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Double Side Coating of DLC on Silicon by RF-PECVD for AR Application

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Abstract

Diamond like Carbon (DLC) films were deposited on mono crystalline, double side polished silicon (100) substrates by a capacitively coupled 13.56 MHz RF plasma enhanced chemical vapour deposition (RF-PECVD) system, using acetylene (C_2H_2) as process gas. DLC films were deposited at a constant power of 200 W with 100 sccm flow of C_2H_2 and at deposition temperatures of 25ºC (RT), 150ºC and 300ºC. DLC films were characterized by Fourier- transform Infrared Spectroscopy (FTIR), Ellipsometry and Raman Spectroscopy. Characterization of DLC films for anti-reflective (AR) property by FTIR on double side coated silicon at room temperature showed enhancement in maximum transmission of about 89% in 3- 5 µm wavelength. Raman and Ellipsometry analysis confirmed the formation of DLC films with Ad/Ag ratio of 0.53- 0.82 and refractive index (n) of 2.3.

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Keywords: DLC; Anti-reflective coating; RF- PECVD; Silicon; Double side coated

1. Introduction

Diamond- like Carbon films are amorphous metastable form of carbon. These films can be either be hydrogenated films (a-C: H) containing D fractions smaller than 50% or non- hydrogenated (a-C) films containing 85% or more D bonds.[1, 2] These films contains attractive mechanical, optical, electrical, chemical and tribological properties

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and can be used in applications for anti- reflective coatings for solar cells, IR optical materials, wear resistant and low friction coatings, orthopaedic implants etc [3, 4, 5, 6, 7].These films can be prepared for tailor made needs and applications by different methods such as direct ion beam deposition, plasma enhanced chemical vapour deposition,

physical vapour deposition, plasma source ion implantation, pulsed laser deposition, sputtering, filtered vacuum arc, mass selected ion beam deposition, microwave deposition, ECR plasma CVD [8, 9]. These films can be deposited on a variety of materials such as metals, Silicon, GaAs, glass, Germanium etc. [10, 11, 12]. The commonly used anti-reflective films are CeO, CeO_2, Al_2O_3, MgF_2, SiO_2, TiO_2 and ZnS [13].

In the present study DLC films are deposited on Silicon substrates having double side polished, coated on both sides to enhance IR transmittance for anti- reflective applications.

2. Experimental details

DLC films were deposited on to mono crystalline, double side polished silicon (100) substrates of 3 mm thickness. The deposition system consists of a 13.56 MHz RF- PECVD system of Roth & Rau, Germany, model: HBS 500. DLC films were coated on both sides of the silicon substrates. The substrates were pre- cleaned with soap water, distilled water and with isopropyl alcohol in an ultrasonic bath. Prior to deposition the substrates were cleaned in argon (Ar) plasma at a flow rate of 300 sccm and a constant bias voltage of 400 V for 20 minutes.

DLC deposition was carried out with C_2H_2 as process gas in a constant power mode with RF power of 200 W and at an operating pressure of 2.0×10^{-3} mbar. The deposition temperatures were varied at 25ºC (RT), 150 ºC and 300 ºC to study the effect of deposition temperature on anti- reflective film property.

Film thickness and refractive index of the DLC film were determined by J.A.Woollam, MX 2000X ellipsometer in the wavelength of 400- 1000 nm. Raman analysis of the DLC films was carried out by Seki Technotron, STR 300 Raman spectroscope with a 514 nm laser. The IR transmittance was measured by Agilent, Cary 660 Fourier transform infrared spectrometer in the range of 4000- 400 cm^{-1} to study the anti- reflective property.

3. Results and discussion

The refractive index value of the DLC coating obtained from the ellipsometry measurement was found to be 2.3 @ 1000 nm. The optimized thickness of the DLC coating was determined from the equation.

$$d_f = \frac{\lambda}{4n}$$

where, d_f is the thickness of the film in nm, λ is the wavelength of the incident light in nm and n is the refractive index of the coating. Considering the infrared (IR) transmission in the wavelength range of 3.6 – 4.9 µm, the average wavelength of this region i.e. 4.2 µm was selected for calculation of film thickness to be deposited, this amounts to be 462 nm to be deposited on both sides of silicon substrate. From the initial experimentation the deposition rates at 25ºC (RT), 150 ºC and 300 ºC are found to be 13.9, 14.0 and 11.1 nm/min respectively. Based on the above deposition rates the required thickness has been coated on both sides of the substrate and the thickness was found to be within 30 nm from the required coating thickness.

Table 1. Refractive Index of DLC coated on both sides silicon substrates.

Deposition Temperature (ºC)	Refractive Index at 1000 nm
25 (RT)	2.35
150	2.35
300	2.38

Table 1 and Figure 1 show the refractive index of the DLC films coated on both sides of a silicon substrate at different temperatures, 25 (RT), 150 and 300 ºC. There was no substantial change in refractive index wrt deposition temperature.

