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The relation of carbon non-uniformity and deflect coil tilt angle in diamond-like carbon coating process by mathematical model

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Abstract

Today, the improvement for performance of diamond-like carbon (DLC) film is suddenly grown in surface overcoat field. Many researchers try to use methods and new technology for DLC performance improvement. This research will study about the relation of carbon non-uniformity and Deflect coil tilt angle for carbon uniformity improvement and prediction by mathematical model. The experiment was designed by DOE method and also used regression method to find the proper equation. Samples were used single side polished/etched germanium wafer prepared by coating with graphite rod originated from purity of carbon. The conditions were controlled as follows: 30 angstrom of etching depth, 6 angstrom of adhesive thickness, and 400 pulses of DLC count. XRF was used for thickness measurement. Moreover, for the mathematical model, its relation will be described using Minitab program and regression method for analysis. Afterwards, the validate equation was evaluated to find the most accurate equation by percent error.In conclusion, found equation degree 6 give the highest accuracy because from data validation give the least of percentage of error.

Keywords: Diamond-Like Carbon, Coating, Carbon uniformity

1. Introduction

Currently, the performance improvement of diamond-like carbon (DLC) film is challenging and suddenly grown in surface overcoat field because of its many advantages. DLC films are used for protect corrosion and chemical reaction at surface of materials, and for improvement in mechanical properties of materials, such as improve hardness and friction coefficient [1]. Thus, it has been widely used for many fields of industries, for instance, automotive, hard disk drive, tooling industry [2] and biomedical devices [3]. The DLC films can be generated by many methods; i.e., ion beam method that uses the principle of condensing from beam energy and growing film with sp3 bonding, sputtering method uses the principle of bombarding, cathodic arc use graphite rod and use power supply set to generate carbon plasma by ignition, PECVD method use principle of RF power to produce carbon plasma [2, 4]. However, the DLC films have many methods to coat. Although, there have been made use of the DLC film in coating applications and industries. However, still face problems regarding the properties of the DLC films, such as carbon uniformity on material surface, ratio of sp3 bond in DLC films, and adhesion between DLC films and material surface. Therefore, a number of researchers have paid attention to performance improvement of DLC films, such as use of multi-doped method and modified chemical vapor deposition method to improve mechanical properties [5], use of microwave-sheath voltage to study carbon uniformity [6], optimization of DLC deposition parameters to improve DLC film performance [7] and optimization of mechanical properties of DLC films by unbalance magnetron sputtering method [8]. Moreover, researchers also focus onstudy characterization of DLC films and parameters affecting properties of the films, such as study of characterization of DLC films by spectroscope ellipsometer [9], study of optical property of DLC films [10], study of mechanical properties of DLC films [11], study the characterization of DLC films using XPS

and Raman spectroscope [12], study characterization of N-doped DLC films by Hydrocarbons Pyrolysis Method [13], and study of surface property and biological behavior of Si-DLC films [14]. This research aims to study the relation of carbon uniformity with DLC film and deflect coil tilt angle (DCTA) and to explain its relation using mathematic modelbecause in current the factory has problem about carbon uniformity. It has effected with quality of materials because DLC thickness for all of range in pallet does not has uniform enough and need to improve quality in process for new product supporting in future. DLC film was coated on germanium substrate and measured its thickness by XRF. Then, the determination of the most accurate mathematic model from regression analysis to describe the relation between carbon non-uniformity and angle of DCTA and validate equation to find the most accuracy equation by using percent error and R-Square method.

2. Experiment

2.1 Machine system

DLC machine layout of Nexus cluster DLC Xi from Veeco Instruments Inc. was shown in figure 1. The pulse filtered cathodic arc (PFCA) was used to generate carbon plasma. First, samples were loaded into load lock chamber (pressure 10-2 torr). Second, the samples were automatically transferred to etching chamber through isolate door (pressure 10-4 torr). Third, etching process was performed using RF method. The condition of this step was used as follows: 99.999% of Argon gas, 11 sccm of gas flow control, and 420 volt of control voltage. The etching used for cleaning lubricant by smearing and depth was controlled by time. Then, the samples were transferred to coating chamber for coating adhesive and DLC film (pressure 10-7 torr). The adhesive was deposited on the sample surface using bombarding method and its thickness was controlled by operation time. Afterwards, the samples were coated with DLC controlled thickness by pulse count. The XRF method was used to measure sample thickness.

