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TOTAL INTERNAL REFLECTION BASED ANGLE FILTER FOR SIDE IMAGE MITIGATION IN A CURVED LIGHTGUIDE

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TOTAL INTERNAL REFLECTION BASED ANGLE FILTER FOR SIDE IMAGE MITIGATION IN A CURVED LIGHTGUIDE

Abstract

A system is provided for removing extraneous side images produced by light emitted at high angles from a display in a head mounted display (HMD), which results in light rays traveling along undesired paths that bounce one or three times from a worldside surface of a lightguide in the HMD, instead of the two bounces along the path taken by the light that forms the primary image. The system includes an optical element that couples the display to a prism to provide light to a lightguide in the HMD. The optical element is fabricated to include a V-shaped groove. Light incident upon the V-shaped groove at relatively high angles, e.g., light traveling along paths that would bounce one or three times in the lightguide, is totally internally reflected out of the path that couples the light into the HMD lightguide.

Background

Head mounted display (HMD) systems include a micro display that emits an image into a full width, half maximum (FWHM) cone that has an opening angle of approximately 20°, centered approximately normal to the display surface. As illustrated in FIG. 1, light rays that form a primary image for display to a user wearing the HMD are emitted at lower angles relative to the axis of the cone. These light rays are coupled into the lightguide of the HMD and bounce twice from a world side surface of the lightguide before entering the eye of the user. Light rays that are emitted at higher angles relative to the axis of the cone are also coupled into the lightguide of the HMD. High angle light rays bounce from the worldside surface either one or three times before entering the user's eye. The high angle light rays create side images in addition to the main image. The dim blurred side images interfere with the user's view of the world and detract from the experience of using the HMD

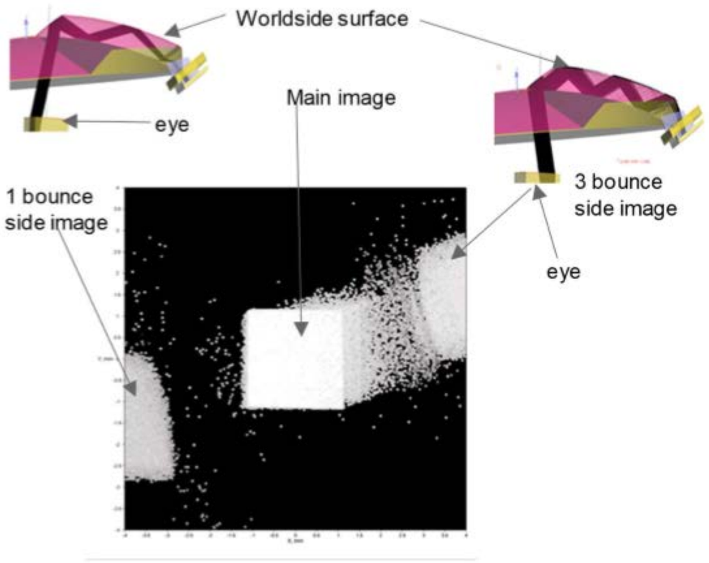

Fig. 1

Description

An example HMD, as shown in Figure 2, includes two see-through eyepieces that provide image light to a user along with a view of the surrounding environment. The image light may be augmented reality data that provides information of one or more objects in the surrounding environment. Additionally, the image light provides other information to the user such as text messages, email messages, phone call information, *etc*. The HMD includes electronics and a display unit to project the image light to the user. The electronics are either coupled to a secondary electronics device that provides the data for generating the image light, or the electronics include wireless communication technology that allows for the receipt of the information via a wireless network, such as bluetooth, Wi-Fi or cellular.