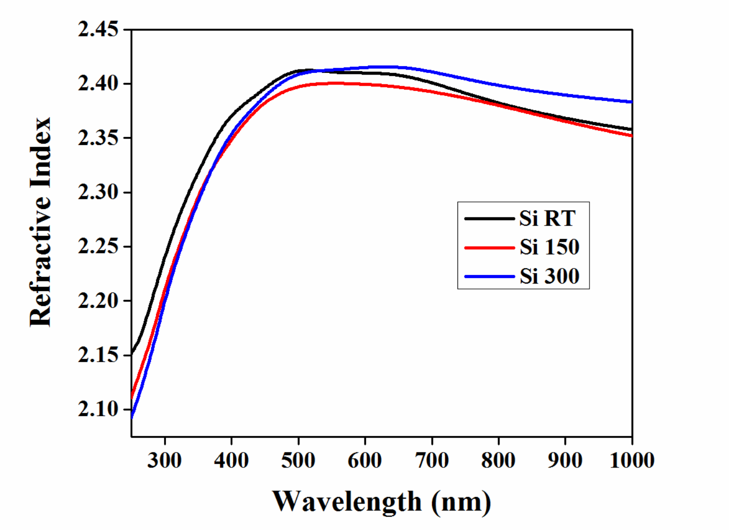
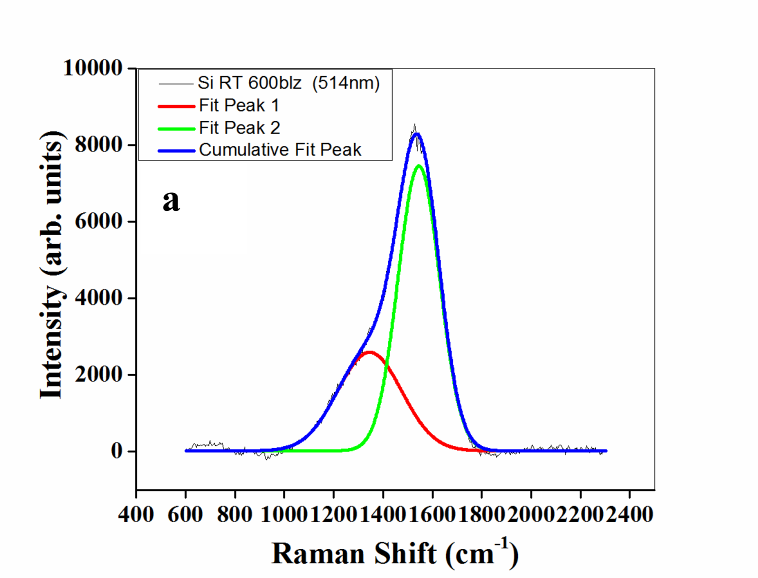


Fig. 1. Refractive index of DLC coated on both sides of silicon substrates.

Table 2. Raman Data of DLC coating from peak fitting analysis.

Deposition temperature (ºC)	G peak position (cm^{-1})	D peak position (cm^{-1})	Ad/Ag
25 (RT)	1545.012	1345.28	0.5321
150	1561.40	1345.086	0.6181
300	1551.74	1370.128	0.8253



