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NOVEL TECHNIQUES FOR EXAMINATION OF LIGHT OPTICAL ELEMENTS

Abstract

Examining a light optical element (LOE) may include placing a first slit optically between a projector configured to emit light and the LOE's first major surface and placing a second slit optically between the LOE's second major surface and a detector. Facet parallelism between two facets may be deduced based on a shift of the image reflected from the first facet to the second facet relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet. Facet refractive index homogeneity or deviation may be deduced based on the light transmitted through the facet relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet.

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Background/Summary

FIELD OF THE INVENTION

[0001] The present disclosure relates to the field of near eye display systems such as head-mounted displays. More specifically, the present disclosure relates to techniques for examining facets of lightguide optical elements (LOE) of near eye display systems.

BACKGROUND OF THE INVENTION

[0002] Consumer demands for improved human-computer interfaces have led to an increased interest in high-quality image head-mounted displays (HMDs) or near-eye displays (NED), commonly known as smart glasses. These devices can provide virtual reality (VR) or augmented reality (AR) experiences, enhancing the way users interact with digital content and their surrounding environment.

[0003] Consumers are seeking better image quality, immersive experiences, and greater comfort when using HMDs. They expect displays with high resolution, vibrant colors, and minimal distortion to create a realistic and enjoyable viewing experience.

[0004] A critical component in NED systems is the waveguide, which guides light from a system image projector to the user's eyes. Waveguides function based on total internal reflection along their major surfaces to propagate light and use reflection off facets placed along the waveguides to direct the light to the user's eyes. Achieving optimal waveguide performance requires precise design and manufacturing to prevent imperfections that could degrade the user's visual experience.

[0005] Assessing the optical performance of a waveguide before integrating it into an NED system can help reduce production costs. Key factors for achieving optimal waveguide performance include ensuring the facets are parallel and have a homogeneous refractive index. Conventionally, testing these characteristics was time-consuming and expensive, which limited the availability and adoption of NED systems.

[0006] Therefore, there is a demand for innovative techniques to examine waveguides efficiently.

SUMMARY OF THE INVENTION

[0007] The present disclosure introduces innovative techniques for measuring LOE optical performance. Previous methods for measuring facet parallelism in LOE used coupling prisms as disclosed in, for example, U.S. Pat. No. 11,226,261 and PCT International App. Pub. No. WO2023/007491. In contrast, the techniques disclosed herein do not require coupling prisms. In one embodiment, the LOE is measured by coupling light into the waveguide through one or more of the major surfaces to reflect off or transmit through one or more of the facets. This eliminates the need for a coupling prism, simplifying the measurement system mechanics and improving testing efficiency.

[0008] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate various example systems, methods, and so on, that illustrate various example embodiments of aspects of the invention. It will be appreciated that the illustrated element boundaries (e.g., boxes, groups of boxes, or other shapes) in the figures represent one example of the boundaries. One of ordinary skill in the art will appreciate that one element may be designed as multiple elements or that multiple elements may be designed as one element. An element shown as an internal component of another element may be implemented as an external component and vice versa. Furthermore, elements may not be drawn to scale.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 illustrates an exemplary implementation of a near-eye display device.

[0010] FIG. 2 illustrates a schematic diagram of an exemplary system for measuring parallelism of partially reflecting facets of an LOE.

[0011] FIG. 3 illustrates a schematic diagram of an exemplary system for measuring parallelism of partially reflecting facets of an LOE.

[0012] FIG. 4 illustrates a schematic diagram of an exemplary system for measuring parallelism of partially reflecting facets of an LOE.

[0013] FIG. 5 illustrates a schematic diagram of an exemplary system for measuring parallelism of partially reflecting facets of an LOE.

[0014] FIG. 6 illustrates a schematic diagram of an exemplary system for measuring parallelism of partially reflecting facets of an LOE.

[0015] FIG. 7 illustrates a schematic diagram of an exemplary system for measuring homogeneity of refractive index of facets of an LOE.

[0016] FIG. 8 illustrates a flow chart of an exemplary process for measuring parallelism of partially reflecting facets of an LOE.

