Technical Report Synopsis:

Design and Specification of Diamond Turned Optics[1]

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Abstract
This synopsis covers the key topics in the paper "Design and Specification of Diamond Turned Optics" authored by Robert A. Clark. A list of updated diamond machinable materials will be presented and discussed. The surface figure and finish for both spherical and aspherical application will be explained. Polishing and coating as post-process will be introduced in the end.

Materials
The author considered materials which can form optical quality surface after diamond turning process as diamond machinable materials as listed in Table 1. Diamond machinable materials include non-ferrous metals, polymers, and several crystals. Note that silicon based optical glass is not diamond machinable.

Table 1. Diamond machinable materials

Metals: Aluminum Alloys: 1100, 2011, 2107, 2024, 3003, 5086, 5186, 6061, 7075, A201 Cast, Copper (OFHC, Electroplated), Beryllium Copper, Brass, Tin, Silver, Gold, Zinc, Nickel (Electroless Plate)
Polymers: Acrylic, PMMA, Polycarbonate, Lexan, Polystyrene, Copolymers, NAS, SAN, CR-39, TPX
Crystals: Germanium, Zinc Sulfide, Zinc Selenide, Barium Fluoride, Silicon, Cadmium Telluride, Mercury Cadmium Telluride, Tellurium Dioxide, Gallium Arsenide, Amtir, Lithium Niobate, Potassium Dihydrogen, phosphate (KDP)

Metals
All aluminum alloys are diamond machinable, however, heat-treatable series of 2000, 6000, and 7000 are recommended for diamond turning process. 6061 alloy is preferred alloy for its low-cost and avilibility in different stock sizes. The A201 Cast aluminum alloy has been used for optical material and it is diamond machinable. A201 has several advantages as optical material: 1. it is free of crystallites; 2. It can be cast to near net shape to reduce machining time; 3. Mirror made with A201 using diamond turning process has significantly improvements in TIS.
Nickel in wrought or electrolytic plate form is not diamond machinable, however, deposition of electroless nickel plate can be applied for several reasons: 1. increase corrosion resistance; 2. Increase wear resistance; 3. make some substrate material diamond machinable; 4. apply reflecting surface where the traditional method is impossible to reach; 5. allow post polishing for soft materials.

Polymers
Acrylic, polycarbonate, and polystyrene are most commonly used in diamond machining for prototype preparation. The new available copolymers include NAS, SAN, CR-39 and TPX

Crystals

Germanium is commonly used in IR applications, has the best surface finish quality among other materials and it is diamond machinable. Zinc sulfide is diamond machinable and can transmit wavelength of 0.4 to 12.0 microns and has better machinability than zinc selenide.

Surface figure and finish

In this section, the author listed several surface figure and finish specification of diamond machined optics including radius of curvature, irregularity, aspheric figure, clear aperture and slope. The following table summarized the typical specification for diamond machined optics.

Table 2. Typical specification for diamond machined optics

Surface figure	Specification
Radius of curvature	+/- 0.05%
Irregularity	1/4 rings
Clear aperture	Based on application
Slope	2 arc seconds
RMS surface roughness	10 Å

There are several key points the author mentioned for those specifications. For radius of curvature, the typical tolerance is +/- 0.05%. For the optics with long radius of curvature (greater than 2000mm), the tolerance could reach +/-0.1%-1%. The contact profilometry is commonly used to measure the aspherical diamond machined optics, it has its advantage of measuring departure of the surface from theoretical value in a direct absolute sense. The clear aperture of an optical surface highly depends on the specific application, for example, there is a great difference in requirement of clear aperture between a scanning system or a multi-mirror system and visual or IR channel system. Slope, defined as the angle of the tangent to the steepest inclination of a local perturbation from the global power departure, is controlled by the same feature with irregularity, but it is valid to specify both for diamond machined optics.

The author also mentioned a new method to specify the surface roughness using contacting or non-contacting profilometer. The surface roughness is specified as Total Integrated Scatter (TIS) rather than scratch and dig. A new ASTM Standard for the measurement of surface roughness is based TIS. TIS is given by:

$$\mathrm{TIS} = \left(\frac{4\pi\delta}{\lambda}\right)^2$$

Where δ is the RMS surface roughness and λ is the test wavelength.

Post polish and coating

The author stated that if accuracies required for a specific diamond machined optics are well beyond the capabilities of available equipment, then it may be necessary to further process the optic with a post polish process. Commonly, the figure accuracy produced by the diamond turning machine tool is adequate and only the finish must be improved to minimize scatter in the short wavelengths.

Anti-reflective coating can be applied in the same manner as conventionally polished and machined optics. Residual reflection can be held to 0.2% to 0.3%

Proposed tolerance tabulation table

The author proposed a revised tolerance tabulation table which added a base radius tolerance, astigmatism, and slope. The surface roughness was kept in the scratch and dig fashion, because the new standard is not readily used in the industry. The test wavelength is standardized on 632 nm. The proposed table is shown below using a singlet as example.

	Radius	Radius Tol.	Power	Irreg.	Astig.	Slope	Scratch/Dig	C.A
R1	6.9302	±.004	4	1	.5f	2 sec	60/40	.280
R2	5.392*	±.004	3	1	.5f	2 sec	80/50	.320

*R =
S =
K=
A_1 =
A_2 =
A_3 =
A_4 =

Conclusion

In the paper "Specification and manufacturing considerations of diamond machined optical components[2]" authored by Mark Craig Gerchman, the author discussed similar topic in specifications and material selection of diamond machined optics. This paper was published in 1986 which is 5 years early than Clark's paper. We can see a fast development in diamond turning technology by comparing two papers: more diamond machinable materials became available including A201 cast aluminum alloy, NAS, SAN, CR-39, and TPX. The specification is also changed for surface roughness: the ASTM Standard for the measurement of surface roughness was only a concept in 1986. Today, the diamond machining tools have been widely used in optical fabrication industry. This paper is useful for people who is looking for the information in specification in diamond machined parts, because most of the standards developed in this paper are still valid today.

Reference

1. R. A. Clark “Design and specification of diamond-turned optics” Critical Review Vol. CR38, Infrared Optical Design and Fabrication, ed. R. Hartmann, [1991]
2. M. C.Gerchman “Specifications and manufacturing considerations of diamond machined optical components” Proc. of SPIE Vol. 0607, Optical Component Specifications for Laser-Based Systems and Other Modern Optical Systems, [1986]