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Deposition and characterization of amorphous carbon thin film

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Abstract: The amorphous carbon thin films of 500 nm thickness was deposited on Si (100) and stainless steel (SS) substrates by filtered cathodic vacuum arc (FCVA) technique. The 100 nm chromium interlayer was deposited by R.F. magnetron sputtering system to improve the adhesion strength between the substrate and the film. The Raman study showed the broad peak ~1560 cm^{-1} indicating the amorphous carbon. The AFM studies revealed the smooth morphology of the films with small surface roughness. The wear studies indicated the low friction coefficient of ~0.14. The carbon films prepared on stainless steel indicated the upper critical load of 11 N and the hardness value of 27 GPa a with the young's modulus of 240 GPa.

Keywords: Diamond like carbon thin films, filtered cathodic vacuum arc, Raman spectroscopy, atomic force microscopy, scratch test.

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1. Introduction:

Diamond-like carbon (DLC) coating is amorphous carbon and exhibits excellent properties such as high hardness, high young's modulus, high wear resistance, low friction coefficient and low surface roughness. DLC coating is divided into different groups such as amorphous carbon (a-C), amorphous carbon hydrogenated (a-C:H), tetrahedral amorphous carbon with hydrogenated (ta-C:H) and tetrahedral amorphous carbon (ta-C) depending on the hydrogen content and ratio of sp^2/sp^3 bonds. It finds applications in tribological, optical, micro-electronic, automobile and biomedical fields [1-7]. The properties of amorphous carbon coating depend on deposition methods and its parameters. The desired properties can be obtained by choosing the appropriate method and controlling the deposition parameters. The optimum interlayer thickness can improve the adhesion with the substrates. The good adhesion property between the substrate and the coating is the basic necessity for all the applications. The amorphous carbon films were deposited by different techniques such as, sputtering, electro deposition, filtered vacuum arc deposition, plasma enhanced chemical vapor deposition and filtered cathodic vacuum arc (FCVA). The FCVA technique has many advantages over other techniques and produces high quality coatings with high sp^3/sp^2 content [8, 9]. In the present study, amorphous carbon film of 500 nm thickness was deposited on Si (100) and stainless steel substrates by filtered cathodic vacuum arc (FAVC) technique. The microstructure, wear, scratch and nanoindentation properties of the amorphous carbon film were investigated.

Materials and Methods:

The stainless steel and Si (100) substrates was cleaned thoroughly to remove the residues of oil, grease and any other contamination. The silicon substrates were cleaned using the soap solution, running tap water and then ultrasonically cleaned in acetone. The cleaning process of metal surfaces includes surface polishing with SiC (different grit sizes; 1000, 2000 and 4000) papers and diamond paste. The Si and SS is surface treated using the Ar ions with the Ar flow rate of 50 sccm and at 300 V bias for 10 min. The argon plasma etching process was used to achieve adhesion strength and maximum surface smoothness. The chromium (Cr) inter layer was deposited by R.F magnetron sputtering with a power of 200 W using the argon flow rate of 30 sccm. The amorphous carbon film was deposited by S bend FCVA technique with the current and voltage of ~0.25 A and 25 V, respectively **[10]**. The amorphous carbon deposition was carried out with the bias voltage of 100 V for 25 min. Raman spectroscope (JASCO, NRS-3300) was used to analyze the structure of the amorphous carbon films at room temperature. The energy of 532 nm from Nd-YAG laser was used as the excitation source. The formation of the interlayer, amorphous carbon layer , surface morphology and surface roughness of the film was studied using field emission scanning electron microscopy (FESEM) (TESCAN, Model: MIRA II LMH) and atomic force microscopy (AFM) (XE-100 Park systems). The wear of the amorphous carbon film was examined by CSM tribometer. The adhesion strength was performed by CSM scratch tester in the load range 1-25 N. The nanoindentation was performed using CSM Nanoindenter.

Results and Discussion:

Raman spectroscopy was used to study the structural properties of the amorphous carbon films in the wave number range 1000-2000 cm^{-1}. Figure 1 shows the Raman spectra of the amorphous carbon film prepared at a bias of 100 V. Raman spectrum showed the broad peak ~1560 cm^{-1}, indicating the presence of sp^2 and sp^3 contents. The peak I_G ~ 1560 cm^{-1} indicating the amorphous carbon. The G band corresponds to the symmetric C–C stretching mode in graphite-like materials and the D band is attributed to disorder in the graphite-like domains affected by sp^3 bonds **[11]**. The film prepared at 100 V did not show significant D peak. The peak was fitted with Gaussian function and the I_D/I_G ratio was calculated to find the sp^3 content in the films **[12]**. A higher value of Id/Ig ratio corresponds to higher sp^2 content. The Raman studies showed the higher sp^3 fraction **[13-15]**.