[0017] FIG. 9 illustrates a flow chart of an exemplary process for measuring homogeneity of refractive index of facets of an LOE.

DETAILED DESCRIPTION

[0018] Certain embodiments of the present invention provide a light projecting system and an optical system for achieving optical aperture expansion for the purpose of, for example, head-mounted displays (HMDs) or near-eye displays, commonly known as smart glasses, which may be virtual reality or augmented reality displays. Consumer demands for better and more comfortable human computer interfaces have stimulated demand for better image quality and for smaller devices.

[0019] FIG. 1 illustrates an exemplary implementation of a near-eye display device 1. The near-eye display device 1 is disclosed here merely as an example and the inventive techniques disclosed herein are not limited to such devices.

[0020] In the illustrated embodiment of FIG. 1, the near-eye display 1 employs compact image projectors or projection units 3 optically coupled so as to inject an image into light optical elements (LOE) 10. Optical aperture expansion of light from the projection unit 3 may be achieved within LOE 10 by one or more arrangements for progressively redirecting the image illumination employing a set of partially reflecting surfaces (interchangeably referred to as “facets”) that are ideally parallel to each other and inclined obliquely to the direction of propagation of the image light, with each successive facet deflecting a proportion of the image light into a deflected direction. Partially reflecting facets may also work as a coupling-out arrangement that progressively couples out a proportion of the image illumination towards the eye of an observer located within a region defined as the eye-motion box (EMB).

[0021] The overall device 1 is preferably supported relative to the head of a user with each projection unit 3 and LOE 10 serving a corresponding eye of the user. In one particularly preferred option as illustrated here, a support arrangement is implemented as a face-mounted set of lenses (e.g., Rx lenses, sunglasses, etc., referred colloquially herein as “eye glasses” or “smart glasses”) with lenses 5 to which the projection unit 3 and LOE 10 are optically connected and a frame with sides 7 for supporting the device relative to ears of the user. Other forms of support arrangement may also be used, including but not limited to, head bands, visors or devices suspended from helmets.

[0022] The near-eye display 1 may include various additional components, typically including a

controller **9** for actuating the projection unit **3**, typically employing electrical power from a small onboard battery (not shown) or some other suitable power source. Controller **9** may include all necessary electronic components such as processing unit or processing circuitry to drive the image projector **3**.

[0023] FIG. **2** illustrates a schematic diagram of a system **50** for measuring parallelism of partially reflecting facets **101-104** of an LOE **10**. The system **50** may include a display-collimator (imaging its image at infinity) section **20** including an imaging collimator **21** and a collimating lens **22**, two devices **131**, **132** having respective slits formed thereon, and a collimating image acquisition section **30** including a lens **31** and a detector **32**. System **50** may also include a processing unit **100** that may control one or more of the display-collimator section **20**, the image acquisition section **30**, and the devices **131**, **132**. The processing unit **100** may also control machinery **40** for moving (i.e., controlling the lateral positioning of) the LOE **10** under examination relative to the other elements of the system **50**.

[0024] The processing unit **100** may include one or more processors (such as, for example, microprocessors, microcontrollers, etc.), memory, etc. programmed (e.g., software, firmware, etc.) to control various of the elements of the systems disclosed herein and for calculating/deducing parallelism and homogeneity of refractive index of the LOE facets.

[0025] As shown in FIG. **2**, the devices **131**, **132** may be placed such that their respective slits are disposed across from each other with the LOE **10** therebetween so an image projected by the display-collimator section **20** reaches the image acquisition section **30**, specifically the detector **32**, without any angular shift caused by the LOE facets **101-104**. This can be used to calibrate the system **50** as a reference for the position of the image for an ideal pair of parallel facets.

[0026] FIG. **3** illustrates a schematic diagram of system **50** with both the device **132** and the LOE **10** shifted from their positions shown in FIG. **2**. The slits of devices **131** and **132** are placed such that the direct image projected by the display-collimator section **20** reaches facet **101**. Any light transmitted by facet **101** is blocked from reaching the image acquisition section **30**. Light reflected by facet **101** reaches facet **102**, which reflects some of the light to the image acquisition section **30**. Light reaching the detector **32** corresponds to light that has been twice reflected, first by the facet **101** and second by the facet **102**. By measuring the shift of the detected image captured at detector **32** in the arrangement of FIG. **3** relative to the image captured in the arrangement shown in FIG. **2**, the system **50** may deduce the parallelism between surfaces **101** and **102**.

