# Utilization of Oxygen Plasma For Plasma Ashing and Etching Process

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# Utilization of Oxygen Plasma For Plasma Ashing and Etching Process

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ABSTRACT

The development of plasma technology is growing rapidly, so that the plasma formation process can be run quickly. Plasma controlling can easily be done, thus simplify determining the desired plasma species. Oxygen plasma is one of the high reactive ions in oxygen plasma. Oxygen ion reactivity can be used as an ion bombardment on the substrate. Oxygen ions reactivity can be used for DLC coating bombardment to remove or create a micro pattern. Besides that on the process of bombardment, both oxygen and DLC (carbon) can bind or remove DLC much quicker. A high-density plasma generation has been developed in the plasma formation. The use of dipole electrode and an automatic settings on the RF, DC bias and gas pressure, resulted a better plasma control. This machine has a characteristic with a radio frequency (RF) working around 2 MHz. This RF plasma is directly controlled by a voltage regulator from 60 V to 250V. DC bias is also controllable from 0 V to 600 V. The pressure could be varied from 10 Pa to 100 Pa with an automatic gas flow rate control. In this study, the RF voltage was varied from 200V to 250 V, while the DC-bias was varied in a range of - 400V to 600 V and the gas pressure variation was taken between 20 Pa to 40 Pa. The base pressure was below 0.1 Pa. The first sample used is a SKD 11 DLC coated with a thickness of 5 μm. These samples are used to test the plasma ashing process. The second sample used is a Si wafers coated with a 5μm DLC and implementing the masking oxide polymer. The second sample is used to test the plasma etching. From the research, it is found that the use of oxygen plasma is very effective for ashing or etching process with a plasma parameter control. The suitable etching rate for ashing is about 5.2 nm / s. The etching rate is 5.2 nm / s and the gas pressure is 20 Pa. The RF voltage is 250 V and the DC bias voltage is 600V. The etching rate of 1.67 nm / s is suitable for plasma etching process to produce anisotropic shape. This condition occurs at a gas pressure of 40 Pa, a RF voltage of 250 V and a DC bias voltage of - 450 V. The plasma parameters control is very important, especially controlling the plasma species for a suitable ashing or etching process. The plasma controlling would affect the oxygen ion bombardment reactivity of the DLC layer.

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## INTRODUCTION

Carbon such as Diamond like Carbon (DLC) has been developed by Physical Vapor Deposition (PVD) and Chemical Vapor Deposition (CVD) method. By implementing this method everyone could be able to create an unique layer of carbon with a characteristic like diamonds, such as a hardness of 50 - 80 GPa (Kadilaya, 2006), high thermal conductivity, nano scale of atomic structure (< 5 nm), low friction coefficient (< 0.01 to 0.7), abrasion resistance, chemical reaction resistant, and transparency to infrared. The main objective of DLC in machining is to improve the steel mechanical properties such as the cutting tools hardness and strength (Sokovic, 2011). DLC is more durable especially for machinery parts, gears, shafts, pins, mold-dies equipment, punch, stamping, etc (Richardson, 2003). By implementing this process the tribology aspects on machining equipment could also be solved (Holmberg, 2009; Romina, 2011). To allow creating a relatively thick DLC coating, a method is developed, which is using a several interlayer method. Cr is one of the interlayer widely used (Bouzakis, 2010; William, 2006). This multilayer system was able to provide a dense DLC adhesion. The Cr substrate could also prevent the coated material corrosion and friction (Dobrza, 2003; Lukaszkowicz, 2011). Chromium is also used for masking to create a pattern. The micro patterns on a DLC surface is expected to make a permanent layer pattern on a DLC.

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Micro-pattern is one of the most important technologies for optical elements mass production (Bohm, 2001). Mold-stamping process takes place above the glass transition temperature. Either the substrate material or the coating material must have a sufficient strength and toughness at a high temperature. Diamond-like carbon (DLC) coatings and glassy carbon materials is suitable for this micro pattern.

Plasma is the fourth phase of matter, where the plasma occurs due to the ionization process. Free electrons that have been raised by the RF (Radio Frequency) will be accelerated with the DC bias in the system, so that it will hits the gas molecules in the chamber. Consequently, gas molecules will split into atoms and ionized.

$e + A \rightarrow A+ + 2e$

Plasma has two main parts, firstly, is the sheath plasma in which there are many free electrons and bulk plasma with ions inside. Plasma was used to remove a sample layer or could be used to control patterning on a sample. This kind of plasma is called as a dry plasma etching (Dry Etching). Chemical solution (Wet Etching) was used for sample layer removing before dry etching was found. The chemical solution reactions would cause the sample layer damage. Wet etching was never been used again due to the less efficient and the danger of chemical solutions. The plasma etching principle is a process when a chemical etching occurs followed by an ion bombardment. There are many advantages using this plasma etching process; just a small amount of solution used; eliminates the acids dangerous handling; available for isotropic or anisotropic etching profile, and has a better control process. The disadvantage of this system is that there are some corrosive gases and has a bit complex instrumentation.

