# Practical Guide to Specifying Optical Components

*OPTI 521 – Introduction to Opto-Mechanical Engineering*

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## Introduction

This paper is intended to serve as a practical guide for specifying and tolerancing optical components. The information contained is by no means all inclusive. Rather, it is an overview of the relevant standards (specifically ISO 10110) and provides qualitative descriptions of the various optical specifications and how to specify these on optical drawings.

## ISO 10110

ISO 10110 "Optics and Optical Instruments – Preparation of drawings for optical elements and systems" is perhaps the most widely accepted standard on the subject of optical element specification and tolerances. The purpose of this specification is to develop a universally accepted and understood specification as a basis for international manufacturing and inspection. Since it is intended to be a worldwide standard, it uses codes and symbols extensively, rather than text that would need to be translated into numerous languages. This specification has 13 parts. The first is a general overview and background of the specification. The remaining 12 parts provide detailed descriptions of the symbols and codes for various optical specifications. A brief overview of each of these will be covered in this paper. Table 1 shows what each section covers, as well as the corresponding symbol when applicable.

**Table 1. ISO 10110 Contents**

| SECTION | TITLE | SYMBOL |
|---|---|---|
| 1 | General – Differences between optical and mechanical drawings | N/A |
| 2 | Material imperfections – Stress birefringence | 0/ |
| 3 | Material imperfections – Bubbles and inclusions | 1/ |
| 4 | Material imperfections – Inhomogeneity and striae | 2/ |
| 5 | Surface form tolerances | 3/ |
| 6 | Centering tolerances | 4/ |
| 7 | Surface imperfection tolerances | 5/ |
| 8 | Surface texture | √ |
| 9 | Surface treatment and coating | λ |
| 10 | Table representing data of a lens element | N/A |
| 11 | Non-toleranced data | N/A |
| 12 | Aspheric surfaces | N/A |
| 13 | Laser irradiation damage threshold | 6/ |

Section 2 – Stress birefringence. Stress within an optical material creates an anisotropic index of refraction. This effect is most pronounced in transmissive optics. Residual stress in the glass can develop due to rapid cooling from the molten state. Annealing can mitigate residual stress similar to mechanical parts. Stress birefringence is denoted by '0/A' where 'A' specifies the maximum optical path difference for two orthogonal polarized light directions in nm/cm of material thickness. If the tabular drawing format is used, this specification should be included with the optical material description.

$$A = {}^{\Delta s}/_{a} = K\sigma$$

$\Delta s$ = optical path difference (nm)
a = sample thickness (cm)
K = stress optic coefficient difference (nm/cm)/(kg/mm2)
$\sigma$ = stress (kg/mm2)

**TABLE 2.1. Suggested Values of A Supporting Various Applications.**

| A | Application |
|---|---|
| <2 | Polarimeters and interferometers |
| 5 | Precision optics such as astronomical telescopes |
| 10 | Photographic optics and microscopes |
| 20 | Magnifying glasses and view finders |
| not specified | Illumination optics such as condenser lenses |

Figure 1. Common Stress Birefringence values (ISO 10110)

Section 3 – Material imperfections – bubbles and inclusions. Bubbles are pockets of trapped gas within the glass. Inclusions are opaque or highly scattering regions within the glass caused by contaminants or localized crystallization. The drawing indication is 1/N x A where N is the number of maximum size defects allowed, A is the square root of the cross-sectional area of the maximum size defect allowed. If the tabular drawing format is used, this specification should be included with the optical material description. ISO 10110-3 provides more detailed nomenclature to restrict bubbles/inclusions that are smaller than the maximum, as well as concentrations of bubbles/inclusions.

Section 4 – Material Imperfections – inhomogeneity and striae. Inhomogeneity is the variation of refractive index within an optical component and is caused by variation of chemical composition. Striae are localized changes of the index of refraction, resulting from incomplete mixing of the melted glass. The drawing indication is 2/A;B where A is the class number for inhomogeneity and B is the class for striae.