[0027] FIG. **4** illustrates a schematic diagram of system **50** with the LOE **10** shifted from its position shown in FIG. **3** to, in this arrangement, measure parallelism between surfaces **102** and **103**. The slits of devices **131** and **132** are placed such that the direct image projected by the display-collimator section **20** reaches the facet **102**. Any light transmitted by facet **102** is blocked from reaching the image acquisition section **30**. Light reflected by facet **102** reaches facet **103**, which reflects some of the light to the image acquisition section **30**. Light reaching detector **32** corresponds to light that has been twice reflected, first by the facet **102** and second by the facet **103**. By measuring the shift of the detected image captured at detector **32** in the arrangement of FIG. **4** relative to the image captured in the arrangement shown in FIG. **2**, the system **50** may deduce the parallelism between surfaces **102** and **103**. With the information of FIGS. **2**, **3**, and **4**, system **50** may also deduce parallelism between facets **101** and **103** by simple mathematical calculation.

[0028] For instance, suppose that the image detected in the arrangement where the two slits are facing one another (as in FIG. **2**) is centered around the zero position, for the arrangement shown in FIG. **3** the center of the image is shifted 20" to the left, and for the situation presented in FIG. **4** the image is positioned 20" to the right. From those measurements, the system **50** can deduce that facets **101** and **102** are parallel and facet **101** is rotated 6.66" clockwise if the material of the LOE has an index of refraction of 1.5 according to the equation $\alpha = \theta / 2n$ where α is the mechanical deviating angle between two facets ($\alpha = 0$ means perfect parallelism), θ is the observed angular

image shift and n is the refractive index of the LOE.

[0029] By continuing shifting the entire LOE **10** such that all its facets had their turn in front of the slit of the device **132**, the system **50** can deduce the parallelism of the entire facets structure.

[0030] A similar technique may be implemented using system **60** of FIG. 5. In system **60**, the display-collimator section **20** includes an auto collimator and replaces the imaging collimator **30** of the previous figures with a mirror **14**. The slit of the device **132** is disposed optically between the second major surface **13** and the mirror **14** such that light from the projector **20** travels through the slit of the device **131** to the first major surface **12** and to a first facet **101**, light reflected by the first facet **101** and a second facet **102** travels from the second facet **102** to the second major surface **13** and through the slit of the second device **132** to the mirror **14**. Light reflected by the mirror **14** travels through the second slit of the device **132** to the second major surface **13** and to the second facet **102**, light reflected by the second facet **102** and the first facet **101** travels from the first facet **101** to the first major surface **12** and through the first slit of the device **131** to the detector **32**. Light reaching detector **32** would have traveled via the two relevant facets twice and, thus, the intensity of light received at the detector **32** is significantly decreased from the originally projected light.

[0031] Any kind of structure where one measures the reflection deviation of light hitting at least one pair of facets in the array could be considered. For instance, one could measure the reflection of light between a first facet i and $i+2$ instead of $i+1$ or even measure the reflection of light between a first facet i and $i+n$ where n is a shifting integer between 1 and $N-1$ where N is the total number of facets. An exemplary system **70** is shown in FIG. 6 where the slit of the device **132** is positioned in front of facet **103** and could be shifted to facet **104**.

[0032] FIG. 7 illustrates a system **80** for measuring homogeneity of refractive index of facets **101-104** of the LOE **10**. The LOE **10** may be manufactured from individual coated plates or slices **1000-1004** glued together. The interfaces between adjacent plates form the facets. For example, the interface between adjacent plates **1000** and **1001** form the facet **101**. The quality of the LOE **10** will be governed, not just by how parallel the facets **101-104** may be, but also by homogeneity in the refractive index of the plates **1000-1004** at the interfaces forming the facets **101-104**.