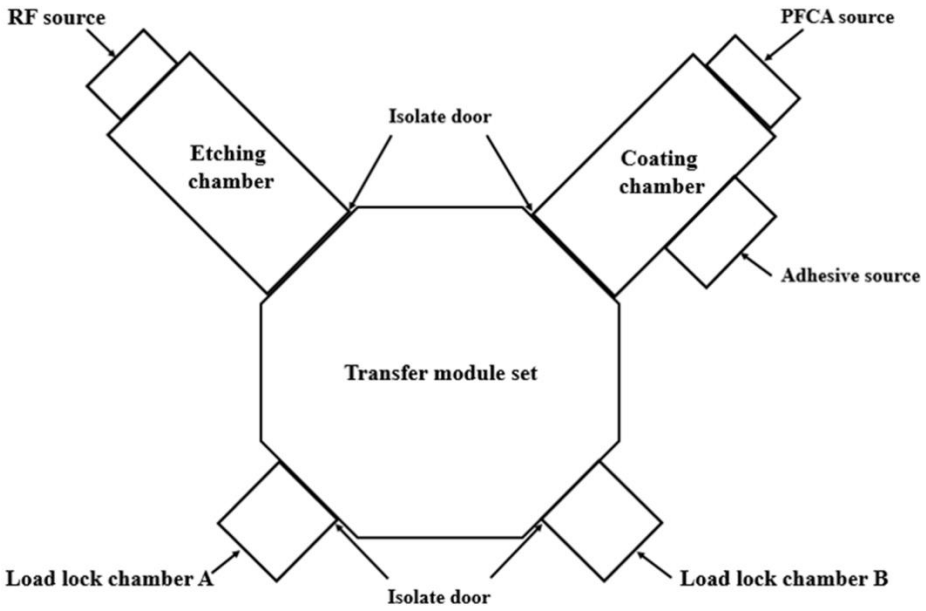

Figure 1 DLC machine diagram.

2.2 DLC film preparation

Graphite rod (0.3 inch in diameter and 12 inch in length) was used as DLC source having purity of carbon 99.999%. Single side polished/etched germanium wafer was used as substrate with 1 inch of diameter doping with N-Type method and thickness in range of 198 – 250 micrometer. Depth control, adhesive thickness, and DLC pulse control count were 30 angstrom, 6 angstrom, and 400 pulses, respectively. Germanium wafer was used 5 pieces per run and attached on 5 inch of flat pallet exhibited in figure 2.

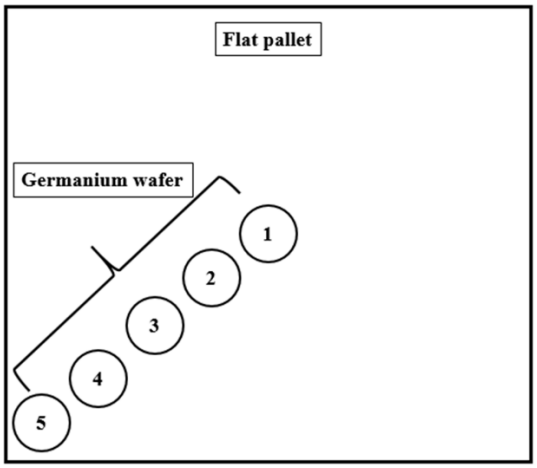

Figure 2 Germanium wafer on flat pallet

2.3 Parameter for experiment

Figure 3 displayed the DLC chamber diagram. The major parameter for this experiment is deflected coil tilt angle (DCTA). The DCTA is equipment in PFCA source used to control carbon plasma direction to coat on substrate. Deflection coil made from copper has diameter 2 inch contacted with filer coil. Subsequently, after graphite rod was arced by ignition method, carbon plasma was mixed randomly with micro particle and plasma beam. Thus, the micro particle mixed in the plasma beam was necessary to be eliminated by filtering while the plasma was being grown on surface of substrate by RF method. After filtering, the beam direction had to be carefully controlled, because such a direction played an important role in carbon uniformity in terms of DLC thickness per length. The change in DLC thickness affects definitely DLC characteristics in terms of the optical property [10].