Table 1 Inhomogeneity classes

| Class | Maximum permissible variation of refractive index within a part [$10^{-6}$] |
|---|---|
| 0 | ± 50 |
| 1 | ± 20 |
| 2 | ± 5 |
| 3 | ± 2 |
| 4 | ± 1 |
| 5 | ± 0,5 |

Table 2 Classes of striae

| Striae class | Density of striae causing an optical path difference of at least 30 nm in % |
|---|---|
| 1 | ≤ 10 |
| 2 | ≤ 5 |
| 3 | ≤ 2 |
| 4 | ≤ 1 |
| 5 | Extremely free of striae<br>The restriction to striae exceeding 30 nm does not apply<br>Further information to be specified in a note |

**Figure 2. ISO 10110-4 Inhomogeneity and striae classes**

Section 5 – surface form tolerances. The surface form tolerances covered are intended for spherical surfaces but can be applied to plano and aspheric surfaces with caution. The drawing indication is 3/A(B/C) and units are in fringes. There are also provisions for RMS specification in fringes. These specifications are measured on an interferometer.

| | | |
|---|---|---|
| A | Saggita tolerance | The tolerance on power of the surface. This is the P-V deviation of the best fit sphere from a sphere with the nominal radius of curvature. |
| B | Irregularity | The P-V error relative to the best fit spherical surface |
| C | Rotationally symmetric irregularity | The P-V of the best fit aspheric surface. This includes errors that are symmetric about the center of the effective aperture, such as edge roll and zonal errors. |

Section 6 – Centering tolerances. ISO 10110-6 addresses centering with only two tolerances – surface tilt and edge run-out. Centering accuracy is defined in other specifications by deviation, decentration, edge run-out, image run-out, edge thickness difference, full indicator movement, and others. The drawing indication for centering is applied for each optical surface as 4/σ or 4/σ(L) where σ is the maximum possible tilt angle in arc-min or arc-sec and L is the maximum permissible lateral displacement in millimeters.

Section 7 – Surface Imperfection Tolerances. These are localized imperfections (e.g. scratches and digs) on the surface of an optical element. The drawing symbol is 5/NxA where N is the number of allowed perfections and A is the length of the side of a square in millimeters. Coating imperfections are preceded by a C (e.g. C NxA), long scratches by an L, and edge chips by an E. This designation is for Method 1 of the two inspection methods for surface imperfections. Method 1 is the Obscured Area Method and is related to how much surface area the imperfections obscure. Method 2 is the Visibility Method and is based on the visibility of imperfections under controlled lighting conditions.

Section 8 – Surface texture. Surface texture is a global characteristic of an optical surface and does not include localized imperfections which are covered in the preceding section. The designation is a check mark as shown in Figure 3 where "a" designates the type of surface (G for ground and P for polished), "b" indicates the type of measurement (Rq, RMS, or PSD), and "c" indicates the scan length and increment.

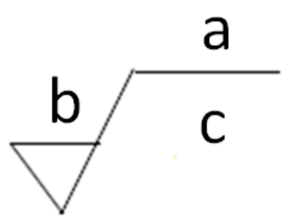



**Figure 3. Surface texture designation**

Section 9 – surface treatment and coating. This section covers both optical and protective coatings that are specified on optical surfaces. The drawing indication for an optical thin film coating is (λ) where the circle is tangent to the surface of interest. A protective coating is indicated by a chain thick line just above the surface of interest. Unless otherwise specified, the area to be coated is assumed to be the clear aperture defined on the drawing. The type of coating (mil spec, manufacturer's trade name, etc.) is specified in the box attached to the indicator symbol.

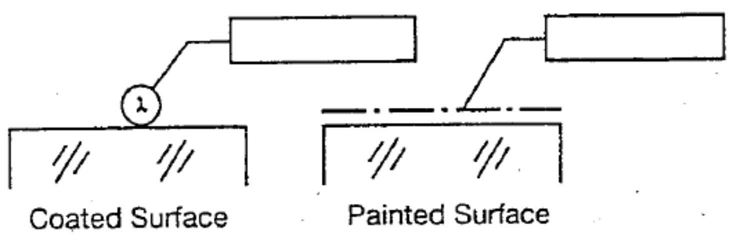



FIG. 9.1. Indication that surface is to be coated.

**Figure 4. Surface coating indication**

Section 10 – Tabular form. The tabular form is an option on ISO 10110 drawings for single lens elements that can be depicted in a single view. In this case, the various specifications can be documented in a table rather than in the field of the drawing. The format for the tabular form is shown in Figure 5. There are three zones. Zone 1 contains standard information found on a drawing title block. Zone 2 contains the tabular lens data and is broken up into three fields. The left and right field pertain to the left and right optical surfaces respectively. The middle field pertains to the lens material. The order in presenting the lens data is specific, as is shown by the specification symbols in each column.