[0033] To measure homogeneity of refractive index of facets **101-104** the devices **131**, **132** may be placed such that their slits face one another as in FIGS. 1 and 7. The calibration of the system takes place in the arrangement as showed in FIG. 1, where LOE **10** is placed relative to the devices **131**, **132** such that projected light propagates through the LOE **10** through a single slice **1000** without crossing different plates along the path. That is, in calibration, light from the imaging unit **20** is transmitted normal to the first and second major surfaces **12**, **13** through a portion **1000** of the LOE **10** not including a facet.

[0034] To measure homogeneity of refractive index of facet **101** the devices **131**, **132** remain placed such that their slits face one another. However, as shown in FIG. 7, the LOE **10** has been shifted left such that projected light enters the LOE **10** through the first major surface **12** at slice or plate **1001** and then crosses the interface between the plate **1001** and the plate **1000** (i.e., the facet **101**). If the refractive index of plates **1001** and **1000** is not the same at the interface **101**, then, according to Snell law, there will be deflection of the light rays as the light crosses the interface between the two surfaces that can be measure using the arrangement of FIG. 7.

[0035] By further shifting the LOE **10** left, the interfaces between plates **1002** and **1001**, **1002** and **1003**, etc. may be examined such that differences in the refractive index of the facets **102**, **103**, etc. may be detected. Assuming that the light enters normally to the major surface **12** of the LOE **10** and exits at the angle β , then we can deduce that $\Delta n = n_1/n_2 - 1 = \cot(\theta/n_2\beta$ where θ is the slanting angle of the facets ($\theta=0$ means that the facets are parallel to the major surfaces of the LOE **10**, in the figures θ equals 38 degrees).

Methods

[0036] Exemplary methods may be better appreciated with reference to the flow diagrams of FIGS. 8 and 9. While for purposes of simplicity of explanation, the illustrated methodologies are shown

and described as a series of blocks, it is to be appreciated that the methodologies are not limited by the order of the blocks, as some blocks can occur in different orders or concurrently with other blocks from that shown and described. Moreover, less than all the illustrated blocks may be required to implement an exemplary methodology. Furthermore, additional methodologies, alternative methodologies, or both can employ additional blocks, not illustrated.

[0037] In the flow diagrams, blocks denote “processing blocks” that may be implemented with logic. The processing blocks may represent a method step or an apparatus element for performing the method step. The flow diagrams do not depict syntax for any particular programming language, methodology, or style (e.g., procedural, object-oriented). Rather, the flow diagrams illustrate functional information one skilled in the art may employ to develop logic to perform the illustrated processing. It will be appreciated that in some examples, program elements like temporary variables, routine loops, and so on, are not shown. It will be further appreciated that electronic and software applications may involve dynamic and flexible processes so that the illustrated blocks can be performed in other sequences that are different from those shown or that blocks may be combined or separated into multiple components. It will be appreciated that the processes may be implemented using various programming approaches like machine language, procedural, object oriented or artificial intelligence techniques.

[0038] FIG. 8 illustrates a flow diagram for an exemplary method **800** for measuring parallelism of facets of an LOE. As shown in FIG. 8, the method **800** may include calibration by, at **810**, projecting light normally to the major surfaces of the LOE, at **820**, shifting one or more of the slits to face each other across a portion of the LOE that does not include a facet, and, at **830**, measuring the projected light to measure un-deviated parallelism.

[0039] At **840**, the method **800** may include shifting at least one slit and/or the LOE such that light from the projector travels through the first slit to the first major surface and to a first facet (facet i) and such that the second slit blocks light transmitted by the first facet and such that light reflected by the first facet to a second facet travels from the second facet to the second major surface and through the second slit to the detector. At **850**, the method **800** may include measuring the deviated reflection from the image as detected by the detector relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet. At **860**, the method **800** may include deducing the parallelism between the first facet and the second facet based on the measured deviation. The method may then repeat for further facets down the LOE.

[0040] FIG. 9 illustrates a flow diagram for an exemplary method **900** for measuring homogeneity of refractive index of facets of the LOE. As shown in FIG. 9, the method **900** may include calibration by, at **910**, projecting light normally to the major surfaces of the LOE, at **920**, shifting one or more of the slits to face each other across a portion of the LOE that does not include a facet, and, at **930**, measuring the projected light across the portion of the LOE that does not include a facet.

