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Modern Optics Drawings: The journey from MIL to ANSI to ISO drawing formats

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ABSTRACT

Successful fabrication of optics across multiple vendors and countries requires simple communication techniques. Drawing standards have been used across the optics industry in the United States since the 1960s with the implementation of MIL-STD-34 and subsequently ASME/ANSI Y14.18M. Though both standards are now inactive, designers and fabricators continue to use either these standards or modified versions of these standards. Concurrently, much of the international community has moved towards implementing ISO 10110 since the late 1990's. As standards development efforts continue for optics and photonics in ISO/TC 172 to improve global standardization, understanding how to read and interpret these standards, and notably the optical drawing standard ISO 10110, is critical. This paper discusses how to interpret a single drawing across traditionally-used standards within the United States. Deconstructing the basics of the three standards mentioned allows designers and fabricators to communicate in a single language. Understanding the history and development of optical standards and how they relate can help ease the transition to a single international standard for optical engineers and fabricators within the United States.

Keywords: optical design and fabrication, optical engineering, optical standards and testing, drawings

1. INTRODUCTION

Standards for optics within the United States were first published in the 1950s and 1960s. These standards were originally written for military hardware procurement but were applied across the entire industry. They covered a wide variety of topics; many of them have since become inactive[1–4] whereas others are still in use today.[5,6] Among the topics covered by the MIL standards were optics drawings, specifications and notations; they were adequate at the time for their intended use. Since that time, optics drawings proceeded to convey more complex optical elements as manufacturing technology improved, and applications grew and greatly diversified. Creating a modern optics drawing using these inactive standards leads to a large employment of notes and depends greatly on additional communication with fabricators.[7]

In subsequent decades, specific MIL standards started to transition into discipline-focused standards development organizations. The standard for optics drawings, specifically, transitioned from being a MIL standard to an ASME standard.[8,9] With this transition, a more clear definition of what was expected in an optics drawing became prevalent. The ASME standard maintained much of what was present in the MIL standard but clarified specific optical terms and how the optical properties should be defined for a fabricator. The ASME standard allowed the user to create a drawing how they wished. There were suggestions on how a drawing should be defined but without a uniform method of implementation. Most optics companies within the United States still follow the guidelines outlined in ASME/ANSI Y14.18M. Unfortunately, this standard has not been updated since 1986 and was formally withdrawn in 2005. Moreover, this standard is not a global normative standard.

Currently, the ISO optics drawing series continues to be updated with major input from the United States, specifically with the purpose to ensure that the international standard contains US optical shop friendly options.[10-23] As the complexity of optics continues to grow with increases in manufacturing and metrology capabilities, continually updating the optics drawing standard is essential and expected.

Various works have been published about the ISO 10110 drawing series and how to implement it.[7,24–26] This paper is intended to show translation and correlation of the optics standards from MIL to ASME to ISO. This work and an associated publication are explicitly written to help ease the transition for designers and fabricators.[27] Example drawings are provided for two different types of refractive optics, one spherical on both surfaces and the other aspheric on one surface. Both elements are rotationally invariant (or symmetric) and therefore do not invoke the general surface standard which has been discussed elsewhere.[28–30]

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2. UNITED STATES DRAWING STANDARD HISTORY

Optics drawings in the United States were left to the designers and fabricators to create their own language and notation. Definitions were put in place to create the outlines of a dialog. There is no single way to read these drawings. The key to understanding the two standards created within the United States is that outside of main optical element properties (radii, thickness, etc.), conversations between a designer and fabricator must occur across notes left on the drawing. When working in-house or with the same supply base constantly, this system worked well and efficiently. However, modern optical design, engineering, and fabrication often involves multiple parties and even when work is single supplier-based, the old US system is at best on par with global standards.

Table 1. Optics drawing standards that have been used in the United States, both active and withdrawn, and their comparative ISO standard.

Standard Number	Description	Status	Comparative Standards
MIL-STD-10A	Military Standard: Surface Roughness, Waviness and Lay	Cancelled	ISO 10110-8 ASME B46.1
MIL-STD-34	Military Standard: Preparation of Drawings for Optical Elements and Optical Systems; General Requirements for	Cancelled	ISO 7944 ISO 10110 Series ASME/ANSI Y14.18M
MIL-C-675C	Military Specification: Coating of Glass Optical Elements (Anti-Reflection)	Active	ISO 10110-9 ASME/ANSI Y14.18M
MIL-G-174B	Military Specification: Glass, Optical	Inactive	ISO 7944 ISO 10110-18 ISO 12123 ASME/ANSI Y14.18M
MIL-M-13508C	Military Specification: Mirror, Front Surfaced Aluminized; For Optical Elements	Inactive	ISO 10110-9 ASME/ANSI Y14.18M
MIL-PRF-13830B	Performance Specification: Optical Components for Fire Control Instruments; General Specification Governing the Manufacture, Assembly, and Inspection of	Active	ISO 10110-7 ISO 10110-8 ISO 10110-9 ISO 14997 ANSI PH3.617
ASME Y14.5	Dimensioning and Tolerancing	Active	ISO 128 ISO 1101 ISO 8015
ASME/ANSI Y14.18M	Optical Parts	Withdrawn	ISO 10110 Series ISO 14999-4 ISO 12123
ASME B46.1	Surface Texture	Active	MIL-STD-10A ISO 10110-8
ANSI PH3.617	Definitions, Methods of Testing, and Specifications for Appearance Imperfections of Optical Elements and Assemblies	Inactive	ISO 14997 MIL-PRF-13830B

2.1 Example Lenses

The properties of the two example lenses (one spherical on both surfaces and the other aspheric on one surface) are provided in Table 2. This information is provided in a tabular description for the two lens elements discussed in the remainder of this paper.

