OPTI-521 **Synopsis of Technical Report** **Chia-Ling Li** 2013/11/4

Paper: *R.Barry Johnson, "What's Different about Ultraviolet and Infrared Optics?", SPIE Critical Review Vol. CR43, Optomechanical Design, pp.61-75, July 1992.*

1. Introduction

When designing ultraviolet and infrared optical systems, we need to pay attention to some engineering considerations that are different from the visible optical system design. The synopsis provides some comparisons of the design and fabrication issues between ultraviolet and infrared optical systems. These issues are the available optical materials, surface finish, mechanical and optical fabrication techniques, housing and mounting methods, alignment and test, and cost.

2. Optical Materials

Table 1. Properties of optical materials in ultraviolet, visible, infrared spectrums

	Ultraviolet (UV)	Visible	Infrared (IR)
Spectrum	Near UV: 400-300 nm Far UV: 300-200 nm Deep UV: < 200 nm	400-700 nm	Near IR: 0.7-3 μm Middle IR: 3-6 μm Far IR: 6-15 μm Extreme IR: > 15 μm
Number of optical materials available	lowest	largest	middle
The range of the refractive index of optical materials	narrowest	middle	widest
Dispersion	highest	middle	lowest
Special issue	solarization		internal absorption
Common materials	fused or synthetic silica calcium fluoride (CaF_2) lithium fluoride (LiF) magnesium fluoride fluorocrown glasses	dominated by glasses	germanium (Ge), silicon (Si) sapphire, ZnSe, ZnS glasses with chalcogenides calcium aluminate glasses germanate glasses metal fluorides and oxides

Table 1 lists the property comparisons for optical materials in ultraviolet (UV), visible, infrared (IR) spectrums. The low refractive index of the ultraviolet optics produces less surface reflection losses, but requires more lens elements than for an equivalent infrared lens system. W.L. Wolfe mentions more detail information for the optical material used in the infrared.[ii]

3. Structural Materials

Selection of the structural materials is affected by the coefficient of thermal expansion (CTE) and the temperature coefficient of refractive index (TCRI) of the optical materials. The combined effects of CTE (α) and TCRI ($\partial n/\partial T$) causes a defocus (δ) for a single lens with a focal length f in a housing of overall length L of

$$\delta = \left[-\frac{f}{n-1}\frac{\partial n}{\partial T} + \alpha f + \alpha L\right]\Delta T\,.$$

In general, passive techniques are used for IR optics to maintain the focal length while active techniques are needed for high precision UV optics. For a lens with numerical aperture NA, the Rayleigh criterion for resolution (**R**) is **0.61λ/NA**, and the Rayleigh depth of focus (**D**) is **±λ/(2NA^2)**. Therefore, the precision and dimensional stability requirements for UV systems are much more exacting than for infrared systems because the ratio in wavelengths between these two spectrums is large. Table 2 shows the CTE and TCRI of common optical materials, and the CTE of common structural materials.

Table 2. CTE and TCRI of common materials

	Materials	CTE (ppm/°C)	TCRI (ppm/°C)
Optical materials	Fused silica	0.5	8.1
	Silicon	4.2	39
	Germanium	6.1	67
	Sapphire	6.7^P / 5^S	13.1
	ZnSe	7.8	61
	Chalcogenides	13	-
	Calcium fluoride	24	-90
	Lithium fluoride	37	-16
Structural materials	6061 aluminum	23.6	-
	17-4 PH stainless steel	10.8	-
	Invar	0.9	-
	Titanium	8.6	-

4. Lens Configurations

The common features of UV and IR optical systems are all-reflective optics, catadioptric optics, and relatively few optical elements. In general, IR optics have a much larger field of view than UV optics whereas UV optics have a much tighter tolerance on field flatness and distortion. For IR optics, binary or diffractive optical surfaces are also used.

5. Coatings

The number of materials available for coatings in the UV and IR spectrums is limited to approximately the same number as can be used to construct lenses. Almost any functional coating type can be realized in the IR, but in the UV spectrum antireflective coatings are not available for wavelengths shorter than 250 nm. Only bandpass filters can be made in this spectral region, but with great difficulty and expense.

In the infrared, the reflective coatings typically use gold, aluminum, or enhanced silver; while in the ultraviolet with wavelength greater than 150 nm, typically use UV-enhanced aluminum or special coating stacks.

6. Fabrication and Test

Fabrication of optical elements used in the UV and IR spectrums is done by conventional grinding and polishing techniques. Figure 1 presents the theoretically predicted levels of scattered light as a function of surface roughness and wavelength. The relationship between surface roughness and wavelength for a constant amount of scattered light is directly proportional. It means that UV optical surfaces require greater care and quality than IR optical surfaces. Cost and schedule seem to grow exponentially with decreasing surface roughness.

For UV optics conventional polishing methods are essentially the only option. The fundamental surface figure requirements are $\lambda/4$ for both UV and IR optics; however, the physical scale is extremely different. Testing of surface figure is more difficult for UV optics because the wavelength of light used in a typically surface measuring interferometer is about two times greater. The same is true for system level testing, like resolution, MTF, etc.