[0041] At **940**, the method **900** may include shifting at least one slit and/or the LOE such that light from the projector travels through the first slit to the first major surface and to a first facet of the facets and light transmitted through the first facet travels from the first facet to the second major surface and through the second slit to the detector. At **950**, method **900** may include measuring light transmission as deviated by the first facet. At **960**, the method **900** may include deducing homogeneity of slices based on the measured deviated light transmission relative to the light transmitted normal to the first and second major surfaces through the portion of the LOE not including a facet.

[0042] While the figures illustrate various actions occurring in serial, it is to be appreciated that various actions illustrated could occur substantially in parallel, and while actions may be shown occurring in parallel, it is to be appreciated that these actions could occur substantially in series. While a number of processes are described in relation to the illustrated methods, it is to be appreciated that a greater or lesser number of processes could be employed, and that lightweight

processes, regular processes, threads, and other approaches could be employed. It is to be appreciated that other exemplary methods may, in some cases, also include actions that occur substantially in parallel. The illustrated exemplary methods and other embodiments may operate in real-time, faster than real-time in a software or hardware or hybrid software/hardware implementation, or slower than real time in a software or hardware or hybrid software/hardware implementation.

DEFINITIONS

[0043] The following includes definitions of selected terms employed herein. The definitions include various examples or forms of components that fall within the scope of a term and that may be used for implementation. The examples are not intended to be limiting. Both singular and plural forms of terms may be within the definitions.

[0044] An “operable connection,” or a connection by which entities are “operably connected,” is one in which signals, physical communications, or logical communications may be sent or received. Typically, an operable connection includes a physical interface, an electrical interface, or a data interface, but it is to be noted that an operable connection may include differing combinations of these or other types of connections sufficient to allow operable control. For example, two entities can be operably connected by being able to communicate signals to each other directly or through one or more intermediate entities like a processor, operating system, a logic, software, or other entity. Logical or physical communication channels can be used to create an operable connection.

[0045] To the extent that the term “includes” or “including” is employed in the detailed description or the claims, it is intended to be inclusive in a manner similar to the term “comprising” as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term “or” is employed in the detailed description or claims (e.g., A or B) it is intended to mean “A or B or both.” When the applicants intend to indicate “only A or B but not both” then the term “only A or B but not both” will be employed. Thus, use of the term “or” herein is the inclusive, and not the exclusive use. See, Bryan A. Garner, *A Dictionary of Modern Legal Usage* 624 (2d. Ed. 1995).

[0046] While example systems, methods, and so on, have been illustrated by describing examples, and while the examples have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit scope to such detail. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing the systems, methods, and so on, described herein. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention is not limited to the specific details, the representative apparatus, and illustrative examples shown and described. Thus, this application is intended to embrace alterations, modifications, and variations that fall within the scope of the appended claims. Furthermore, the preceding description is not meant to limit the scope of the invention. Rather, the scope of the invention is to be determined by the appended claims and their equivalents.

Claims

1. A system for measuring parallelism and homogeneity of refractive index of facets of a lightguide optical element (LOE), the LOE including a light-transmitting substrate having first and second major surfaces parallel to each other such that light coupled into the light-transmitting substrate is trapped between the first and second major surfaces by total internal reflection and the facets configured to couple the light out of the substrate, the system comprising: one or more devices having formed thereon a first slit and a second slit; a processing unit configured to control at least one of the first slit and the second slit such that the first slit is disposed optically between a projector configured to emit light corresponding to an image and the first major surface, the first

slit disposed such that light from the projector travels through the first slit to the first major surface and to a first facet of the facets and such that the second slit is disposed optically between the second major surface and a detector, the second slit disposed as to block light transmitted by the first facet and such that light reflected by the first facet and a second facet, from the facets, travels from the second facet to the second major surface and through the second slit to the detector; the processing unit configured to deduce the parallelism between the first facet and the second facet based on a shift of the image as detected by the detector relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet from the facets; the processing unit configured to control the at least one of the first slit and the second slit such that the second slit is disposed optically between the second major surface and the detector such that light from the projector travels through the first slit to the first major surface and to the first facet and light transmitted through the first facet travels from the first facet to the second major surface and through the second slit to the detector; and the processing unit configured to determine the homogeneity or deviation in refractive index between surfaces of the first facet based on the light transmitted through the first facet, as detected by the detector, relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet from the facets.