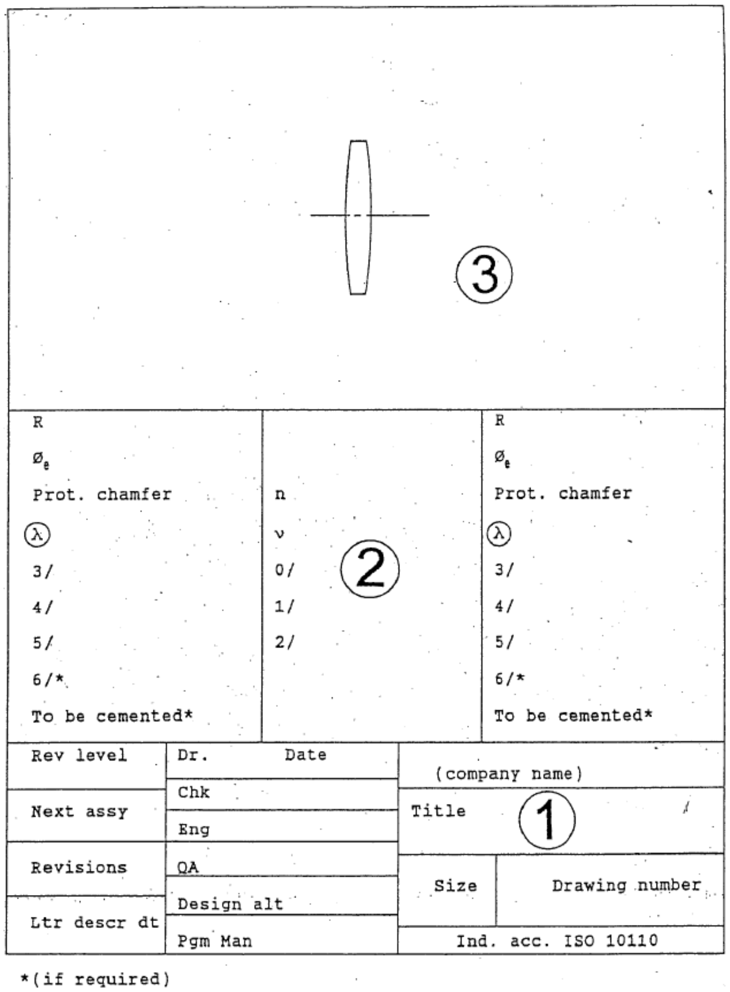



FIG. 10.1. ISO 10110 Tabular format.

**Figure 5. Tabular Format**

Section 11 – non-toleranced data. This section develops standard tolerances to the various specifications which apply if a feature is not specifically toleranced. These are provided in Figure 6.

| Property | Range of maximum (diagonal) dimension of the part [mm] | | | |
|---|---|---|---|---|
| | up to 10 | over 10 up to 30 | over 30 up to 100 | over 100 up to 300 |
| Edge length, diameter [mm] | ±0,2 | ±0,5 | ±1 | ±1,5 |
| Thickness [mm] | ±0,1 | ±0,2 | ±0,4 | ±0,8 |
| Angle deviation of prisms and plate | ±30' | ±30' | ±30' | ±30' |
| Width of protective chamfer [mm] | 0,1 - 0,3 | 0,2 - 0,5 | 0,3 - 0,8 | 0,5 - 1,6 |
| Stress birefringence acc. to ISO/DIS 10110-2 [nm/cm] | 0/20 | 0/20 | - | - |
| Bubbles and inclusions acc. to ISO/DIS 10110-3 | 1/3x0,16 | 1/5x0,25 | 1/5x0,4 | 1/5x0,63 |
| Inhomogeneity and striae acc. to ISO/DIS 10110-4 | 2/1;1 | 2/1;1 | - | - |
| Surface form tolerances acc. to ISO/DIS 10110-5 | 3/5(1) | 3/10(2) | 3/10(2) (all Ø 30) | 3/10(2) (all Ø 60) |
| Centring tolerances acc. to ISO/DIS 10110-6 | 4/30' | 4/20' | 4/10' | 4/10' |
| Surface imperfection tolerances acc. to ISO/DIS 10110-7 | 5/3x0,16 | 5/5x0,25 | 5/5x0,4 | 5/5x0,63 |

Figure 6. Non-toleranced data

Section 12 – Aspheric surfaces. When using an aspheric surface, the term "asphere" or the specific type of asphere should be indicated on the drawing. The equation of the surface should be provided in a note. Tolerance of the surface form can be addressed with a table that indicates the differences between the nominal value of the surface sag and the actual surface sag.