Table 2. Key optical parameters of sample lenses. Unless otherwise noted, units are in mm.

	Sample Lens		**Sample Asphere**	
Surface 1 Radius	345.16	Concave	222.20	Convex
Surface 1 Aspheric Coefficients	None		None	
Surface 2 Radius	1641.93	Convex	77.80	Convex
Surface 2 Aspheric Coefficients (units are mm^4, mm^6, and mm^8 as appropriate)	None		k = -2.75 A_4 = 0.0 A_6 = -1.2324e-9 A_8 = 4.0898e-12	
Surface 1 Clear Aperture	523.20		45.00	
Surface 2 Clear Aperture	737.00		45.00	
Center Thickness	113.00		7.00	
Optical Material	Schott N-BK7		Schott N-SF5	

2.2 MIL-STD-34

MIL-STD-150 defined optical definitions and how an optical system should be analyzed.[31] Though many critical aspects of optical fabrication were defined and metrology methods were discussed within MIL-STD-150, no single drawing standard was provided. MIL-STD-34 was first introduced in 1960 to build on the mechanical drawing standard, MIL-STD-8, and MIL-STD-150; it added optics-specific properties and their notations.[1,32]

MIL-STD-34 created a singular method of how optics drawings should be implemented. As will be seen with ISO 10110, there is a commonality throughout MIL-STD-34. The key difference between MIL-STD-34—and ASME/ANSI Y14.18M, as seen in subsequent sections—and ISO 10110 is that this standard conveyed most information in written terms either through dimensions or in notes. Because of the large amount of information that needs to be discussed, drawings following MIL-STD-34 can look significantly cluttered.

Information conveyed through notes included the focal lengths, clear aperture, surface quality, and centering. Material definitions of the optical element were, unexpectedly, within the title block of the drawing. This definition of properties, such as units and material information, followed standard mechanical drawings.

As MIL-STD-34 is based on MIL-STD-8, dimensional properties were defined on the view of the optical element. This reduced reliance on notes for defining an optical surface. Some tolerances for these dimensions were stated as words, such as the power and irregularity in fringes. These dimensions are more commonly stated in waves or nanometers on modern drawings.

One key aspect that MIL-STD-34 was missing was how surface finish is defined. At the time MIL-STD-34 was written, a tolerance for a polished surface finish was not typically necessary due to manufacturing methods and optical requirements. Defining a surface finish on an optics drawing required cross-referencing MIL-STD-10A.[2] As MIL-STD-10A was written for surface finish of mechanical components, communicating the surface finish of an optic became difficult. Mechanical surfaces do not require tight roughness and waviness callouts. Optical surfaces may require tight tolerances on roughness and waviness values to assure system quality. Additionally, unlike MIL-STD-8 and MIL-STD-34, all units must be defined in either inches or micro-inches in MIL-STD-10A. Such a requirement in optics drawings induced non-trivial difficulties in tying the specification to optical performance, typically written in metric units.

Additionally, defining a non-spherical surface on an optic with MIL-STD-34 required the definition of the equation and orientation of the aspheric surface. When the non-spherical surface was rotationally variant, the definition and offset needed to be clearly defined and shown on the view of the optic.

MIL-STD-34 is best understood by analyzing a print itself. In Figure 1, a drawing of a conventional lens with spherical surfaces is shown that follows MIL-STD-34. In Figure 2, a drawing of a sample aspheric optical component is shown that follows MIL-STD-34.

Both drawings leave the fabricator trying to find additional key information. A fabricator must break down the drawing to understand the dimensions or tolerances pertinent to the requirements.

2.3 ASME/ANSI Y14.18M

ASME/ANSI Y14.18M was created in an effort to update and supersede MIL-STD-34.[8] The goal for this standard was to move control of optics drawing standards away from the US Military to a voluntary engineering organization. ASME/ANSI Y14.18M relied heavily on ASME Y14.5, excluding when an optical dimension or tolerance was noted.[33] At the time of the standards implementation, the ISO standards for optics drawings were not in place.

The authors of ASME/ANSI Y14.18M tried to expand MIL-STD-34 to include further necessary definitions within an optics drawing. This standard increased the overall number of documents to reference. These included ANSI PH3.617 and ANSI Y14.36 in addition to ASME/ANSI Y14.18M.[9,34] Breaking up the complexity within a single standard encouraged more widespread implementation due to ease of execution.

This optics drawing standard was last revised in 1986, and has since been deactivated. Since that time, optical manufacturing methods have grown to include a wider variety of optical elements, including more prevalent aspheres and the emergence of freeform optical surfaces.

One of the key benefits of ASME/ANSI Y14.18M was the open-endedness of drawing requirements. Users could create a customized drawing template and respective standard implementation. This allowed companies and users to follow the standard while still creating a drawing based on how optical designers communicated with their fabricators.

Each dimension within ASME/ANSI Y14.18M was defined, but their explanation was ambiguous. The standard required significant designer and fabricator communication for effective implementation. All dimensional values and tolerances follow ASME Y14.5. Values that have a tolerance outside of what can classically be defined within ASME Y14.5 were outlined in ASME/ANSI Y14.18M. Similar to MIL-STD-34, the definition and explanation for how to handle a non-spherical surface required use of an equation and a method for verifying said equation, e.g. a sag table.

Example drawings within the ASME/ANSI Y14.18M standard were provided to assist in the creation of a template. The standard contained an explicit statement that sample drawings were for reference. Users could express their drawing in any way they wish. As a result, the reliance on notes subsequently became commonplace within United States optical drawings.

