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Plasma Etching with Metallic Masking for Micro-Patterning onto DLC Coated Mold-Dies

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ABSTRACT: Diamond like carbon (DLC) coating is used as a mold-die material to imprint the designed micro-patterns onto optical plastic and oxide-glass products. The plasma etching system is developed to make micro-patterning onto DLC coating only by oxygen gas without any etchants. In-situ plasma diagnosis by spectroscopy is performed to describe the plasma chemistry during plasma etching process. The chromium-masked DLC coating is prepared as a test-specimen for plasma etching; micro-groove patterns with different widths and pitches are also accommodated to analyze the present etching behavior. When DC bias is -450 V, and pressure, 40 Pa, the etching rate reaches to 5 μm/H.

Key words: Plasma oxygen etching, Metallic masking, Micro-patterning, In-situ plasma diagnosis

1. Introduction

Micro-patterning has become one of the most essential technologies for mass-production of optical elements [1]. Since mold-stamping process takes place above the glass transition temperature, both substrate materials and coatings must have sufficient strength and toughness at the elevated temperature even in inert gas atmosphere. Diamond-like carbon (DLC) coating and glassy carbon materials are suitable to this micro-patterning. With respect to plasma ashing and etching, the high dense RF-DC plasma technology is found to be effective to remove DLC coating for ashing and etching [2].

In the present paper, this RF-DC plasma technique is optimized to control the oxygen plasma species for efficient etching of amorphous carbon coating. First, two dimensional micro-grooving pattern is directly facilitated onto the surface of DLC coating by chromium masking. This sample is used for plasma etching only with use of oxygen gas supply. Etching process condition is optimized by in-situ plasma diagnosis; variation of carbon mono-oxide peak in the measured spectra is useful for real time monitoring of etching process. Nearly constant etching rate is attained irrespective of the metallic mask width and pitch: e.g. it becomes 5 μm/H when the DC bias is -450 V and pressure, 40 Pa. Uniform etching takes place irrespective of geometries in patterning.

2. Experiment Procedure

2.1 Plasma Etching

RF-DC plasma etching system was developed to investigate the optimum condition for etching of amorphous carbon coatings, as shown in Figure 1. After preliminary experiments, DC bias and pressure was selected to -450 V and 40 Pa, respectively.

2.2 Plasma Diagnostic

The spectroscopic measurement system with optical detector was used to analyze oxygen plasma species in this experiment. First, oxygen plasma state was described by this spectroscopic measurement to analyze the plasma chemical reactions between oxygen and electrons without samples: e.g. $O_2 + e \rightarrow 2O + e$. In second, the measured spectra during plasma etching the DLC-coated samples, were analyzed to detect the peak of resulting species from the direct reaction between carbon in DLC coating and oxygen-based species. In this plasma diagnosis, NIST reference data were used together with reported data in papers.

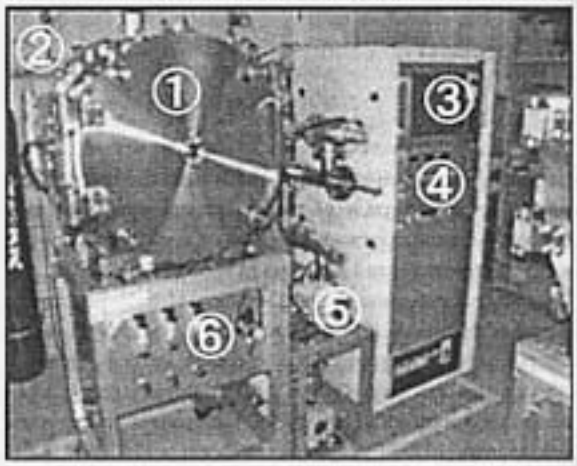


Figure 1. High dense plasma etching system. 1: Chamber, 2: RF-plasma generator, 3: Control-panel, 4: Electric sources, 5: Evacuation system, 6: Gas supply.

2.3 Sample Specimen

Un-balanced magnetron sputtering was used to form DLC coating with amorphous SiC and metallic chromium interlayer as illustrated in Figure 2. Chemical masking technology was used to form various micro-groove patterns as chromium masks. Owing to the bottom layer by amorphous SiC and chromium, the substrate material is free from plasma etching.