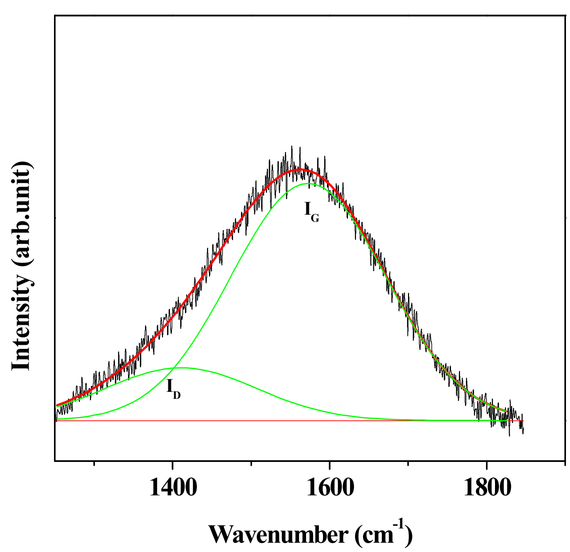

Figure (1): Raman spectrum of the amorphous carbon film on SS substrates deposited at a bias of 100 V.

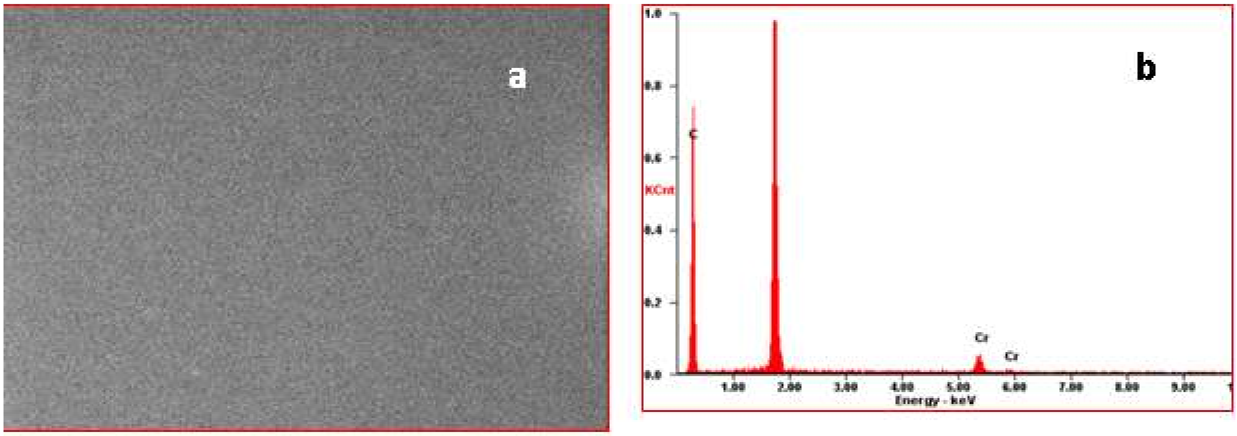

Figure (2): (a) Surface morphology of the amorphous carbon film deposited on Si (100) and (b) EDAX spectrum.

Figure 2 shows the surface morphology of the amorphous carbon films obtained from FESEM. The films show the structureless and very smooth morphology. The energy-dispersive analysis of X-Ray (EDAX) indicated the presence of carbon and chromium on the silicon substrates. Figure 3 shows the AFM image of the amorphous carbon film and reveals the amorphous nature of the film with very smooth morphology. The surface roughness of the film is also measured using AFM and is found to be ~ 2 nm **[16-18]**.

The wear studies of amorphous carbon film on stainless steel substrate with Cr interlayer were analysed. The track radius was 10 mm and normal load of 10 N for 100 m distance. The results showed that the film deposited at 100 V possess the friction coefficient of 0.14, (Fig.4) indicating the very low coefficient of friction of the amorphous carbon films due to the graphitic nature of the carbon content in the film **[19,20]**. The amorphous carbon films have not shown any chipping or peeling off resulting the good adhesion of the film with the substrate. The friction coefficient value is minimum due to its low surface roughness values as mentioned in the AFM studies.

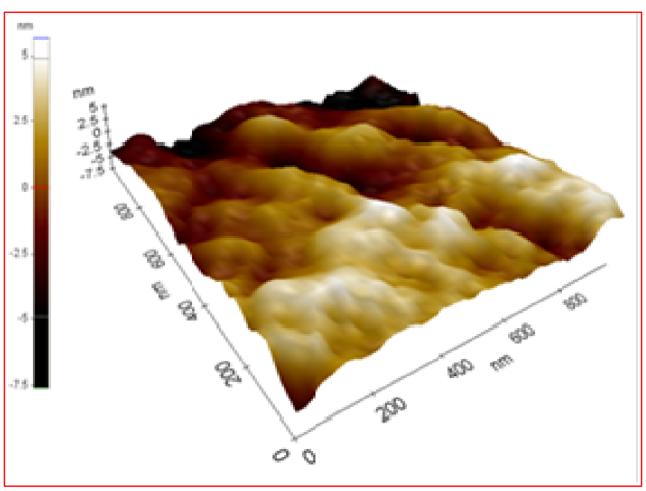

Figure (3): AFM image of the amorphous carbon film deposited on Si (100) substrates