Many critical values or callouts of an optical element are defined within a note or table. The reliance of notes was both a major benefit and a major restriction of the standard. Unlike MIL-STD-34, the ASME/ANSI Y14.18M standard allowed the designer to communicate through their own methods. Because of the reliance on notes, ASME/ANSI Y14.18M ended up limiting which fabricators a designer could use. A designer typically had to have communication back and forth when a new fabricator was used to ensure that their intention case across with the verbiage chosen for a dimension, tolerance, or method of test. The inevitable need for notes resulted in a potentially confusing optical drawing. The freedom of both standards induced the need for continual communication between the optical engineer and fabrication staff.

Figure 3 and Figure 4 show drawings of the same components as Figure 1 and Figure 2, but drawn in accordance with ASME/ANSI Y14.18M.

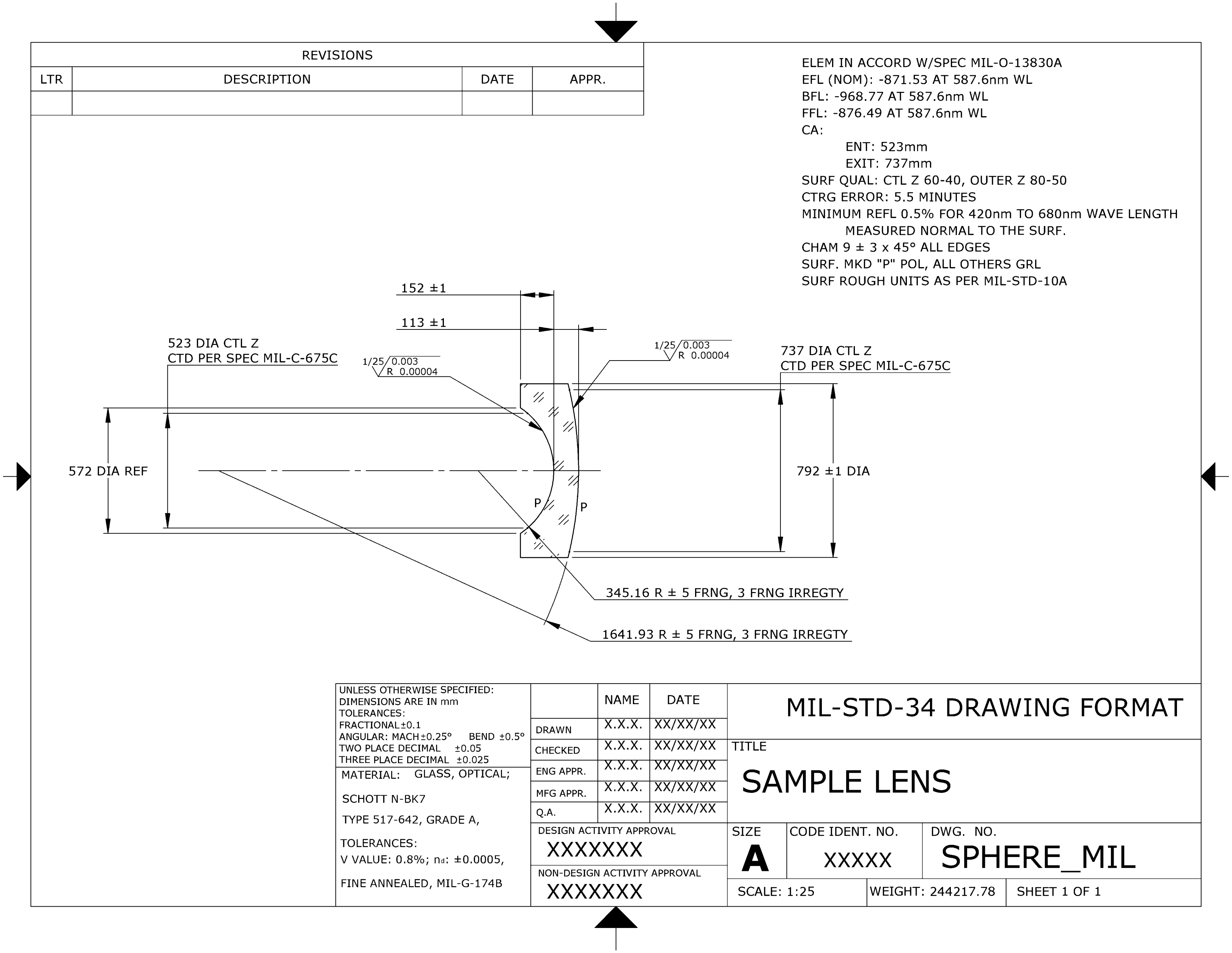

Figure 1. Sample spherical lens drafted following MIL-STD-34.