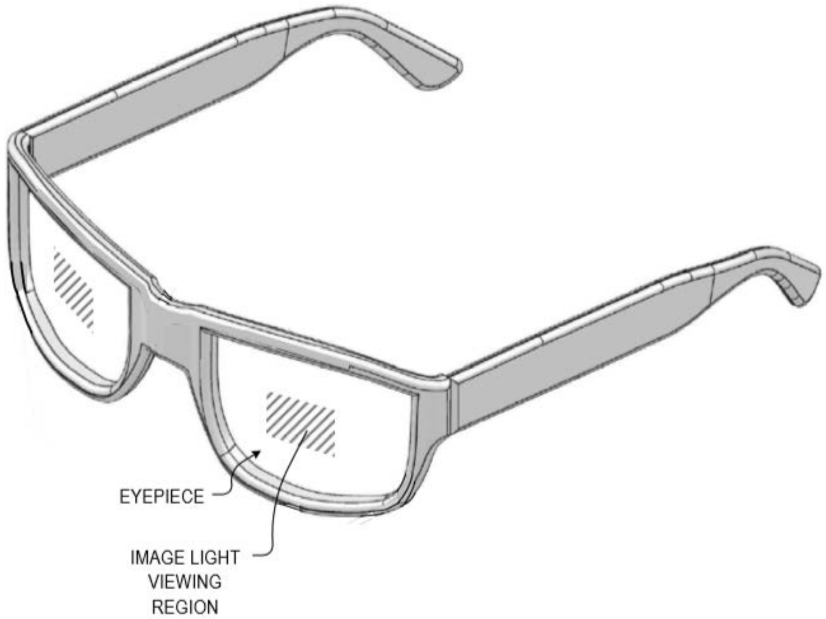

Fig. 2

Each eyepiece includes a lightguide that provides an optical pathway for the image light to propagate from the display unit to the image light viewing region, which is arranged to be aligned with the user’s eye. The lightguide relies on total internal reflection (TIR) for propagating the image light from an input coupler to an output coupler, which redirects the light out of the HMD and toward the eye of the user in the image light viewing region. The eyepieces additionally include vision correction lensing for the user. The present disclosure provides a filter to remove high angle light rays that form side images in the image seen by the user, thereby improving the overall quality of the images used by the user wearing the HMD.

An example optical structure suited for an HMD is shown in Figure 3. The tan regions represent the display system that generates light rays and the purple regions represent the optical structure that filters rays at high incident angles and allows rays at lower incident angles to pass through for coupling to a lightguide in an HMD system such as the system shown in FIG. 2. Only light rays from a single pixel of the display are shown.

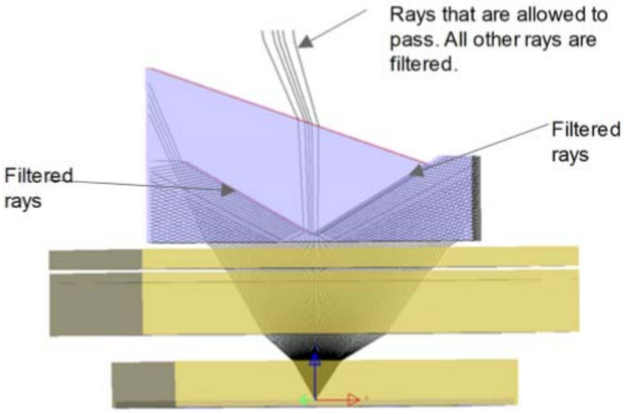

Fig. 3

Whether or not a ray passes through an airgap in the V-shaped groove is determined by the incidence angle of the ray and the critical angle for total internal reflection of the V-shaped groove. The critical angle is determined by the materials that are used to fabricate the optical structure. The slopes of the V-shaped groove are adjusted such that only rays that are incident on the surfaces of the V-shaped groove below a certain design incidence angle are allowed to pass. Aligning the filter axis with the linear polarization of the display improves efficiency of the filter by reducing Fresnel reflections in the optical structure. As discussed below, the filter can be implemented using other profiles besides the V-shaped group to enable location dependent angle filtering.

In one embodiment, the optical structure used for filtering high angle light rays is fabricated using two pieces, as illustrated in FIG. 4. The purple region is a prism that is disposed proximate a second (tan) optical element to form a V-shaped groove with an airgap.