2. The system of claim 1, the processing unit configured to control lateral movement of the LOE relative to the first and second slits, or viceversa, to measure parallelism and homogeneity of refractive index of additional facets of the LOE.

3. The system of claim 1, the processing unit configured to calibrate by capturing at the detector an image emitted by the projector that travels through the portion of the substrate not including a facet.

4. The system of claim 1, comprising: a mirror, the second slit disposed optically between the second major surface and the mirror such that light from the projector travels through the first slit to the first major surface and to a first facet, light reflected by the first facet and a second facet travels from the second facet to the second major surface and through the second slit to the mirror, light reflected by the mirror travels through the second slit to the second major surface and to the second facet, light reflected by the second facet and the first facet travels from the first facet to the first major surface and through the first slit to the detector.

5. The system of claim 1, wherein the projector includes a collimator and the detector includes a camera, or the projector and the detector are part of an autocollimator.

6. A system for measuring parallelism of facets of a lightguide optical element (LOE), the LOE including a light-transmitting substrate having first and second major surfaces parallel to each other such that light coupled into the light-transmitting substrate is trapped between the first and second major surfaces by total internal reflection and the facets configured to couple the light out of the substrate, the system comprising: one or more devices having formed thereon a first slit and a second slit; a processing unit configured to control at least one of the first slit and the second slit such that the first slit is disposed optically between a projector configured to emit light corresponding to an image and the first major surface, the first slit disposed such that light from the projector travels through the first slit to the first major surface and to a first facet of the facets and such that the second slit is disposed optically between the second major surface and a detector, the second slit disposed as to block light transmitted by the first facet and such that light reflected by the first facet and a second facet, from the facets, travels from the second facet to the second major surface and through the second slit to the detector; and the processing unit configured to deduce the parallelism between the first facet and the second facet based on a shift of the image as detected by the detector relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet from the facets.

7. The system of claim 6, the processing unit configured to laterally move the LOE relative to the first and second slits, or viceversa, to measure parallelism of additional facets of the LOE.

- 8.** The system of claim 6, the processing unit configured to calibrate by capturing at the detector an image emitted by the projector that travels through a portion of the substrate not including a facet.
- 9.** A system for measuring homogeneity of refractive index of facets of a lightguide optical element (LOE), the LOE including a light-transmitting substrate having first and second major surfaces parallel to each other such that light coupled into the light-transmitting substrate is trapped between the first and second major surfaces by total internal reflection and the facets configured to couple the light out of the substrate, the system comprising: one or more devices having formed thereon a first slit and a second slit; the processing unit configured to control the at least one of the first slit and the second slit such that the second slit is disposed optically between the second major surface and the detector such that light from the projector travels through the first slit to the first major surface and to the first facet and light transmitted through the first facet travels from the first facet to the second major surface and through the second slit to the detector; and the processing unit configured to determine the homogeneity or deviation in refractive index between surfaces of the first facet based on the light transmitted through the first facet, as detected by the detector, relative to light transmitted normal to the first and second major surfaces through a portion of the substrate not including a facet from the facets.
- 10.** The system of claim 9, the processing unit configured to laterally move the LOE relative to the first and second slits, or viceversa, to measure homogeneity of refractive index of additional facets of the LOE.
- 11.** The system of claim 9, comprising: a mirror, the processing unit configured for the second slit to be placed optically between the second major surface and the mirror such that light from the projector travels through the first slit to the first major surface and to a first facet, light reflected by the first facet and a second facet travels from the second facet to the second major surface and through the second slit to the mirror, light reflected by the mirror travels through the second slit to the second major surface and to the second facet, light reflected by the second facet and the first facet travels from the first facet to the first major surface and through the first slit to the detector.
- 12-20.** (canceled)
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