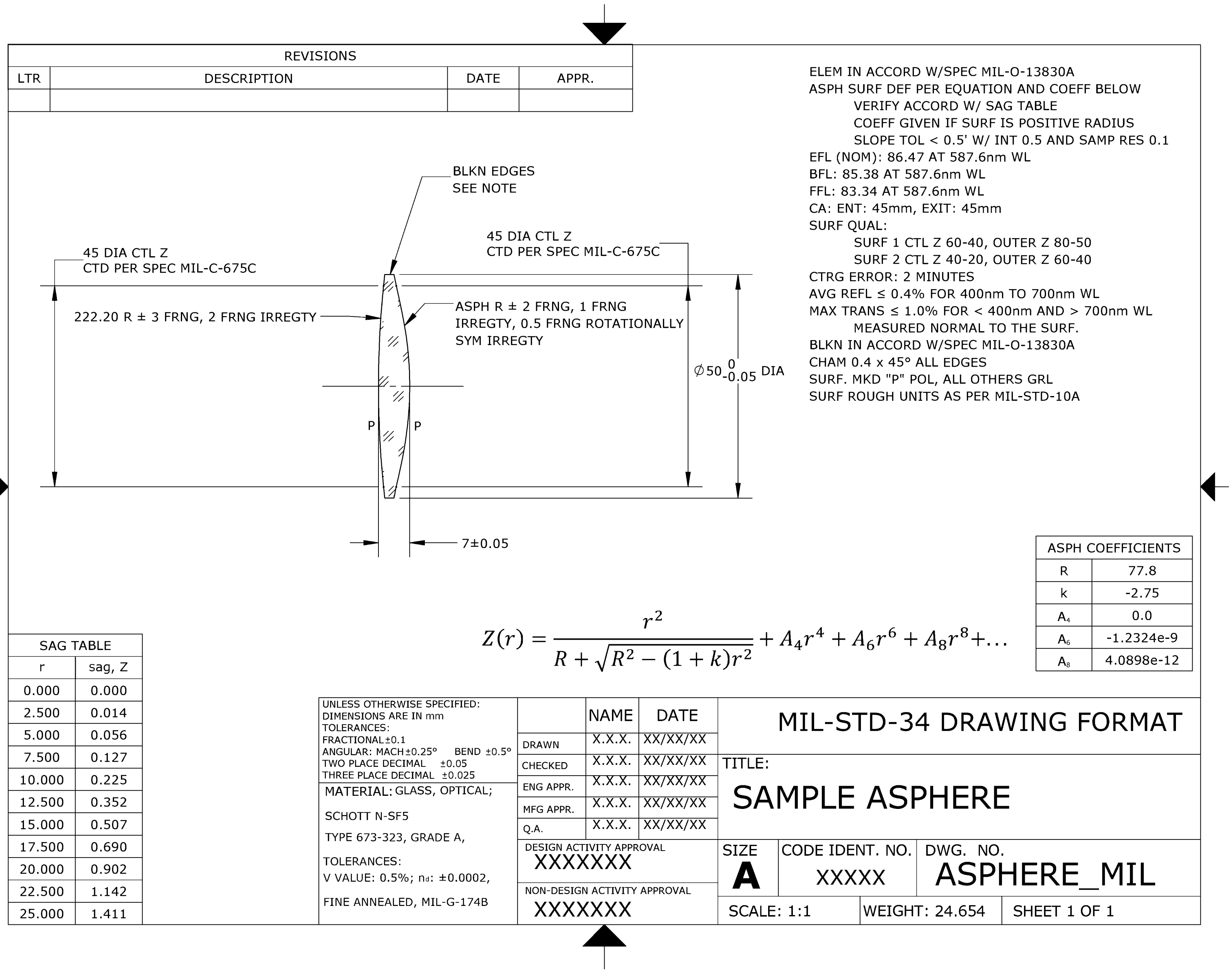

Figure 2. Sample aspheric lens drafted following MIL-STD-34.