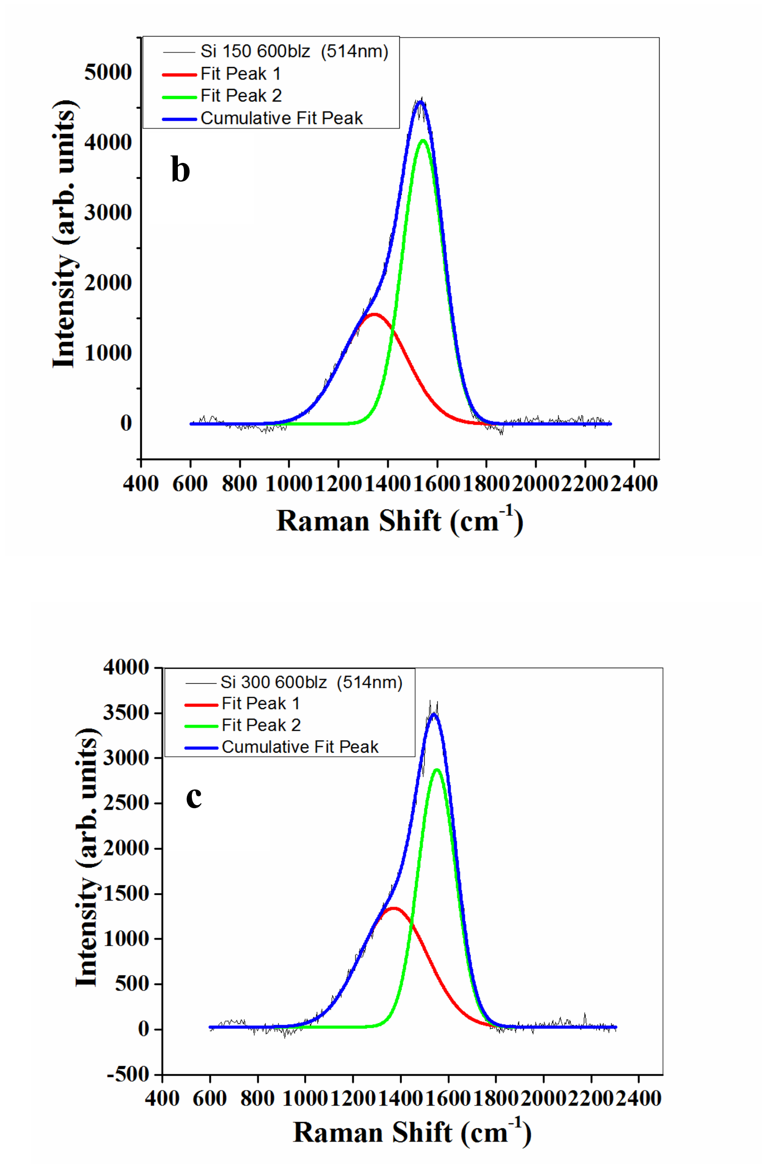


Fig. 2. Raman analysis of DLC coated silicon substrates made by PECVD process at (a) room temperature; (b) 150ºC; (c) 300 ºC

Figure 2 and Table 2, shows the Raman analysis of the DLC coatings deposited at different temperatures on silicon substrates. It can be observed that G peak ranges from 1540 to 1565 cm-1. The D peak ranges from 1340 to 1370 cm-1, an increasing trend can be observed with the increase in temperature which can be attributed to change in strain between the silicon and the DLC. From the Ad/Ag ratio, it can be observed that the D (ring structure) content is marginally increasing (0.53, 0.61, 0.82) with rise in the deposition temperature (25 ºC, 150ºC, 300ºC).

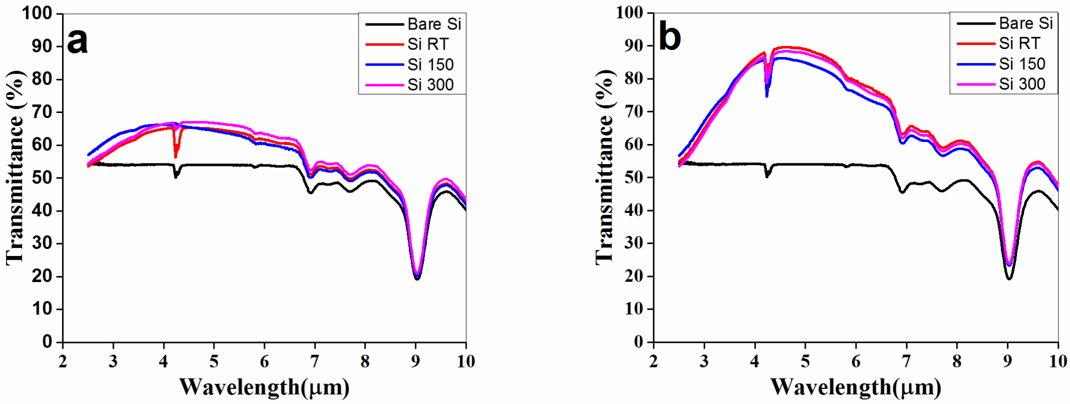


Fig. 3. FTIR plot of DLC (a): coated on single side of silicon substrate; (b) coated on both the sides of silicon substrate

Table. 3. Transmission of DLC films coated silicon substrates.

Deposition Temperature (ºC)	% Transmittance on single side	% Transmittance on both sides
RT (Bare Si)	55	55
RT	66	89
150	66	87
300	67	88

Figure 3 and Table 3 show the FTIR analysis of the DLC coatings on silicon substrates deposited at room temperature, 150ºC and 300ºC. It is evident that the coating deposited on the silicon substrates has enhanced the maximum IR transmission considerably in the range of 3 – 5 μm wavelength when compared to the bare silicon substrate. It has been observed that the double side DLC coating gives better maximum IR transmission of about 89% as compared with the single side deposited DLC coating i.e., about 67 %. Effect of the deposition temperature was not significantly observed on the maximum IR transmission. A peak is observed in FTIR data at about 4.2 μm, which is due to O-H stretching, which is not desired.

4. Conclusion

Analysis on the double side coated silicon substrates displays a considerable increase in the maximum IR transmission when compared to bare silicon substrate. The maximum IR transmission has increased nearly to 89 % from 55%. The effect of deposition temperature is not changed significantly in maximum IR transmission. It may be correlated with the independent nature of refractive index with the deposition temperature. Raman analysis shows small increment in Ad/Ag ratio with increase in deposition temperature which is not affecting much in maximum IR transmission.

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