Available online at www.sciencedirect.com
ScienceDirect
Optik 118 (2007) 29–33
Optik Optics
www.elsevier.de/ijleo

# Design of optical system for head-mounted micro-display

Qiu-Ling Zhao[a,*], Zhao-Qi Wang[b], Tie-Gen Liu[a]

[a]*College of Precision Instrument and Opto-Electronics Engineering, Tianjin University, Key Laboratory of Opto-Electronics Information and Technical Science, MEC, Tianjin 300072, China*
[b]*Institute of Modern Optics, Nankai University, Tianjin 300071, China*

Received 26 July 2005; accepted 2 February 2006

## Abstract

Assembling one optical imaging system with 0.56″ liquid crystal on silicon (LCOS), we achieved one practical head-mounted micro-display system for civilian applications. The optical system consists of three refractive elements and one binary surface. It has a 32° field of view (FOV), a 10 mm exit pupil diameter, and a 20 mm eye clearance distance. Compared with the traditional optical system, the hybrid refractive/diffractive system has a longer working distance and can be used in higher resolution display with better image quality. Designing results indicate that the introducing of binary element in the system with smaller FOV could improve the image quality dramatically.


***Keywords:*** Head-mounted display; Binary optics; Micro-display; LCOS

## 1. Introduction

With the rapid development of virtual environment technology and wearable displays, head-mounted displays (HMDs) are being given more and more attentions. Depending on their purpose, HMD are divided into displays with military and civilian applications [1–4]. The latter includes virtual-reality, surgery, scientific simulation, remote control, entertainment, and so on.

HMD are a special class of micro-displays for personal use which are located together with their optical system and control circuitry in the immediate vicinity of the observer's eyes by means of a special helmet. Placement of the system on the head of the observer imposes stringent requirements on the overall size and mass of the entire system. Due to high quality of the images produced, early HMDs most take CRT as their image sources. But the large dimensions and mass of the CRT reduce the comfort level. Besides, the presence of a high voltage source, located in the immediate vicinity of the observer's head, requires that special safety measures be used. Although today's CRT still offer advantages in resolution and response speed over flat-panel display devices, they have been gradually replaced by liquid crystal display (LCD), liquid crystal on silicon (LCOS), active matrix electroluminescent (AMEL), organic light-emitting device (OLED), etc. [5–7]. These flat-panel display devices have low control voltage, small size, and low power consumption, which make the whole structure simplified and promote the development of the HMD.

Optical imaging system is an important part of the technologies of HMD, which directly affecting the image quality that the user to see in visual space. For using in HMD, there are common challenging design

*Corresponding author. Tel.: +86 22 27892179; fax: +86 22 27406522.
*E-mail address:* qlzhao@tju.edu.cn (Q.-L. Zhao).

0030-4026/$ - see front matter © 2006 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijleo.2006.02.001

issues [8,9]: a long eye relief, a large exit pupil and good performance over a wide spectral range. Besides, the optical system also should be simple and lightweight. This paper we studied designing considerations of optical systems for head-mounted micro-display with LCOS. Based on traditional system, we achieved one hybrid refractive /diffractive system with better performances.

## 2. Design considerations of the optical system for head-mounted display

LCOS is one kind of reflective flat-panel device, which attracts a great deal of attention in the field of micro-display, for good performance and potential low price. For some civilian applications, a small image source and a compact optical system can constitute one HMD with better ratio of performance to price. We designed one compact optical imaging system matching with the LCOS sized 0.56″, and got one practical head mounted micro-display system. We discuss the optical system designing considerations as follows.

### 2.1. Field of view

The field of view (FOV) of the optical imaging system should match with the size of the image source. For a given image source, the system with a wider FOV should have a shorter focal length. So the relative aperture becomes bigger, which would result in a more difficult designing. We have designed one eyepiece with a 40° FOV for display sized 1.1″ diagonal [10], which have a 39 mm effective focal length. In addition, we also designed one optical system for micro-display sized 0.7″ diagonal with a 60° FOV [11], which includes an eyepiece and a reflective relay part. For a 0.56″ diagonal image source, we aim for a system with compact structure. So we define a 32° FOV, and the focal length of the system should be about 25 mm.

### 2.2. Exit pupil

Though the diameter of the pupil of the human eye is typically 3–5 mm, in order to allow for an eye swivel without causing vignetting, the exit pupil of the eyepiece system for HMD should be more than 10 mm [12]. Moreover, a big exit pupil can relieve observer's fatigue after a long time using.

Besides, for getting a maximum FOV, the eye pupil of the observer should be located just on the exit pupil of the optical system, which requires the optical system must have a big enough eye relief. The optical eye relief of an optical system is defined as the distance along the optical axis from the last optical element to the exit pupil. Of greater importance in head-mounted display is the minimum clearance from closest display system component to the eye or exit pupil. Referred to as physical eye relief or eye clearance distance, this parameter determines system compatibility with auxiliary devices, e.g., corrective lenses, etc. Generally the physical eye relief should be more than 20 mm.

### 2.3. Working distance

Due to LCOS is one kind of reflective display device, the optical system should provide the arranging space of lightening parts. Fig. 1 shows the sketch of the system. The lightening part consists of light source, one polarizer, one polarized beam splitter (PBS), and one quarter-wave plate. The illuminating rays from light source reach LCOS by virtue of a PBS and lighten LCOS, then the image information form virtual image though the imaging optical system. So the optical imaging system should have an enough back focal length as working distance.

### 2.4. Optical performances

Besides above Gaussian parameters, optical performances are important for application of HMD, which include transverse ray aberrations, field curvature, distortion, and chromatic aberrations, etc. The resolution of the optical system should meet the requirement of LCOS.

## 3. Design of optical system for micro-display

### 3.1. Traditional optical system

According to the requirements of HMD on optical imaging system, we choose the Plossl eyepiece as the primary structure [13], which has a longer working distance compared with the effective focal length. It consists of two identical cemented doublets with the crown elements facing each other. The FOV is 40°, the effective focal length is 25.4 mm, and the pupil diameter is 5 mm.

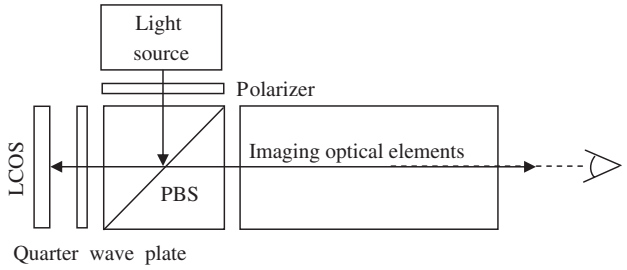


**Fig. 1.** The sketch of the HMD system.