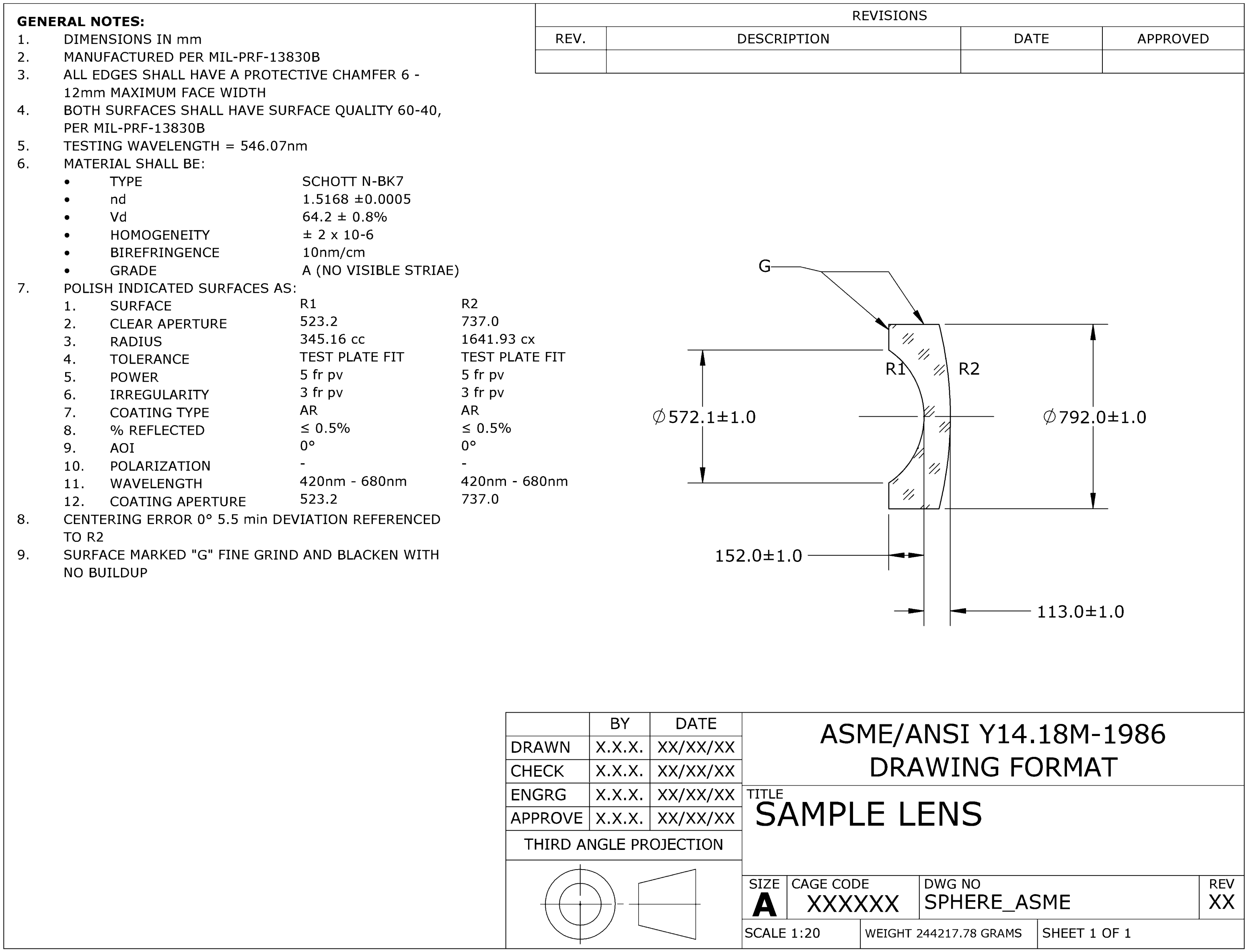

Figure 3. Sample spherical lens drafted following AMSE/ANSI Y14.18M-1986.

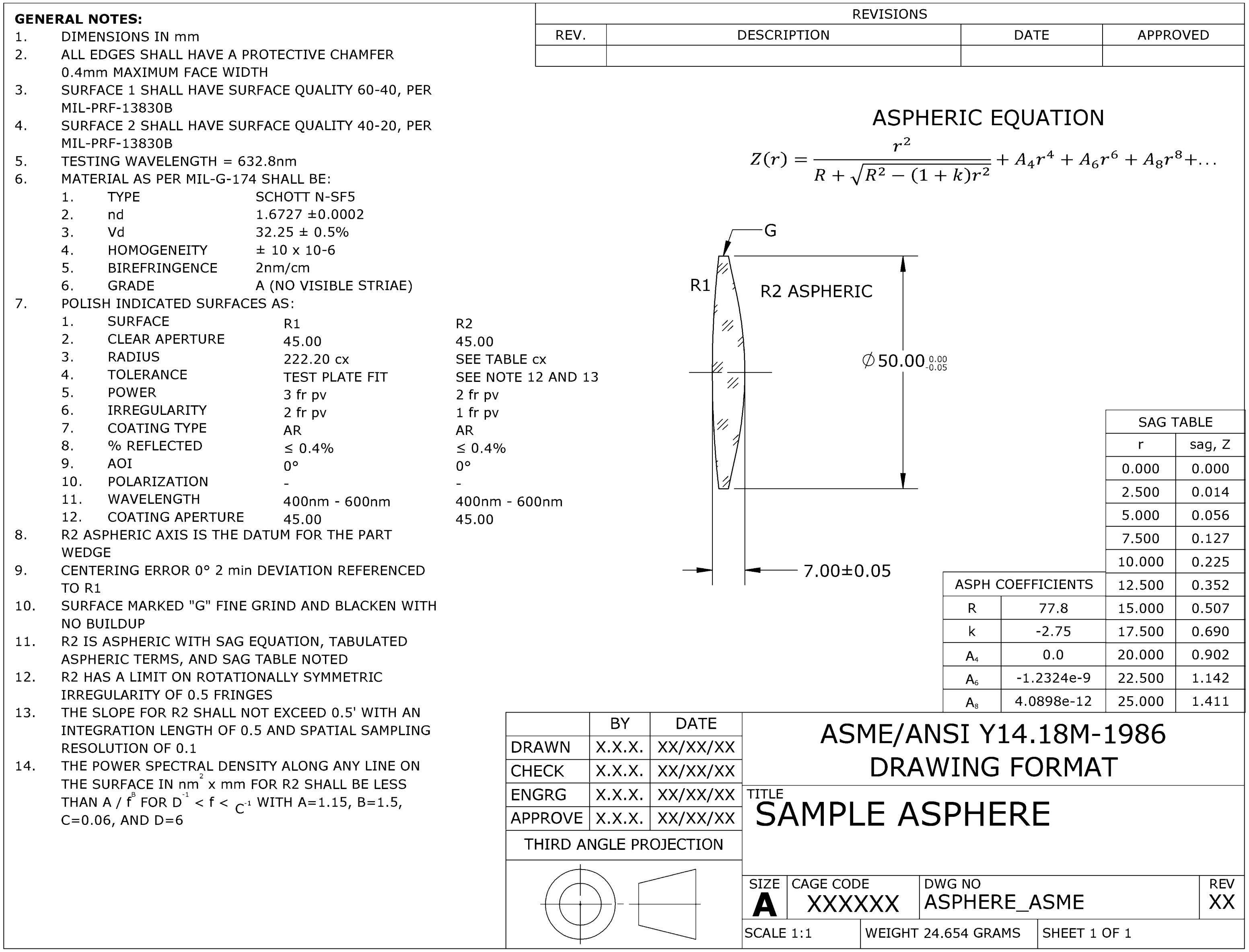

Figure 4. Sample aspheric lens drafted following AMSE/ANSI Y14.18M-1986.

3. ISO 10110 DRAWING HISTORY

ISO Technical Committee 172 – Optics and photonics (ISO/TC 172) was created in 1978 to specifically address the need for worldwide optics and photonics standards. The Technical Committee is composed of seven subcommittees, each of which is tasked with developing standards for a different aspect of the optics and photonics community. As of 2018, subcommittee 1 for Fundamental Standards (ISO/TC 172/SC 1) has published 54 standards and currently has 10 standards under development. The group has a robust committee with 11 participating member countries and 12 observing member countries. Many of these SC 1 standards are critical to their respective industries. No discussion of the activity of SC 1 would be complete without recognizing the wide support given to the entire TC 172 and notably SC 1 by DIN Deutsches Institut für Normung e.V., who provide staff scientists (in this case physicists) operating as secretariat and managing document process, ISO procedures, and lending technical expertise for strong standards development.

