Rapid fabrication of precision surfaces – A new paradigm

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Abstract

Reactive Atom Plasma (RAP^{TM}) processing of substrates is a new technique developed to increase productivity of the manufacturing step by orders of magnitude without sacrificing precision. This is made possible by a paradigm shift in the approach to material removal and/or deposition. Instead of using iterative abrasive processes that are required to remove damage from prior iterations without adding significant amounts of damage/stress/strain in the current iteration, RAP^{TM} relies on chemical etching of the underlying material. Further productivity enhancements are made possible by the use of a sub-aperture atmospheric-pressure plasma source. A large number of manufacturing problems can be solved by suitable modifications to the chemistry and/or processing parameters.

1 Introduction

Applications employing precision surfaces range from semiconductors, optics, biomedical devices, photo-voltaics and magnetic recording media, besides the surfaces required on various precision machines used in the manufacturing of such devices. These surfaces might have a figure (low spatial-frequency) and roughness (high spatial-frequency) requirement, or a requirement for precision structuring/patterning. Other requirements include high laser-damage thresholds, light-weighting and stiffness requirements, birefringence etc. Various manufacturing techniques have been developed over the years to meet these demands – the advent of sub-aperture finishing techniques is a particularly key development. Sub-aperture finishing processes primarily employ a mechanical (or chemical-mechanical) abrasion technique to remove material selectively from a surface. This is typically done in an iterative mode, with the number of iterations (and thence lead time) dictated by the complexity of the surface/substrate.

However, commoditization of technology has been accompanied by commoditization of precision as well. In other words, demands are being placed on manufacturing technologies to deliver increased precision at higher throughput.

1.1 RAP^{TM} Processing

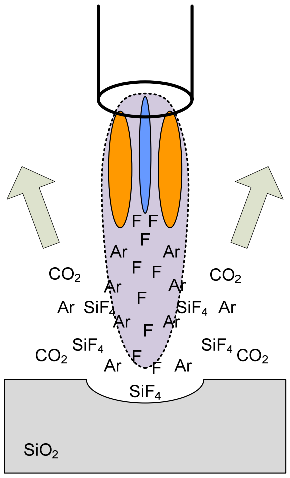


Figure 1: RAP Schematic

Reactive Atom Plasma (RAP^{TM}) processing is an atmospheric pressure plasma process where. An inductively coupled argon plasma is created into which precursors (depending on the chemistry of the substrate) are injected. The plasma breaks down the precursors into active radicals which are then delivered to the surface being engineered. The surface being engineered is downstream of the plasma, and is subjected to both a thermal flux and a radical flux. Various enhancements to the torch design have been performed such that the thermal footprint of the torch is minimized and the radical footprint is maximized. The tool footprint is a combination of the radical and thermal footprints and is Gaussian . It ranges from 10 µn to 10mm full-width half-maximum (FWHM).

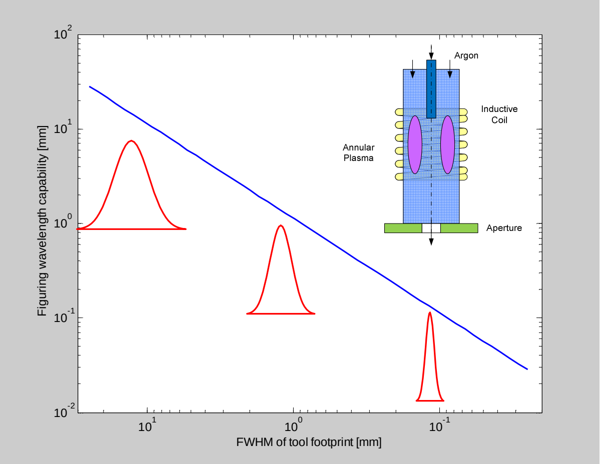
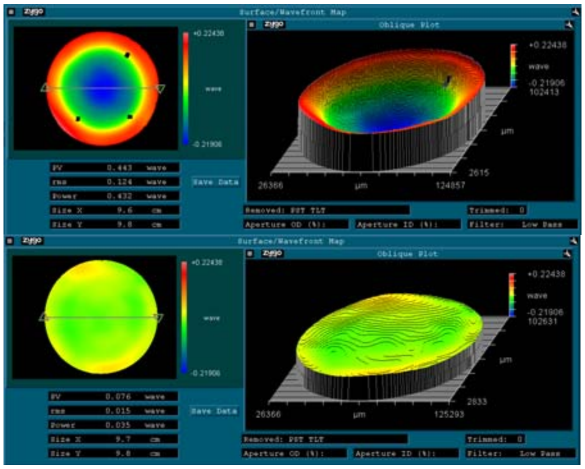