Measurement of scattered flux from the surface of the optics or from the entire lens assembly is significantly more challenging for UV optics than for IR optics. In testing UV optics, as the wavelength shortens, the atmospheric absorption dramatically increases so that measurements must be made in a vacuum environment. Therefore, very few facilities are available for testing UV optics. On the contrary, a number of facilities can measure IR optics.

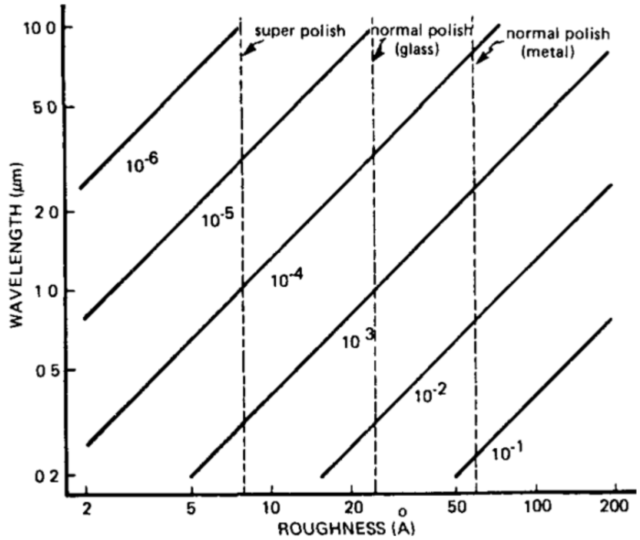

Figure 1. Theoretically predicted levels of scattered light as a function of surface roughness and wavelength.

7. Applications

All the information about UV or IR optics mentioned above can be applied to the design of UV or IR optical system. For example, Fig. 2 shows a passive athermalized IR zoom lens with a magnification range of 3.5-20 power. The lens is made of Ge, ZnSe, and ZnS. Athermalization is accomplished by combining lens groups that are each athermalized about the central movable elements used for the zoom function. This passive athermalization can't be used for UV optics because there are no appropriate optical materials.

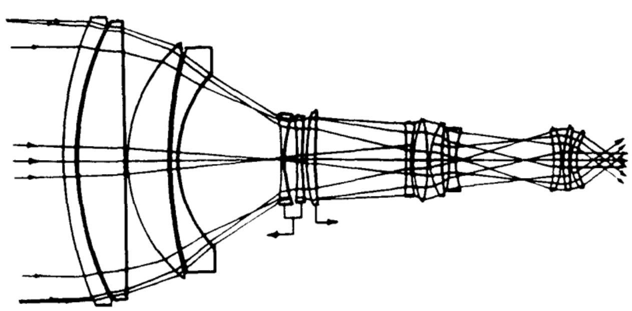

Figure 2. Passive athermalized IR zoom lens

Figure 3 shows another example for UV optical system. It is a projection optical system for submicron lithography. The tolerances are so exacting (0.5 μm) that the housing must be diamond turned and the alignment of the elements is accomplished on the air bearing table. Each optical element is carefully measured in order that the housing can be modified to compensate for optical fabrication errors.

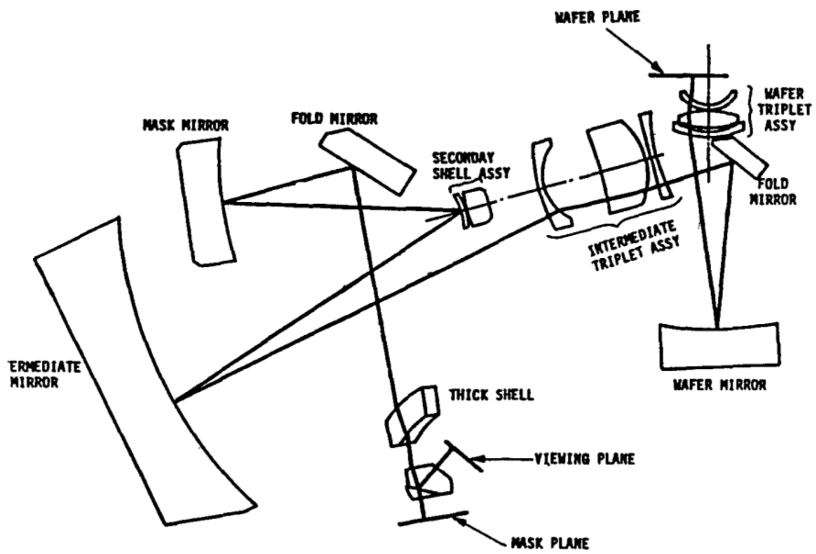

Figure 3. Projection optical system for submicron lithography

8. Conclusions

UV and IR optics have many common features and characteristics while at the same time having a lot of practical differences. These differences may be related to the large wavelength difference and the operating environment. For examples, for UV optical systems, the operating temperature range is very narrow; polarization and partial coherence are of great significance; the narcissus problem doesn’t exist. For IR optical systems, they have opposite conditions to UV optical systems in these cases.

9. References

i. R.Barry Johnson, “What’s Different about Ultraviolet and Infrared Optics?”, SPIE Critical Review Vol. CR43, Optomechanical Design, pp.61-75, July 1992.

ii. W. L. Wolf, “Optical materials for the infrared”, SPIE Critical Review Vol. CR38, Infrared Optical Design and Fabrication, pp.55-68, Apr. 1991.