Standards developed in SC 1 are currently (2018) organized into three separate working groups covering general optical test methods (WG 1), preparation of drawings for optical elements and systems (WG 2), and environmental test methods (WG 3). The most important working group within ISO/TC 172 for optics drawings is WG 2, which has been convened by the US (1992-1997), France (1997-2008), Japan (2008-2016), and most recently the US again (2016-present). Within WG 2, the critical ISO 10110 series is developed and maintained.[10-13,16-23] WG 1 is also key as it develops metrology and verification standards for optics such as the ISO 14999 series and ISO 14997.[14,15]

The development of ISO 10110 can be roughly broken into three stages. In the mid-1990's the general structure and initial implementation of an international drawing standard was executed. The early international version was based on the well-founded DIN 3140 standard that had been under wide successful use in Germany for many decades. The middle stage, from 2000 until roughly 2012, involved solidifying and improving the standard as it became adopted by member bodies.

Currently within the third stage, two key efforts are being undertaken. First, a significant effort to incorporate general surface call outs and capability to enable a wider variety of optical elements (e.g. freeforms) has led to an overhaul of a significant number of standards. Second, the committee has worked to include critically absent methodologies, such as US preferred scratch-dig, and provide more flexibility regarding system factors, such as reference wavelength.

4. HOW IS AN ISO 10110 DRAWING DEFINED?

The ISO standards used to define an optics drawing are given in Table *3*. Most of the standards used are part of the ISO 10110 series, which requires the user to take a different approach than what is historically seen from the US-based standards. As the ISO 10110 drawing standard was originally based on DIN 3140, these drawings utilize a numeric code system for identifying and specifying optical tolerances on the drawing. An innovation of the first edition of ISO 10110 was to allow the tabulation of these coded tolerances, which further alters the format. Each column within the table will include all information for a surface. This is opposed to defining requirements by type. Most ISO 10110 drawings today are provided in this tabular format (although not required by the standard). The difference in format and notation (i.e. symbols) can lead to initial confusion for users accustomed to US standards.

As each requirement type is assigned a numerical code designation, an ISO 10110 drawing itself can be confusing at first. This coded determination of a requirement becomes a significant and unambiguous benefit of the standard when analyzed further. The reduction of text description on a print increases the number of qualified fabricators a designer may use for their optics.[35] The ISO system of normative callouts obviates the need for interpreting a specification. In using the US system, the fabricator may have had to communicate with the designer on what was ultimately being requested. These conversations between fabricator and designer can add to the cost and development time for a system. Moreover, the US standards opened issues in the global marketplace due to technical norms as well as language barriers. A normative coded system of requirements makes interpretation clear regardless of communication factors. All that is required is an understanding of the standard.

Traditionally, one of the most challenging changes in converting from a US-based drawing to an ISO one relates to cosmetic features. Within the United States, MIL-PRF-13830B, or scratch-dig, has been used since 1954.[6] Over time this standard has been renewed and become the go-to specification. The downsides of MIL-PRF-13830B have been well-documented.[36–38] With scratch-dig, the observer will look at an optical surface under specific illumination conditions, and subjective comparison of the visibility or appearance of a scratch or a dig to a set of reference artifacts is made. The scratches and digs are formally defined within the reference but are not measured on each part. The number of scratches and digs are cumulative to determine if the surface meets the requirement. As this specification employs a subjective comparison, there can be discrepancies between observers. Historically, the ISO 10110 surface imperfection specification, derived from DIN 3140, controls the width of scratches and the size of digs. A cumulative function is applied to the number of scratches or digs to verify if the requirement is met. This system is more quantitative, but requires considerably more time to evaluate for compliance.

Table 3. Important ISO standards for optics drawings and their comparative MIL or ASME standard.

Standard Number	Description	Status	Comparative Standard
ISO 7944	Optics and optical instruments - Reference wavelengths	Active	ASME/ANSI Y14.18M
ISO 10110-1	Optics and photonics - Preparation of drawings for optical elements and systems - Part 1: General	Active	MIL-STD-34 ASME/ANSI Y14.18M
ISO 10110-5	Optics and photonics - Preparation of drawings for optical elements and systems - Part 5: Surface form tolerances	Active	MIL-STD-34 ASME/ANSI Y14.18M
ISO 10110-6	Optics and photonics - Preparation of drawings for optical elements and systems - Part 6: Centring tolerances	Active	MIL-STD-34 ASME/ANSI Y14.18M
ISO 10110-7	Optics and photonics - Preparation of drawings for optical elements and systems - Part 7: Surface imperfections	Active	MIL-PRF-13830B ANSI PH3.617
ISO 10110-8	Optics and photonics - Preparation of drawings for optical elements and systems - Part 8: Surface texture	Active	MIL-STD-10A ASME B46.1
ISO 10110-9	Optics and photonics - Preparation of drawings for optical elements and systems - Part 9: Surface treatment and coating	Active	MIL-C-675C MIL-M-13508C ASME/ANSI Y14.18M
ISO 10110-11	Optics and photonics - Preparation of drawings for optical elements and systems - Part 11: Non-toleranced data	Active	MIL-STD-34 ASME/ANSI Y14.18M
ISO 10110-12	Optics and photonics - Preparation of drawings for optical elements and systems - Part 12: Aspheric surfaces	Active	MIL-STD-34 ASME/ANSI Y14.18M
ISO 10110-14	Optics and photonics - Preparation of drawings for optical elements and systems - Part 14: Wavefront deformation tolerance	Active	MIL-STD-34 ASME/ANSI Y14.18M
ISO 10110-17	Optics and photonics - Preparation of drawings for optical elements and systems - Part 17: Laser irradiation damage threshold	Active	Various internal standards
ISO 10110-18	Optics and photonics - Preparation of drawings for optical elements and systems - Part 18: Stress birefringence, bubbles and inclusions, homogeneity, and striae	Active	MIL-STD-34 MIL-G-174B ASME/ANSI Y14.18M
ISO 10110-19	Optics and photonics - Preparation of drawings for optical elements and systems - Part 19: General description of surfaces and components	Active	MIL-STD-34 ASME Y14.5
ISO 12123	Optics and photonics - Specification of raw optical glass	Active	MIL-STD-34 MIL-G-174B ASME/ANSI Y14.18M
ISO 14997	Optics and photonics - Test methods for surface imperfections of optical elements	Active	MIL-PRF-13830B ANSI PH3.617
ISO 14999-4	Optics and photonics - Interferometric measurement of optical elements and optical systems - Part 4: Interpretation and evaluation of tolerances specified in ISO 10110	Active	ASME/ANSI Y14.18M