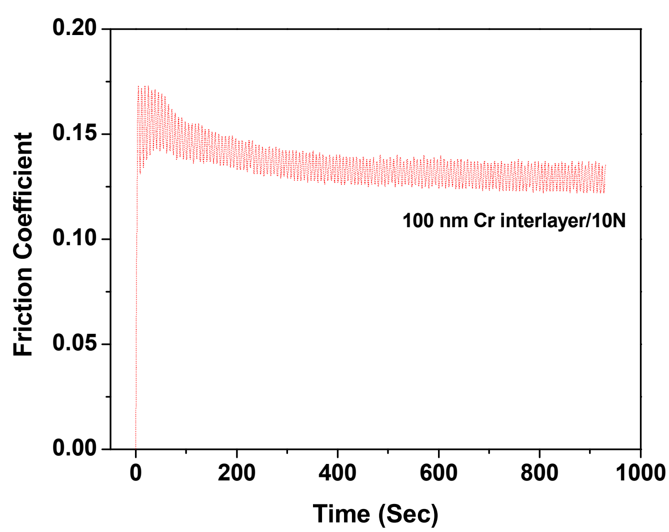

Figure (4): Co-efficient friction of the amorphous carbon films deposited on SS.

The scratch test was carried out to measure the adhesion strength of the amorphous carbon coating with the substrate. The experiment was performed in the load range of 1-25 N. The minimum load at which the failure occurs is said to be critical load (LC_1) (Fig.5). It was observed that the films deposited at 100 V have upper critical load (LC_2) of 11 N.

The substrate was not exposed even it exceeds the upper critical load of 11 N. The adhesion depends on the residual stress and the bonding strength at the interface **[21]**.

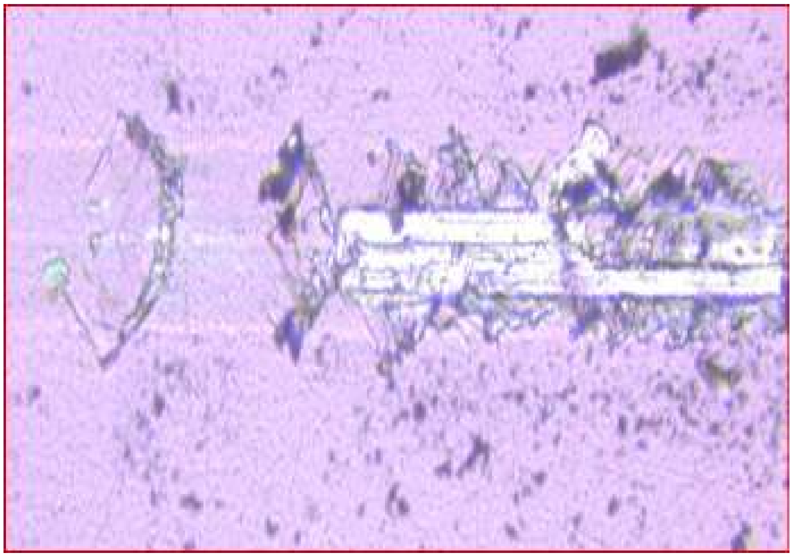

Figure (5): Scratch behaviour of the amorphous carbon film deposited on stainless steel substrate.

The mechanical property of the amorphous carbon film deposited on SS substrate was performed using CSM Nano indenter. It is well known that the hardness and young's modulus vary with sp^3/sp^2 content. The maximum hardness of 27 GPa and young's modulus of 240 GPa was obtained for the amorphous carbon film of 500 nm thickness. The high hardness of amorphous carbon is due to sp^3 bonded carbon. It is known that the substrate bias can improve the ion energy. The amorphous carbon films at higher bias, induces higher carbon incident ion energy and increase the sp^3 contents. At very high substrate bias, energetically favorable graphite structure causes the decrease of hardness **[22-24]**.

Conclusions: The amorphous carbon film of 500 nm thickness with chromium interlayer of 100 nm thick was deposited on stainless steel and Si (100) substrates at 100 V bias by FCVA technique. The amorphous carbon film showed the Raman peak ~1560 cm^{-1} indicating the formation of amorphous carbon. The AFM studies indicated the amorphous nature of carbon films and smooth morphology with a very low surface roughness (RMS value) of ~ 2 nm. The film prepared at 100 V bias showed the low friction coefficient of ~ 0.14. The scratch results showed the upper critical load of 11 N. The hardness and young's modulus of the amorphous carbon film was found to be 27 GPa and 240 GPa, respectively. The results revealed that the amorphous carbon films properties can be enhanced by choosing the appropriate substrate bias and the amorphous carbon coatings on the components and used for mechanical and tribological applications due to its higher hardness and low friction coefficient.

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