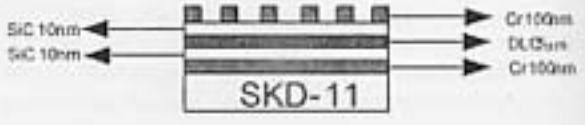
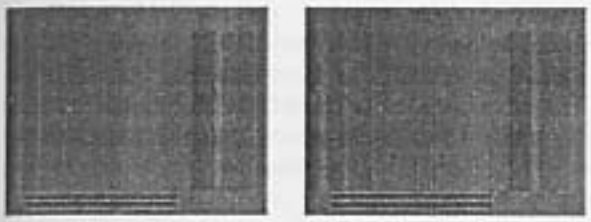


Figure. 1. Sample of plasma etching

3. Experimental Result

Figure 3 (a) depicts the original chromium masking pattern before plasma etching. Both line widths and line distances, were parametrically varied to investigate the effect of masking geometry on the plasma etching behavior. The plasma etching process with DC bias of -450 V and pressure of 40 Pa, was selected to remove the DLC layer below this masking. As shown in Figure 3 (b), original masking pattern was less damaged during etching. After laser profiling measurement by NH-3SP (Mitaka), the average etched depth was 5 μm for the duration time of 3450 s. That is, the average etching rate became 5 μm/H.



(a) (b)

Figure. 3. Chromium-masked DLC-coated SKD 11 mold-die before etching (a) and after etching (b).

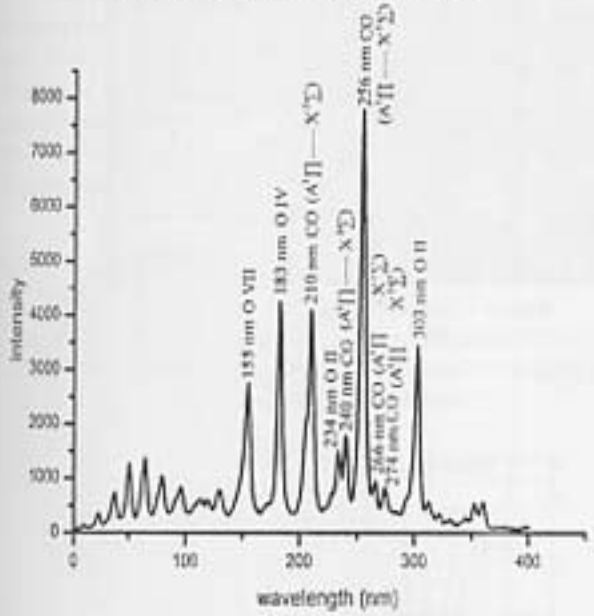


Figure.4. Spectrum of chemical species in-situ measured during plasma etching process.

Figure 4 depicts the in-situ measured spectrum of chemical species during plasma etching. Besides oxygen molecule related peaks at the wavelength 155 nm, 183 nm, 234 nm, and 303 nm, five main emission lines of carbon monoxide are detected at the wavelength of 210 nm, 240 nm, 256 nm, 266 nm, and 274 nm, respectively. Furthermore, the substrate surface remains active by ion bombardment under high DC bias. Hence, a series of chemical reactions is expected to take place by C + O → CO or C + O* → C-O, since oxygen plasma state is governed by oxygen atoms (O) and activated oxygen atoms (O*).

During this etching process, oxygen atom flux is reacted with carbon in the DLC coating by the above reaction to dig the etched region. Hence, the etching behaviour is analyzed by monitoring the measured CO-peak with etching time. Figure 4 depicts time variation of CO-peak at the wave length of 256 nm. After the early slow reduction of CO-peak intensity, the reduction rate of CO-peak becomes nearly constant till t = 2000 s; then, this rate decays in the exponential manner.

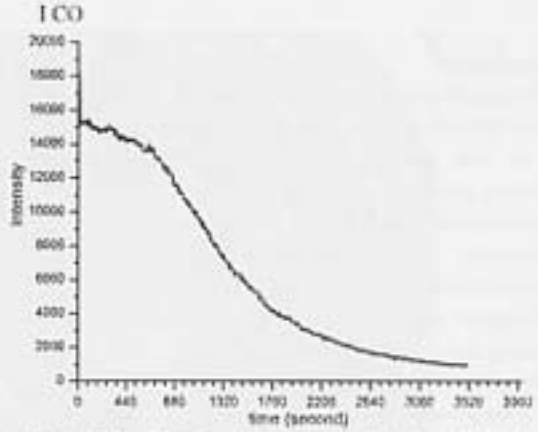


Figure.4. Variation of CO peak intensity with time during plasma etching process.

In the early stage, fresh un-masked DLC coating surface is freely reacted by oxygen atom flux from plasma sheath; chemical reaction to CO is driven by oxygen atom flux, resulting in nearly constant concentration of CO in emission. In the intermediate stage, content of ejected CO gas is mixed with inlet oxygen atom flux, resulting in apparent reduction of CO-intensity peak in Figure. 4. In the final stage, its exponential reduction corresponds to reduction of carbon source in DLC coating with time. In order to further understand this etching process, the theoretical etching model is developed with experimental studies to describe the etching depth profile change with time.

4. Conclusions

Fine micro-grooving patterns are successfully etched onto the DLC coating by plasma oxygen etching without use of any hazardous etchants. This early success leads to two dimensional micro-patterning onto any mold-die materials for mold-stamping of optical polymer and oxide-glass elements.

References

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