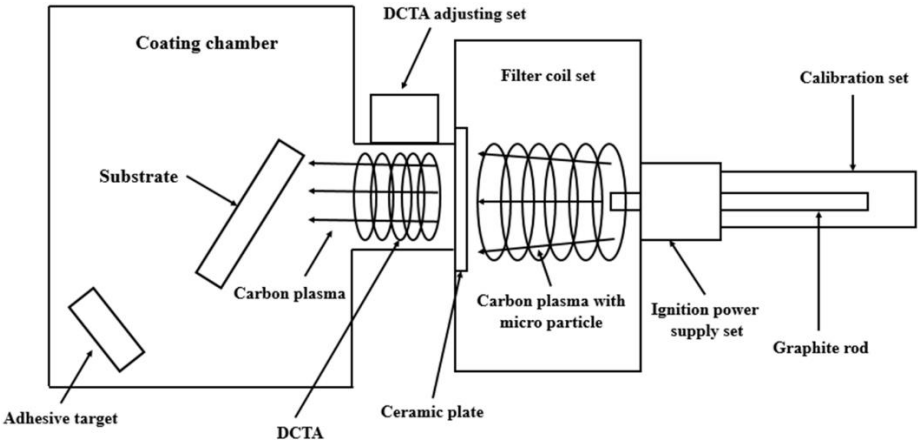

Figure 3 DLC chamber diagram

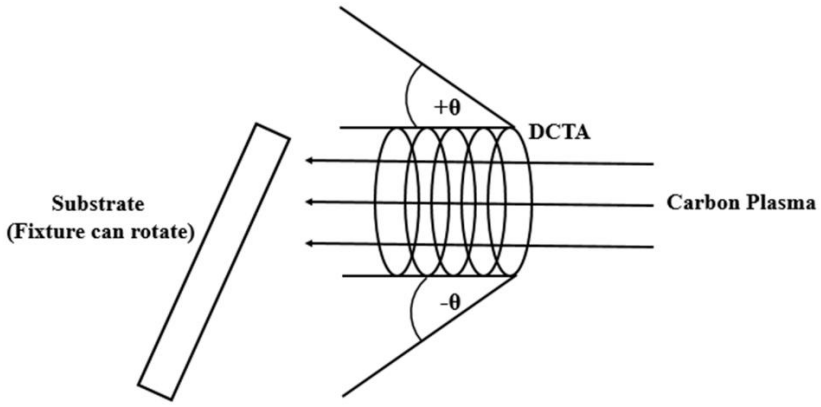

Figure 4 Micro diagrams for DCTA

3. Results and discussion

3.1 Data collection

The data collection from design experiment method (DOE) was shown in figure 5. In this work, the relation between the DCTA and the carbon non-uniformity was investigated. The result indicated that the highest carbon non-uniformity was obtained at the degree of -9. Then, it tended to decrease when the degree of the DTCA was increased until +5 degree. Afterwards, the carbon non-uniformity showed the upward trend. The lowest carbon non-uniformity at the +5 degree of the DCTA was attributed to the highest carbon ion projection as exhibited in figure 4. So can concluded at DCTA +5 degree give the best carbon uniformity because from data calculation has the lowest carbon non-uniformity.