Section 13 – Laser Irradiation Damage Threshold. Pulsed damage requirements are expressed in terms of the fluence (energy density $J/cm^2$) which the part must withstand. Wavelength, pulse duration, irradiated spot size, repetition rate, incidence angle, polarization state, spatial profile, and number of pulses should be defined in a test specification. The drawing indication is $6/H_{th}$; $\lambda$; pdg; $f_p$; $n_{TS}$ x $n_p$ (pulsed) or $6/E_{th}$; $\lambda$; $n_{TS}$ (continuous).

| | | |
|---|---|---|
| 6/ | = | Laser irradiation damage threshold code number |
| $H_{th}$ | = | energy density threshold |
| $\lambda$ | = | laser wavelength (nm) |
| pdg | = | pulse duration group |
| $f_p$ | = | pulse repetition rate (Hz) |
| $n_{TS}$ | = | number of required test sites |
| $n_P$ | = | number of pulses per test site |
| $E_{th}$ | = | power of threshold ($W \bullet cm^2$) |

# APPENDIX

## Common Tolerances

**Optical element tolerances**

| Parameter | Base | Precision | High precision |
|---|---|---|---|
| Lens diameter | 100 µm | 25 µm | 6 µm |
| Lens thickness | 200 µm | 50 µm | 10 µm |
| Radius of curvature | | | |
| Surface sag | 20 µm | 1.3 µm | 0.5 µm |
| Value of R | 0.5% | 0.1% | 0.01% or 2 µm |
| Wedge (light deviation) | 5 arc min | 1 arc min | 15 arc sec |
| Surface irregularity | 1 wave | $\lambda/4$ | $\lambda/20$ |
| Surface finish | 50 Å rms | 20 Å rms | 5 Å rms |
| Scratch/dig | 80/50 | 60/40 | 20/10 |
| Dimension tolerances for complex elements | 200 µm | 50 µm | 10 µm |
| Angular tolerances for complex elements | 6 arc min | 1 arc min | 15 arc sec |
| Bevels (0.2 to 0.5 mm typical) | 0.2 mm | 0.1 mm | µ0.02 mm |

<u>Base</u>: Typical, no cost impact for reducing tolerances beyond this.

<u>Precision</u>: Requires special attention, but easily achievable in most shops, may cost 25% more

<u>High precision</u>: Requires special equipment or personnel, may cost 100% more

Figure 7. Rules of thumb for lenses (OPTI 521 course notes)

| Parameter | Base | Precision | High precision |
|---|---|---|---|
| Refractive index departure from nominal | ± 0.001 (Standard) | ±0.0005 (Grade 3) | ±0.0002 (Grade 1) |
| Refractive index measurement | $\pm 3 \times 10^{-5}$ (Standard) | $\pm 1 \times 10^{-5}$ (Precision) | $\pm 0.5 \times 10^{-5}$ (Extra Precision) |
| Dispersion departure from nominal | ± 0.8% (Standard) | ± 0.5% (Grade 3) | ±0.2%% (Grade 1) |
| Refractive index homogeneity | $\pm 1 \times 10^{-4}$ (Standard) | $\pm 5 \times 10^{-6}$ (H2) | $\pm 1 \times 10^{-6}$ (H4) |
| Stress birefringence (depends strongly on glass) | 20 nm/cm | 10 nm/cm | 4 nm/cm |
| Bubbles/inclusions (>50 µm) (Area of bubbles per 100 $cm^3$) | 0.5 $mm^2$ (class B3) | 0.1 $mm^2$ (class B1) | 0.029 $mm^2$ (class B0) |
| Striae Based on shadow graph test | Normal quality (has fine striae) | Grade A (small striae in one direction) | Precision quality (no detectable striae) |

Figure 8. Rules of Thumb for glass properties (Schott Catalog)

## Commercial Chart for Lenses

OPTIMAX SYSTEMS, INC.

