au NPs.

Because of higher mobility of electrons in the plasma, a sheath with an excess of ions is created between two electrodes in the plasma region [20] which behave like diodes and the electrodes find dc self-bias voltages. The relation between voltages and the area of electrodes is as follow:

$$\frac{V_1}{V_2} = \left(\frac{A_2}{A_1}\right)^q \tag{1}$$

where $V_1$ and $A_1$ are the voltages of the sheath and the area of grounded electrode respectively, and $V_2$ and $A_2$ are the related values for the powered electrodes. There are also different reports for the value of q. For instance, in a capacitive divider state and according to electrodes inverse capacitance, q is assumed to be 2 [20]. Considering the collisionless Child-Langmuir law for the sheath dynamic, q becomes 4 [21,22] and finally, q = 2.5 when the sheath dynamics do follow the collisional Child–Langmuir law [22].

Mashayekhi et al. [23] set q = 2.5 by considering a collisional Child–Langmuir law which is much closer to the experimental results. In our system, $\frac{V_1}{V_2}$ was calculated 0.008. Therefore, the sheath voltage of powered electrode is almost the same as bias voltage ($V_{bias} = -(V_1 - V_2)$). Considering the grounded electrode makes the powered electrode become negative [20] and hence, because of negative sheath potential, the positive hydrocarbon radicals are accelerated toward Ag and Au targets. Based on Eq. (2), the bias voltage of plasma depend on RF power (W) and pressure (P) [20]:

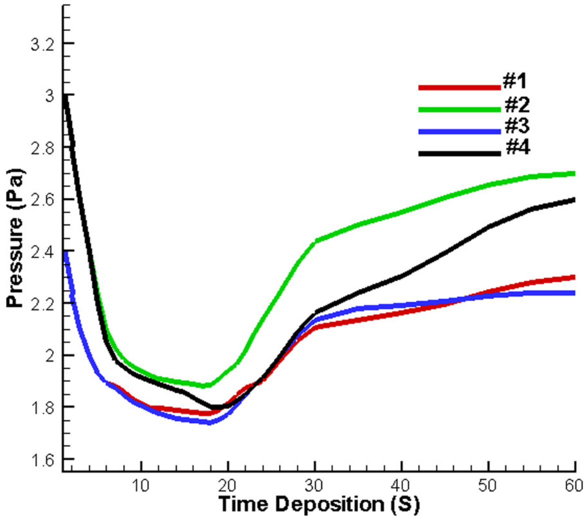

**Fig. 2.** The monitored pressure during deposition process of all samples.

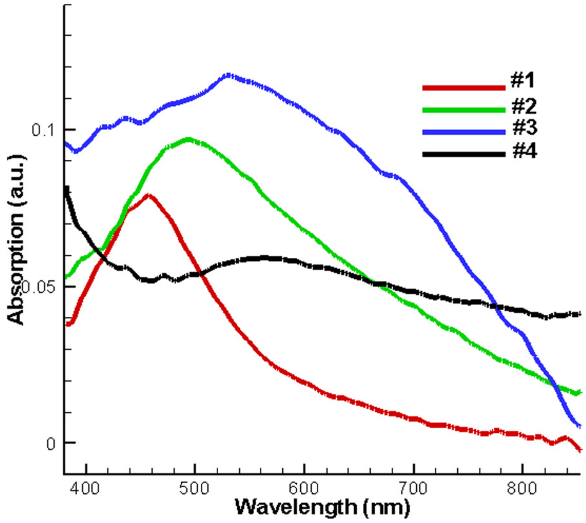

**Fig. 3.** LSPR of Ag and Au NPs for all samples.

**Table 1**
The deposition conditions of two groups of samples with Ag and Au targets.

| Group | Sample No. | Target | Initial pressure (Pa) | Time deposition (s) | RF power (W) |
|---|---|---|---|---|---|
| A | 1 | Ag | 2.4 | 60 | 100 |
| A | 2 | Ag | 3 | 60 | 100 |
| B | 3 | Au | 2.4 | 60 | 100 |
| B | 4 | Au | 3 | 60 | 100 |