As was seen in the MIL-STD-34 drawing, surface finish was not written with optical surfaces in mind. Under the ISO 10110 standard, surface finish has been written to include modern optical texture requirements. More frequently, surfaces require different waviness and roughness specification because of improved manufacturing techniques. The addition of sub-aperture polishing has shown that specifying mid-spatial frequency errors can be critical in some applications.[39]

ISO 10110 has included fabricator-independent requirement classes. A surface may be polished to a pre-determined surface finish without requirements for various frequency ranges. This requirement class system is best represented by optical glass defects beyond the index and Abbe number. The major glass manufacturers have their own respective system of determining the quality of a material by homogeneity, bubbles, inclusions, and striae. By removing this specificity, a drawing may be used for multiple vendors (if allowed by the designer) without changes to the specification.

An ISO 10110 drawing may at first seem complicated, but comparing those above to the MIL or ASME drawings, one can discern the meaning of parameters within each coded section.

5. CHANGING ISO 10110 DRAWING STANDARDS

Changes are occurring to ISO 10110 constantly to ensure the standard is up to industry needs. Other works have covered these changes in further detail across the entire ISO/TC 172/SC1 family of optical standards.[40] Summarized versions of these recent changes are as follows:

- ISO 10110-1 and ISO 10110-10 are merging to encompass all aspects of drawing formats within ISO 10110-1
- ISO 10110-7 has been written to now include the MIL-PRF-13830B, scratch-dig notation; the associated metrology standard, ISO 14997, has been updated accordingly
- ISO 10110-12 clarifies how aspheric or rotationally invariant surfaces should be described on a drawing
- ISO 10110-18 is a new standard that will cover all optical material specifications (ISO 10110-2, ISO 10110-3, and ISO 10110-4) and unifies the class for glass specifications