Sales: (877) 396-7846 ▲ Fax (585) 265-1033
www.optimaxsi.com

| QUICK | RELIABLE | QUALITY |
|---|---|---|

Optimax provides rapid delivery services for a wide variety of optics ranging in size from 10-100mm. Specifications below are general guidelines for tolerancing prototype optics with optical surfaces of f/1 or slower. Tighter tolerances may be possible depending on part specific size, shape and/or material. Optimax stocks a large inventory of ECO-FRIENDLY preferred glasses, see listing.

ASPHERES ▲ CYLINDERS ▲ PRISMS ▲ SPHERES

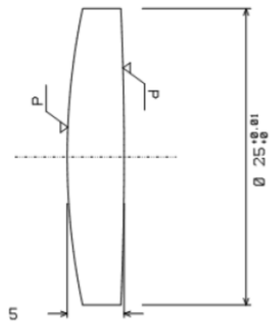
### OPTICS MANUFACTURING TOLERANCES

| ATTRIBUTE | COMMERCIAL QUALITY | PRECISION QUALITY | MANUFACTURING LIMITS |
|---|---|---|---|
| GLASS QUALITY ($n_d$, $v_d$) | ±0.001, ±0.8% | ±0.0005, ±0.5% | Melt controlled |
| DIAMETER (mm) | +0.00/-0.10 | +0.000/-0.025 | +0.000/-0.010 |
| CENTER THICKNESS (mm) | ±0.150 | ±0.050 | ±0.025 |
| SAG (mm) | ±0.050 | ±0.025 | ±0.010 |
| CLEAR APERTURE | 80% | 90% | 100% |
| RADIUS | ±0.2% or 5 fr | ±0.1% or 3 fr | ±0.0025mm or 1 fr |
| IRREGULARITY - Interferometer (fringes) | 2 | 0.5 | 0.1 |
| IRREGULARITY - Profilometer (microns) | ±10 | ±1 | ±0.1 |
| WEDGE LENS (ETD, mm) | 0.050 | 0.010 | 0.002 |
| WEDGE PRISM (TIA, arc min) | ±5 | ±1 | 0.1 |
| BEVELS (face width @ 45°, mm) | <1.0 | <0.5 | No Bevel |
| SCRATCH - DIG (MIL-PRF-13830B) | 80 - 50 | 60 - 40 | 5-2 |
| SURFACE ROUGHNESS ( Å rms) | 50 | 20 | 2 |
| AR COATING ($R_{Ave}$) | $MgF_2$ R < 1.5% | BBAR, R < 0.5% | Custom Design |

Figure 9. Commercial Optics Tolerances (Optimax)

# Example ISO 10110 Drawing

**ISO 10110 drawing:**




DIMENSIONS IN MILLIMETERS

| LEFT SURFACE | MATERIAL | RIGHT SURFACE |
|---|---|---|
| R $58.6^{+0.15}_{-0.15}$ CX | GLASS: N-SK15 | R $277^{+0.8}_{-0.8}$ CX |
| $Ø_E$ $22.5^{+0.1}_{-0}$ | $N_d$ = $1.622960^{+1E-005}_{-1E-005}$ | $Ø_E$ 22.5 |
| Ⓢ 0.9 FOR 450 < L < 750 | $V_d$ = 58.02 | Ⓢ 0.9 FOR 450 < L < 750 |
| 3/ 0.25(.2/.125) | 0/ 5 | 3/ 0.25(.2/0.125) |
| 4/ .3' | 1/ 1X.1 | 4/ 0.3' |
| 5/ 5X0.05;L1X0.001;E0.5 | 2/ 2;3 | 5/ 5X.05;L1X.001;E0.5 |
| 6/ 0.5;1053;3 | | 6/ 0.5;1053;3 |
| POLISHED: RQ 0.01 1/3 | | POLISHED: RQ 0.01 1/3 |

ISO ELEMENT DRAWING INDICATIONS ACCORDING TO ISO 10110

## References


1. Kimmel, R. K., Parks, R. E., ISO 10110 Optics and Optical Instruments – Preparation of drawings for optical elements and systems: A User's Guide, Second Edition
2. Burge, J. H., Specifying Optical Components, Introductory Optomechanical Engineering. Powerpoint slides. 2012.
3. Burge, J. H., Introduction to ISO 10110, Introductory Optomechanical Engineering. Powerpoint slides. 2011.