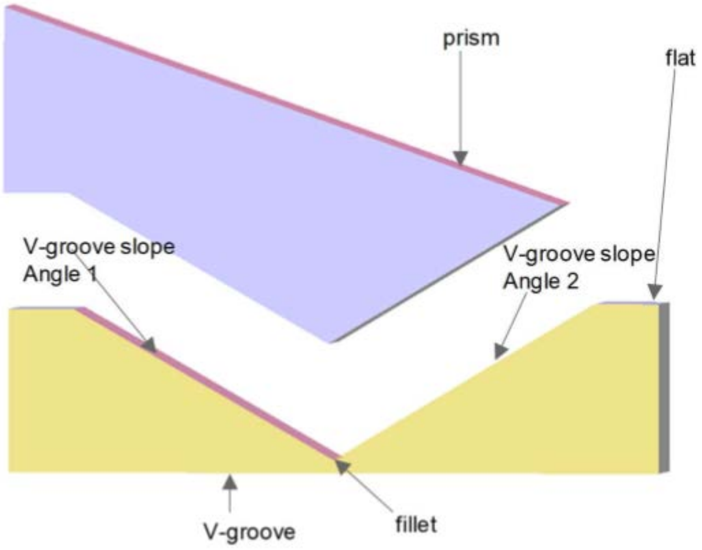

Fig. 4

The design parameters for the V-shaped groove include a first slope angle, a second slope angle, a fillet radius of curvature, material that is used to fabricate the second optical element that includes the V-shaped groove, and a distance from the fillet to a flat region in the second optical element. These parameters are adjustable so that the parameters of the filter are matched to the requirements of the HMD.

FIG. 5 shows results of a simulation of an image seen by a user wearing an HMD without angle filtering (left-hand side) and including angle filtering as discussed herein (right hand side). The simulation results on the right-hand side isolate the effect of light trapped within chiolite used to fabricate the lightguide and a worldside. In the simulation, the worldside of a worldside puck is made to be an absorber.

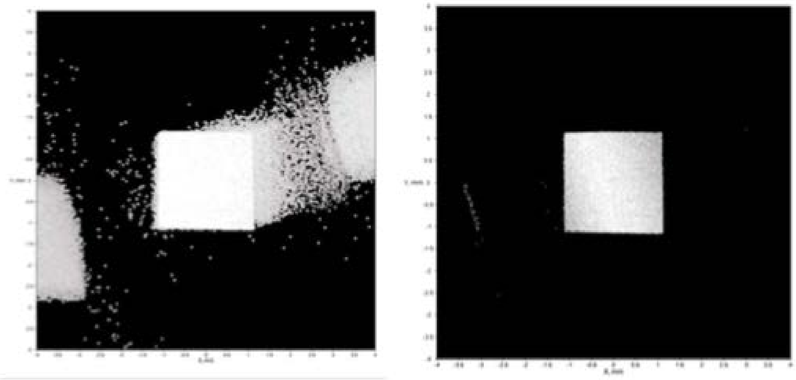

Fig. 5

FIG. 6 illustrates an embodiment of the angle filter that is implemented as a separate plane parallel plate. In this embodiment, the shape of the color correcting prism is unchanged relative to the conventional shape.

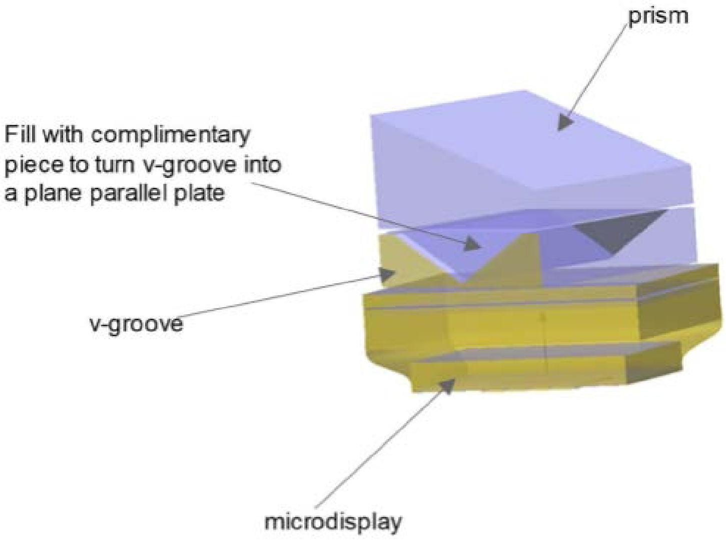

Fig. 6

FIG. 7 illustrates the geometric features of the embodiment of the angle filter shown in FIG. 6. The features include the material used to fabricate the filter, a ledge thickness, a total plate thickness, a fillet radius, a fillet-to-plane thickness, and an airgap thickness.

