INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Development and Performance Evolution of Medium-Pressure Plasma Process for Surface Modification of Fused silica

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SHORT ABSTRACT

A novel non-contact medium-pressure plasma nano-finishing technique is being developed to augment or replace chemo-mechanical polishing (CMP) techniques for finishing such microstructures. The developed process uniformly polishes the complex-shaped gyro, i.e., a hemispherical resonator shell fabricated with fused silica by an ultrasonic milling process. A combination of plasma polishing and cleaning processes is used to achieve sustained polishing of the hemispherical shell. It is essential to understand the brittle damages, such as surface cracks and plastic deformation, that can occur on the surface of hard, brittle materials like glass ceramics, fused silica, etc. The novelty of the present medium-pressure plasma process is that it combines the isotropic material removal capability of low-pressure plasma and the atomistic material removal capability of atmospheric-pressure plasma. This process can simultaneously polish entire complex 3D surfaces, including cavities where no tool or beam can reach.

The present study designed and developed a medium-pressure plasma polishing (MPPP) setup for finishing optical materials. The MPPP plasma process consists of mass flow controllers for precise control of helium (i.e., processing gas), sulfur hexafluoride (i.e., reactive gas), and oxygen (i.e., catalytic gas). The system also consists of a gas dosing valve for controlling the total pressure of the plasma chamber. The pumping system can reduce the chamber pressure during machining. Further, an experimental investigation of atomistic material removal using a medium-pressure plasma process on a fused silica surface is carried out. The effects of plasma polishing factors, such as gas composition, pressure ratio, total pressure, and RF power, on fused silica's material removal rate (MRR) have been investigated while conducting a series of experiments at each parameter. The material removal rate has been improved up to 0.1004 mm3/min at the optimized process parameters, i.e., gas composition of 90:10, pressure ratio of 1:1, total pressure of 5 mbar, and RF power of 80 W. Raman spectroscopy analysis provides clear evidence of a reduction in strain bonds after plasma processing. Further Raman spectroscopic results show that the average ratio (at different depths) improves from 1.88 before plasma processing to 2.12 after plasma processing, enhancing 13% reduction in damaged and strained layers after plasma processing on the substrate surface. During the plasma polishing of freeform and complex surface, i.e., prism, the area surface roughness (Sa) is increased from 0.54 nm to 2.61 nm (at 5 mbar total pressure) and 0.53 nm to 0.57 nm (at 20 mbar total pressure) without any surface contamination. A higher surface roughness value is observed at 5 mbar total pressure than 20 mbar. The experimental study was carried out at different pressures and RF power to evaluate the plasma process while comparing the wet chemical etching process. The buffered hydrofluoric acid and sulfuric acid composition is optimized to achieve a similar MRR as a plasma process. The experiments were repeated three times for different initial surface roughness values for both wet chemical etching and plasma processing. The results suggested that the wet chemical process significantly damages the surface roughness after processing. Hence, plasma processing replacing the hazardous chemical process can reduce the optics' labor-intensive polishing time and cost.