***Experiment:***

First, introduce the developing high dense RF-DC plasma etching system. Different from the conventional plasma etching, no chemical agents are utilized in this process. Two types of DLC-coated samples are employed as a test-piece. DLC-coated with chromium interlayer is used to measure the removal rate of coatings. DLC-coated SKD-11 and Si sample with initial micro-pattern is also used to describe the oxygen plasma etching behavior.

***Plasma Ashing/Etching System:***

In etching process, pure oxygen is used to remove the DLC coating. This system has three main processing parameters: which is the RF voltage, the DC bias and the oxygen gas pressure. In parallel with these parameters, the experimental set-ups has influence the etching process; e.g. the dipole electrode spatial position to the RF plasma generator, the distance between the electrode and cathode, and the distance between the electrode substrate. The typical experimental set-up is depicted in Fig. 1. In the following plasma etching experiments, the above parameters are varied to find the optimal feasible range in those parameters for an efficient DLC coating removal. Under an optimum parameter selection, micro-patterning is performed to describe the etching behavior. This machine has a radio frequency working at around 2 MHz. The RF plasma is directly controlled by a voltage regulator from 60 V to 250V. The DC bias is also controlled from 0 V to 600 V. The pressure is varied from 10 Pa to 100 Pa with an automatic gas flow rate control. In this study, the RF voltage was varied from 200 V to 250 V, the DC bias was set between - 400 V to 600 V and the gas pressure was chosen between 20 Pa to 40 Pa. The base pressure was below 0.1 Pa.

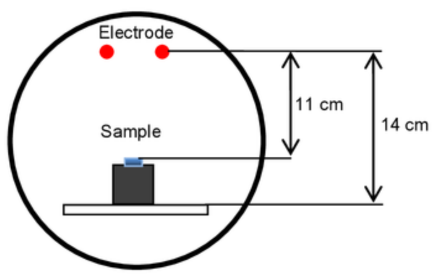


**Fig. 1:** Experimental set-up for plasma ashing/etching.

***DLC coated SKD 11 sample:***

This sample was employed in the preliminary experiments to search for the optimum parameters in plasma ashing. SKD-11 is used as a substrate for DLC coating by using PVD RF sputtering. The DLC film thickness is about 1.1 µm.

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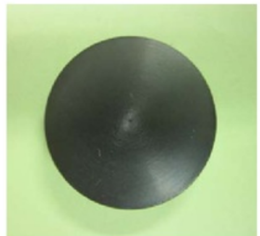

**Fig. 2:** DLC coated sample.

***DLC coated Si sample:***

The second sample used in this experiment is shown in Fig. 3. This sample is used for plasma etching process.

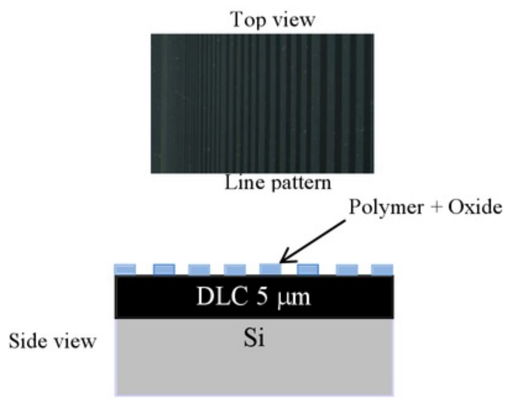


**Fig. 3:** DLC coated Si sample.

Silicon wafer was employed as a substrate and subsequently DLC coating thickness and polymer oxide mask were stacked onto it. The thickness of Si wafer, DLC coating and oxide mask are 0.525 mm, 5 μm and 1.2 μm, respectively. The width of line pattern varies start from 3, 4, 5, 7, 10, 20, 30, 50, 70 and 100 μm (Fig. 3)

## RESULTS AND DISCUSSION

The etching rate was defined by the ratio of the removed DLC thickness to the removal time required. The plasma etching process worked optimally on RF voltage of 250 V, DC bias of - 400 to - 600V and a pressure of 20 Pa.