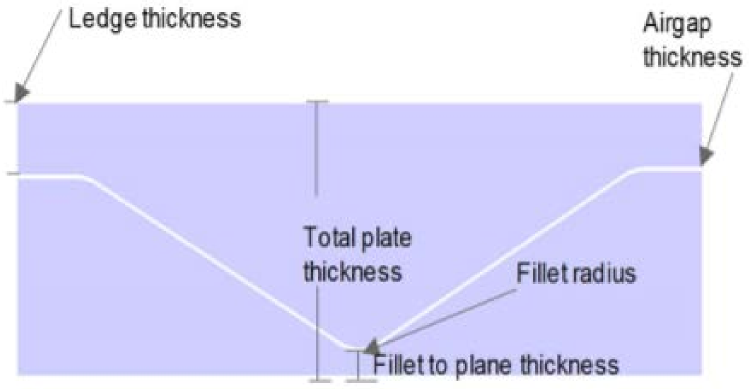

Fig. 7

FIG. 8 is an image simulation using the angle filter shown in FIG. 6. The parameters of the angle filter include 30° and 29° slopes, the material EP5000, 100 micron fillet, and antireflective coating, a 1.65 mm thick plate, a 430 µm ledge, and a 10 µm airgap. The simulation demonstrates that the angle filter removes the side image rate paths when the angle filter is placed between the prism and the display. The worldside of the worldside puck in the simulated optical system was made an absorber to isolate out the effect of other artifacts, i.e., the chiolite to worldside ray path. In some cases, uniformity can be optimized by optimizing the slopes of the V-shaped groove.

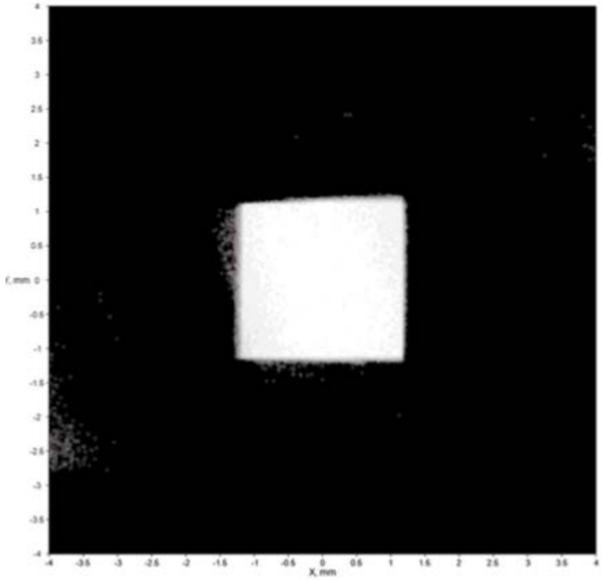

Fig. 8

FIG. 9 is a comparison of grid images for different sized air gaps in the angle filter. One of the primary drivers for residual artifacts within the image is the airgap. In the comparison, the image on the left-hand side is produced using a 25 µm airgap and the image on the right-hand side is produced using a 10 µm airgap.

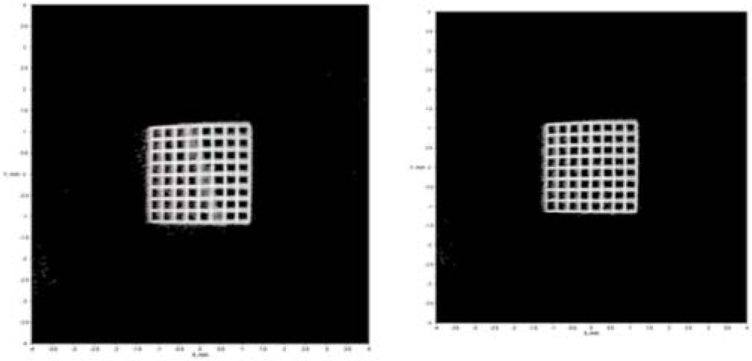

Fig. 9

FIG. 10 illustrates ray paths from a micro display through an angle filter and a lightguide in an HMD, which focuses the light rays that pass through the angle filter onto the pupil of an eye of a user wearing the HMD.