Figure 2: RAP footprint roadmap

1.2 RAP^{TM} Applications

RAP^{TM} is a sub-aperture process with a dynamic range spanning three orders of magnitude and can be applied effectively to a wide range of surface engineering applications. Due to the high material removal rates, atmospheric pressure nature and the excellent stability of the process, a combination of high precision and throughput can be easily achieved. RAP^{TM} can be very effectively applied to the rapid figuring of optical surfaces as illustrated in Figure 3. Experiments on “glass” surfaces have yielded a figure better than 0.075 λ P-V with a roughness under 2 nm RMS for well prepared substrates.



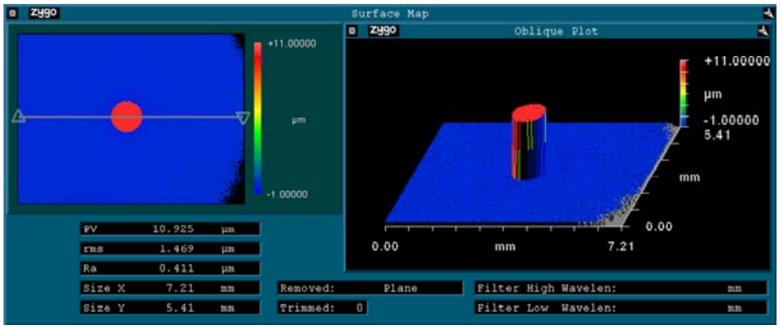
PV 0.443 wave
rms 0.124 wave
Power 0.432 wave
Size X 9.6 cm
Size Y 9.8 cm
Removed: PST TLT
Trimmed: 0
Aperture OD (%):
Aperture ID (%):
Filter: Low Pass

PV 0.076 wave
rms 0.015 wave
Power 0.035 wave
Size X 9.7 cm
Size Y 9.8 cm
Removed: PST TLT
Trimmed: 0
Aperture OD (%):
Aperture ID (%):
Filter: Low Pass

Figure 3: Figuring a fused silica substrate from 0.5l P-V to 0.075 λ P-V in 12 minutes

The Gaussian footprint of the RAP^{TM} process ensures that the desirable features of Gaussian filtering largely desensitize the process to errors in registration and minimize mid-spatial frequency errors. However, the Gaussian shape is also limited in its ability to render higher spatial frequency characteristics to the surface. This limitation can be overcome either by masking the surface to impart high spatial frequencies or through the use of a smaller footprint. The former has the ability to produce high aspect ratio features while the latter has the advantage of programmability on the fly.

10 µm tall posts in low expansion glass material have been fabricated using a mask to pattern the surface and are illustrated in Figure 4. Such features can be imprinted on



PV 10.925 µm
rms 1.469 µm
Ra 0.411 µm
Size X 7.21 mm
Size Y 5.41 mm
Removed: Plane
Trimmed: 0
Filter High Wavelen: mm
Filter Low Wavelen: mm

Figure 4: RAP patterned posts on low expansion glass

aspheric surfaces and can be etched to varying heights across the surface, thus providing the optics designer with increased design possibilities.

The RAPTM process has been implementd on a five-axis motion control platform as illustrated in Figure 5. Steep aspheric surfaces (500 mm clear aperture and upto f/0.3) can easily be fabricated using this platform.

Figure 5: EOS tool platform from RAPT

References:

[1] Subrahmanyan, P. and Gardopèe, G., “Rapid manufacturing of fast aspheres”, ASPE 2006 Annual Meeting, Monterey, CA

[2] Subrahmanyan, P. and Gardopèe, G., Reactive atom plasma processing of mirrors for astronomy, Proceedings of the SPIE, Volume 7018, pp. 701809-701809-12 (2008)