Flatness correction of quartz glass substrate by plasma jet figuring with pulse width modulation control

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Abstract

Plasma chemical vaporization machining (PCVM) is one of the ultra-precision figuring technique for fabricating optical components and for correcting thickness distribution of silicon on insulator and quartz crystal wafer with nanometer order accuracy. In our previous research, the removal volume distribution was controlled by changing the scanning speed of the worktable. However, a discrepancy between the theoretical scanning speed and the actual scanning speed resulted owing to the inertia of the worktable when the rate of change of the scanning speed was rapid. To resolve this issue, we proposed pulse width modulation control of RF power output for generating plasma instead of scanning speed control of the worktable, and obtained preliminary experimental result regarding controllability of material removal rate.

1. Introduction

Plasma process has been applied in various manufacturing fields, such as fabrication of semiconductor device, figuring of optical components, surface modification, surface cleaning, and so on [1-2]. For the fabrication of optical components and finishing of semiconductor wafer, nanometer order form accuracy without introducing subsurface damage (SSD) is essential. However, in the case of conventional machining methods such as grinding and polishing, it is difficult to obtain such high form accuracy without introducing SSD due to their removal mechanism and external disturbance. In contrast, there is no SSD on the surface processed by plasma etching since it utilizes a chemical removal process. We developed plasma chemical vaporization machining (PCVM), which is noncontact chemical figuring technique utilizing locally generated atmospheric-pressure plasma [3-4]. By applying numerically controlled PCVM (NC-PCVM), figuring of X-ray mirror, thickness correction of silicon on insulator (SOI) and quartz crystal wafer have been achieved with form accuracy in nanometer order [5-6].

In our previous study on NC-PCVM figuring, the removal volume distribution on the workpiece was controlled by changing the scanning speed of the worktable. However, a discrepancy between the theoretical scanning speed and the actual scanning speed was resulted due to the inertia of the worktable when the change rate of speed was rapid. Furthermore, in the case of thick dielectric substrate, it is difficult to generate plasma because the electric field to generate plasma becomes weak with increase in substrate thickness. To resolve these issues, we tried to control the removal volume by controlling the applied radio frequency (RF) power for plasma generation by pulse width modulation (PWM) under the constant scanning speed, and developed a jet type plasma generation unit [7].

2. Experimental setup

Figure 1 shows the schematic diagram of open-air type NC-PCVM system. The electrode consists of a coaxially arranged inner alumina tube (d_i=2 mm, d_o=3 mm) and an outer aluminum alloy cylinder with sharpened tip (d_i=3.1 mm). This structure enables to generate an atmospheric-pressure plasma on the thick dielectric substrate because a high electric field for plasma generation is formed at the sharpened edge of the cylinder electrode. The process gases, the flow rates of which are controlled by a mass flow controller, are supplied through the alumina tube.

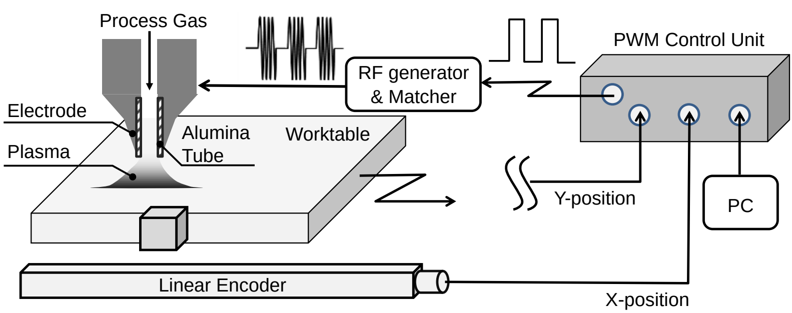

Figure 1: Schematic diagram of NC-PCVM system with PWM RF power control.

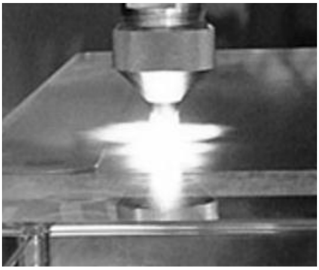

Figure 2: Photograph of plasma.

Table1: Experimental parameters

RF Power (W)	300
Ar Flow Rate (SLM)	5
CF_4 Flow Rate (SCCM)	10
Pulse Repetition Frequency (KHz)	1
Gap Distance (mm)	1.5 (Electrode) 1.0 (Alumina Tube)
Workpiece	Quartz glass (t=1 mm)

Dielectric barrier discharge (DBD) atmospheric-pressure plasma is generated between inner alumina tube and workpiece surface by applying an RF (f=13.56 MHz) electric field. Figure 2 shows the photograph of plasma generated on the quartz glass with a thickness of 6.35 mm under the open-air condition. The relative position between the electrode and the workpiece and the scanning speed of the worktable are controlled by AC servo motors, and information of worktable positions are sent from linear encoders to the PWM control unit. The PWM control unit controls the output of the RF power supply according to the data set of the duty ratios corresponding to the positions on the workpiece.

3. Results and discussion

Figure 3 shows the removal spot and its cross-section measured by scanning white light interferrometer (SWLI). Table 1 shows experimental parameters for obtaining the removal spots. Ring-shaped removal spots with a diameter of about 11 mm were obtained. In the case of our electrode structure, a ring-shaped ion sheath region in which reactive species such as atomic fluorine generated by dissociation of carbon tetrafluoride (CF_4) is formed at the near-surface of alumina tube inside. Therefore, it is assumed that the combination of ring-shaped ion sheath and process gas flow which spreads outward on the workpiece surface resulted in formation of ring-shaped removal spot. The diameter and depth of the removal spot were increased by an increase in the duty ratio of the RF power output, but it resulted in an increase of the depth mainly. Figure 4 shows the relationship between the duty ratio of RF power output and volumetric material removal rate (MRR) of quartz glass. This preliminary experimental result indicates that PWM control of RF power output enables us to control the MRR for figuring with relatively wide range.

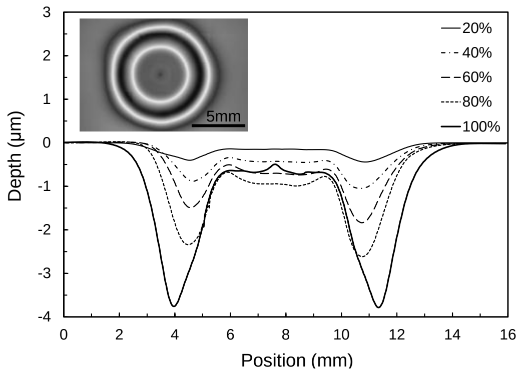

Figure 3: Removal spot and its cross-section measured by SWLI.

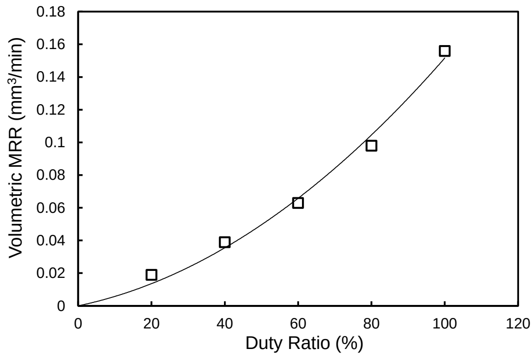

Figure 4: Relationship between duty ratio and volumetric MRR.

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