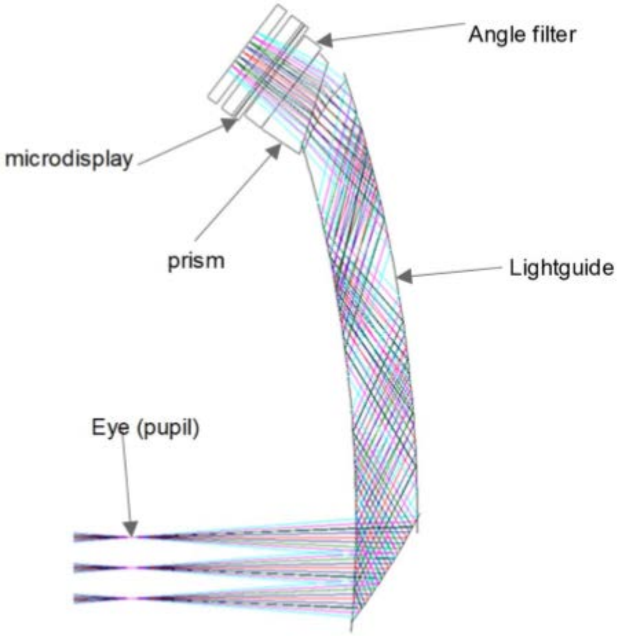

Fig. 10

FIG. 11 is an illustration of a glass X-prism that is used in place of the V-shaped groove in an angle filter. Instead of using two large prisms, the glass X-prism uses intersecting prisms at different angles to reflect high angle light rays out of the optical path to the lightguide of an HMD, as discussed herein.

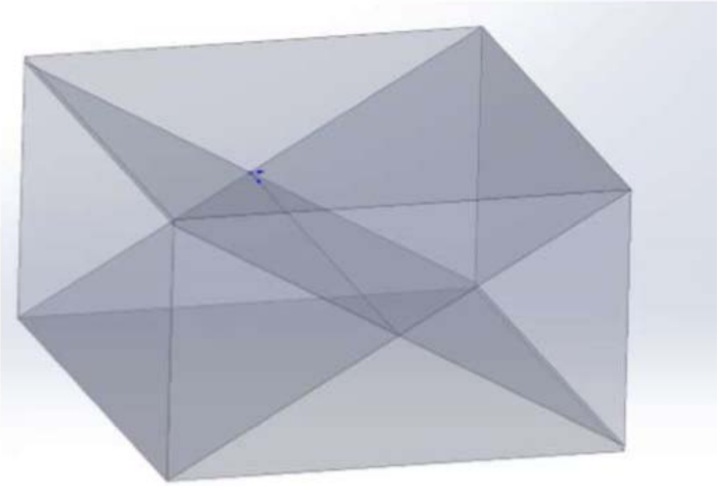

Fig. 11

FIG. 12 is a cross-sectional view of the glass X prism shown in FIG. 11.

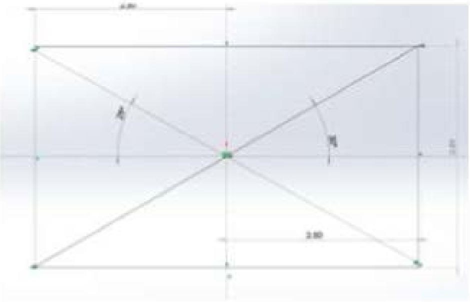

Fig. 12

The glass X prism shown in FIGs. 11 and 12 is advantageously fabricated using glass. In some embodiments, the airgap is replaced by a low index coating and an index matching adhesive.