***Plasma Ashing:***

The DLC-coated SKD-11 sample was masked in the left half by a polyamide taping. Since only unmasked right-half of sample is ashed by this plasma processing, a step, corresponding to the DLC film thickness (Δx), is formed after etching during the duration time (t). Then, the etching rate is defined by

$$Etching\ rate = \frac{\Delta x}{t}\ nm/s \quad (1)$$

Δx = DLC remove thick [nm]
T = time [second]

Fig. 4 shows the sample after plasma ashing to measure the etching rate by Eq. (1).

**Fig. 4:** DLC-coated SKD 11 sample after plasma ashing.

This etching rate is significantly dependent on the plasma processing parameters and set-up configuration. In the case of 20 Pa for pressure, - 600 V for DC bias, 250 V for RF, DLC coating with the thickness of 1.1 μm, was ashed away for 210 seconds; the etching rate is 5.2 nm / s. This high rate is only used for DLC films removal.

***Plasma Etching:***

Fig. 5 shows the SEM results of the line pattern after the etching process. This figure is the profile of the best result after optimizing the parameters of gas pressure, DC bias and RF.

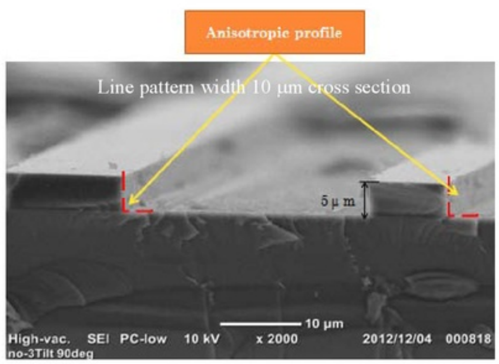


**Fig. 5:** Test Result Line Pattern on Pa = 40 Pa; RF = 250 V; DC Bias = - 450 V; time 3000 s.

At pressures below 40 Pa and DC bias above 450 V form micro patterns are not anisotropic. At a pressure of 40 Pa, a dc bias of 450 V and 250 V RF etching rate that occurred around 1.67 nm / s. In this condition the resulting anisotropic shape, as shown in Fig. 5.

*Discussion:*

The plasma ashing or etching test results is shown in Fig. 4 and Fig. 5. Oxygen plasma process control, greatly affect the results and the time required. In plasma etching process etching rate control should really be considered to produce an anisotropic shape. The result of a previous study (Redationo, 2012) that the lower the pressure of the incoming gas in the chamber and the RF and DC bias voltage the higher the etching rate. High etching rate on a Reactive Ion Etching (RIE) shows that the reaction are highly active. The high etching rate would change the condition become an isotropic etching profile and a lower etching rate would change the profile to be anisotropic (Kuhnke, 2005). This condition also occurs in the etching process line pattern. Ions are highly reactive so that the oxygen plasma on the etching rate increase above 1.67 μm. At a pressures of 20 - 25 Pa, a DC bias voltage of – 600 V and RF voltage of 250 V, a relative high ion temperature and a low ion density would activated a very quick ion movement which result a high reactive RIE. A high RIE reactive would cause ion collision and an uncontrolled ion movement. Ion collision and uncontrolled ion movement results an uncontrolled etching process. This condition is not appropriately used to etch grooves with a width of less than 20 μm. At a pressure of 40 Pa, - 450 V DC bias and RF voltage 250V, the ion temperature is relatively low and the ion density is relatively high. In this condition the relatively slow movement of ions can be controlled so that the ion movement did not result an ion collision. This would causes the ion bombardment on the DLC to run properly, because the incoming ions (bombardment) and the outgoing ions are working smoothly. High density ion bombardment process is very effective because the force generated has a bigger bombardment power. O ion bombardment strength would made the DLC coating easily eroded. The O ions move relatively very slow which allowing an ion bombardment move perpendicular during the process. It is because of the O ions could easily move out (discharge CO) and the incoming O ion bombardment on DLC made an anisotropic etching profile condition.

The pressure function in the plasma etching process would affects the electron and ion temperature and the electron density (Yunata, 2013; Suenaga 2013). The electrons and ions density increases with the increase of the gas pressure, while the electron and ion temperature increased with a decrease of gas pressure. DC bias would increase the temperature where the electron or ion density also increases. Controlling the oxygen plasma etching process is very important, especially for a product with a width below 10 μm, corresponding etching rate is in the range of 1.67 nm / s. In plasma ashing, high etching rate is very effective to remove the DLC layer. It is not necessary to control the oxygen ions direction movement in the ashing process.

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***Conclusion:***

Oxygen plasma is suitable for the plasma ashing or etching process to remove or produce micro pattern on the DLC coating process. It is necessary to control the etching rate, especially for the etching process to produce anisotropic shape.

An etching rate of 5.2 nm / s is suitable for plasma ashing process and an etching rate of 1.67 nm / s for plasma etching process.

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