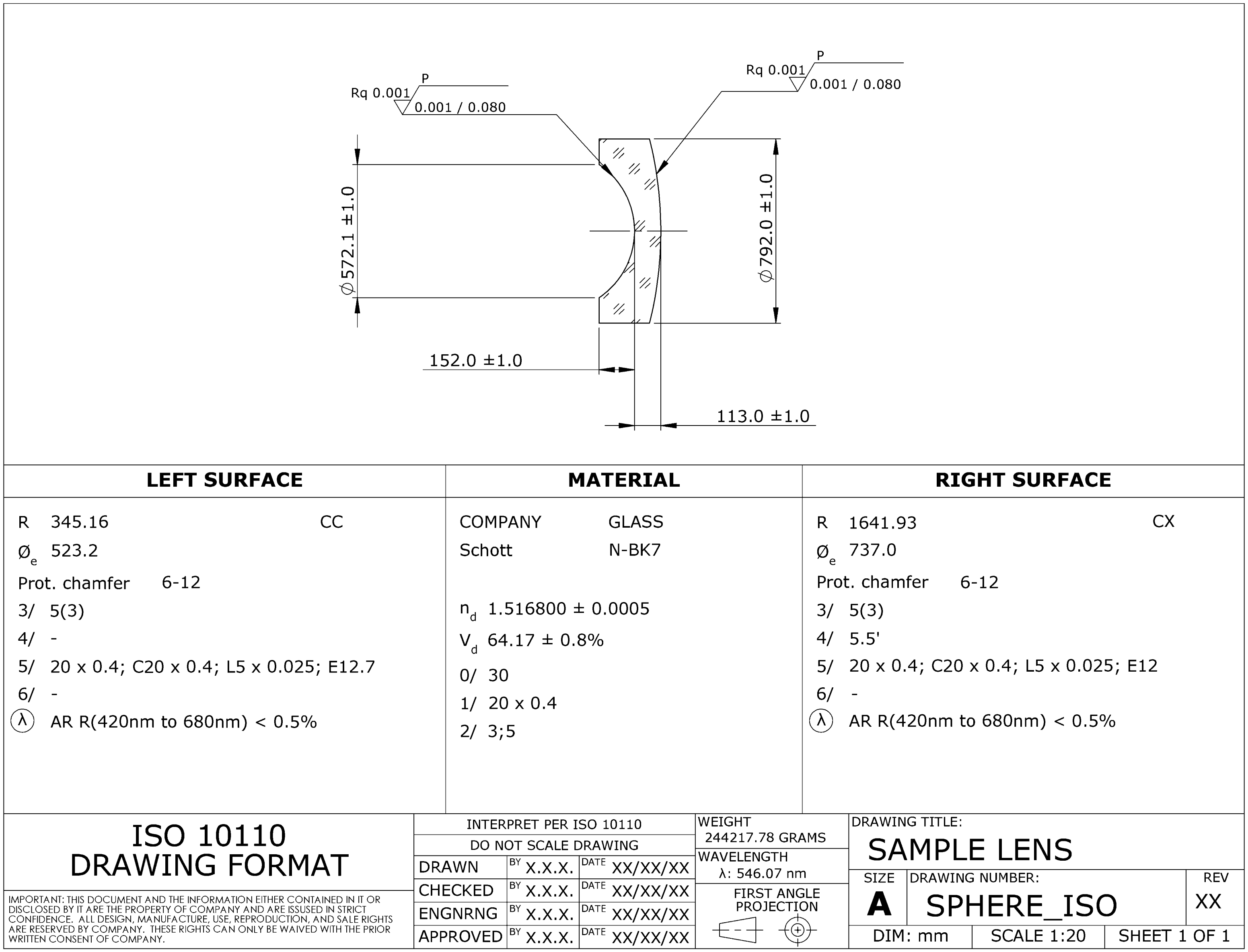

Figure 5. Sample spherical lens drafted following ISO 10110.

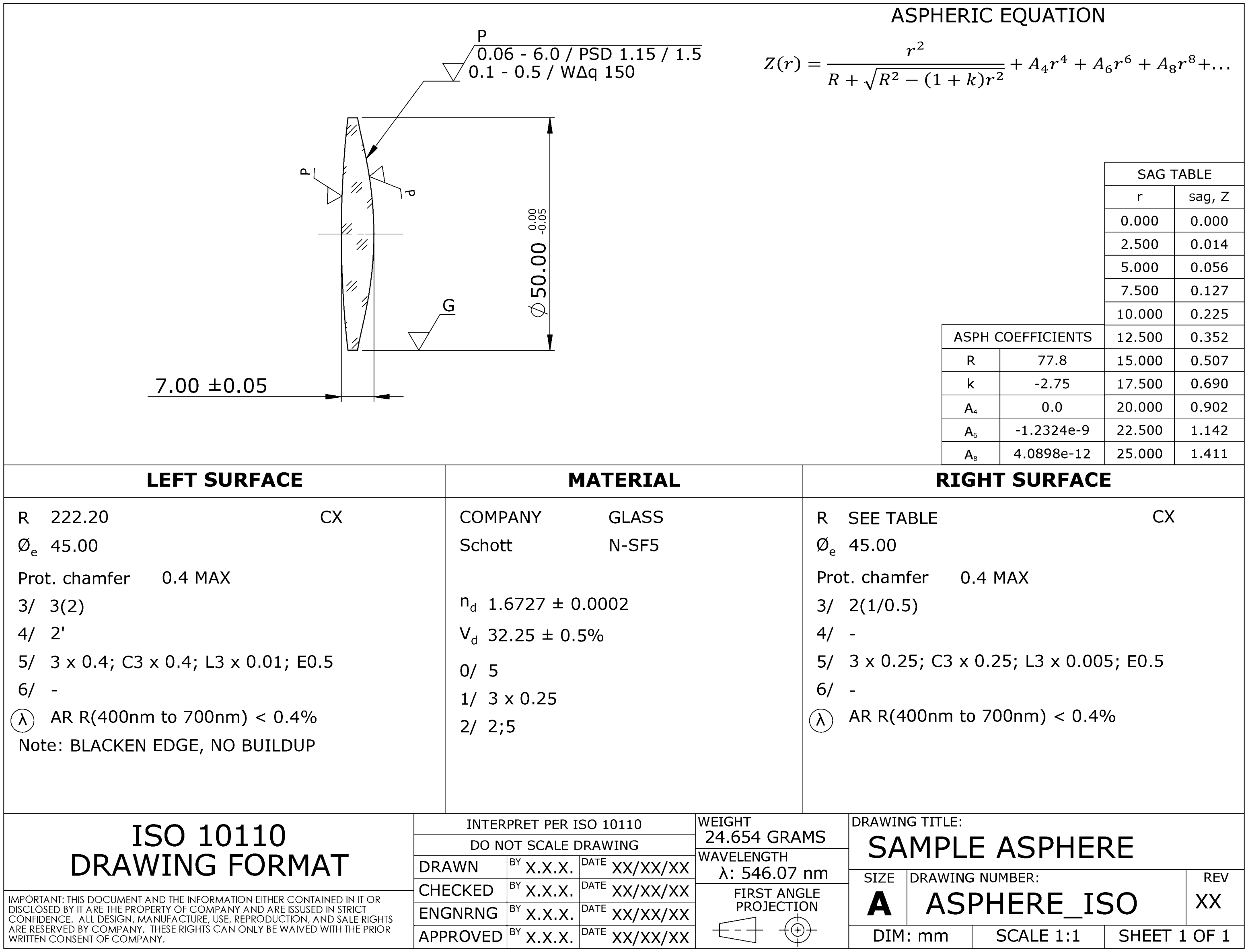

Figure 6. Sample aspheric lens drafted following ISO 10110.

6. CONCLUSIONS

Drawing standards have been present within the United States since the 1950s. These standards relied on the user to include many notes to convey non-dimensional information. Notes made it critical that a designer and fabricator communicate the nuances of each optical element or assembly. Continued reliance on notes has led to confusion and additional manufacturer communication. Globally, ISO optical standards have taken the approach to minimize unnecessary communication by annotating a drawing through a code system that does not rely on the fabricator's language.

More importantly, all optics drawing standards within the United States have since been cancelled. However, cancelling these standards has not had a large impact on the amount of users following these historic standards. This has become an issue because there have not been updates to the standards to account for changes in optical design and fabrication technology. These standards are now outdated and has forced the individual users to develop their own method to convey the necessary information of their optical components or assemblies. ISO 10110 on the other hand is still an active standard and continues to be modified for the needs of modern optical design and fabrication. The path forward with international standards is much clearer than US-based standards; after the initial work of adopting the standard, greater efficiency can be attained.

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