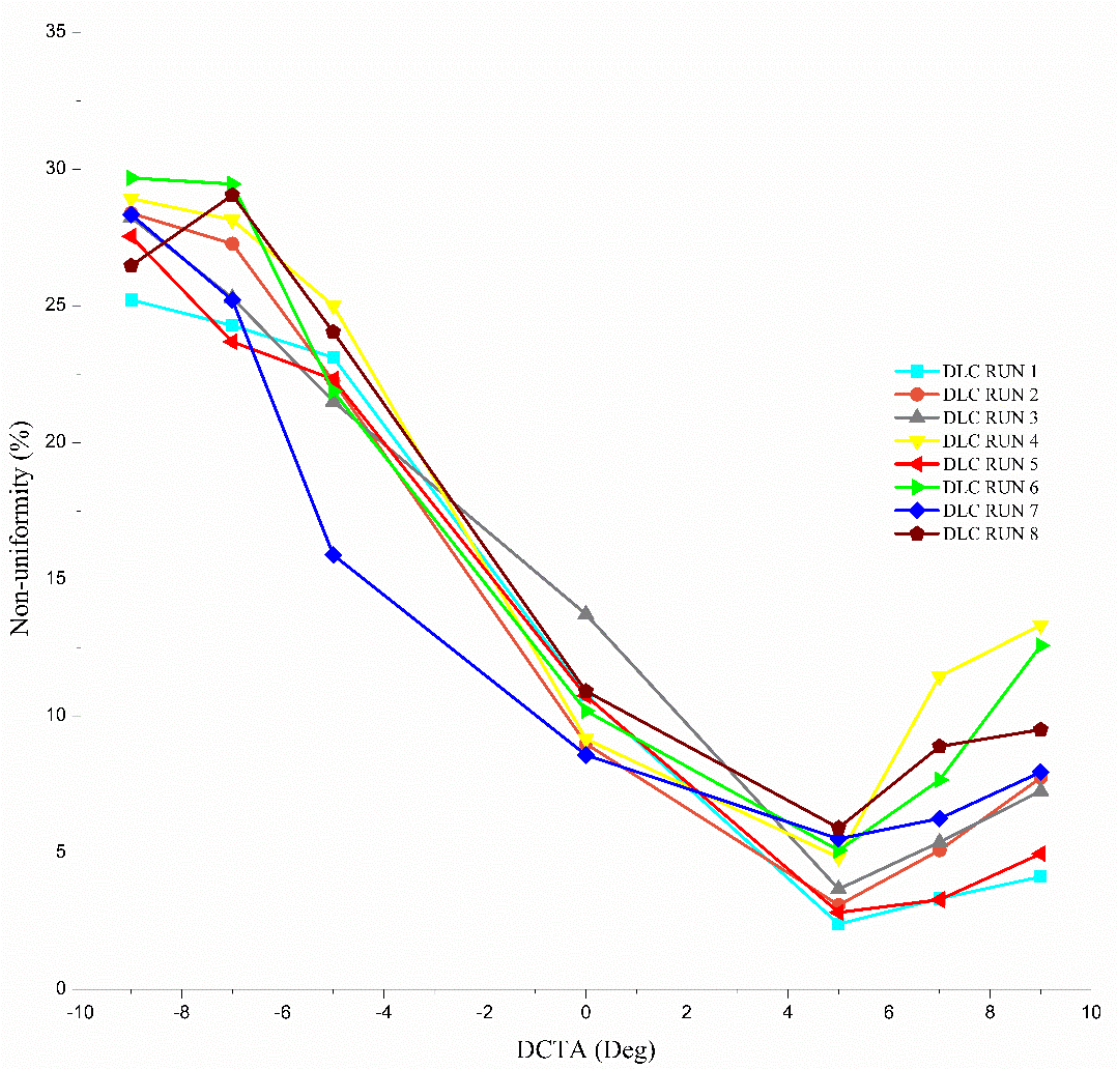

Figure 5 The relation of DCTA and carbon non-uniformity

3.2 Data fitting

Data fitting has been purposed to find the relation between the carbon non-uniformity and the DCTA in mathematical model using regression method operated by Minitab program as shown total 8 equations. From observation can see numerical coefficient will be less if the equation has high power. So it is not significant to calculate. From equations showed as below.

$$N = 15.109 - 1.3060A \quad (1)$$

$$N = 10.857 - 1.3060A + 0.096A^2 \quad (2)$$

$$N = 10.857 – 2.061A + 0.096A^2 + 0.01221A^3 \quad (3)$$

$$N = 10.069 – 2.061A + 0.1556A^2 + 0.01221A^3 + 0.000675A^4 \quad (4)$$

$$N = 10.069 – 2.215A + 0.1556A^2 + 0.0187A^3 - 0.000675A^4 - 0.000057A^5 \quad (5)$$

$$N = 10.379 – 2.215A + 0.0561A^2 + 0.0187A^3 + 0.00278A^4 - 0.000057A^5 - 0.000028A^6 \quad (6)$$

$$N = 10.378 + 0.05614A^2 - 0.142467A^3 + 0.002782A^4 + 0.0034022A^5 - 0.00002831A^6 - 0.00002831A^7 \quad (7)$$

$$N = 10.378 - 0.142467A^3 + 0.0068666A^4 + 0.0034022A^5 - 0.000116A^6 - 0.000022A^7 + 0.00002831A^8 \quad (8)$$

Where N = Carbon non-uniformity
A = Angle of DCTA

In the field of applications, the above equation can be used for prediction about carbon non-uniformity because of DLC thickness on surface affected mechanical properties such as hardness, corrosion rate, friction coefficient and electrical property in semiconductor industry. In the case of manufacturing process, the equation can be used to control or tighten the variation of carbon non-uniformity, leading to an improvement in product quality.

3.3 Validate equation

The equation was validated by comparison of actual data and calculated percentage of error for total 19 DLC runs with DCTA ranges from -9 to +9 degree. The procedure for validation was prepared using germanium wafer as substrate (5 pieces per run) and set in 5positions from 0 to 5 inches. Then, DLC thickness was measured by XRF to calculate carbon uniformity the results of average validation of carbon uniformity obtained from calculation and actual data possessed error found equation 6 has the least percentage of 0.232% and highest accuracy by R-square value is 94.850as exhibited in table 1. This means the equation 6 is applicable and useful to be used in practice.

Table 1 Data validation per equations

Equation	Percentage error (%)	R-square
1	33.591	83.180
2	16.059	91.080
3	6.831	94.440
4	4.460	94.700
5	3.511	94.710
6	0.232	94.850
7	13.403	94.840
8	35.663	94.840

4. Conclusion

This research studies the relation between carbon non-uniformity and deflection coil tilt angle by mathematic model. The most accurate equation is equation 6 because this equation gives the least percentage of carbon non-uniformityshowed 0.232% that can describe such relation is determined. The result shows that the finding equation possesses good advantage in both applications filed and manufacturing process.

5. Acknowledgement

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