Chapter 3

Fabrication and Measurement Instruments

3.1. Introduction

A preliminary structure will be used to demonstrate the features of the micro-lens array. The embodiment including several fabrication processes will be shown in the following sections, and all the fabrication process, technologies and instruments which are available to develop such a preliminary structure will be introduced in this chapter.

First, the semiconductor fabrication process including spin coating, exposure, develop, sputter, lift-off and a particular technology, self-aligned exposure, will be used. Besides, the features and performance of the fabricated structure, such as the geometric structures, light efficiency and light efficiency enhancement were measured by typical semiconductor measurement systems, such as surface profile measuring system, scanning electron microscope (SEM) and ELDIM EZContrast 160R. The major features of the above mentioned instruments will be illustrated in this chapter.

3.2. Semiconductor Fabrication Process

Due to the processing equipment limitations, it is difficult for us to produce a whole display panel including liquid crystal cell, TFT circuits, alignment layer, polarizer and retardation film, therefore, a prototype was utilized to measure the light efficiency and light efficiency enhancement. In general, using conventional fabrication process, such as micro-machining, double-side alignment technology, inkjet printing [18], to fabricate the proposed structure, misalignment between micro-lens array and glass substrate can occur. Misalignment effect will result in light leakage and reducing backlight utilization, thus decreasing contrast ratio of panel, as described in Fig. 3.1. The light with larger inclined angle will produce undesirable retardation after passing through liquid crystal cell. Thus, light leakage is caused and then decreasing contrast ratio. Besides, some light will be blocked by reflective regions and consequently reducing backlight efficiency. Therefore, we proposed a novel fabrication processes including self-aligned exposure to minimize alignment error and fabricate micro-lens array simultaneously.

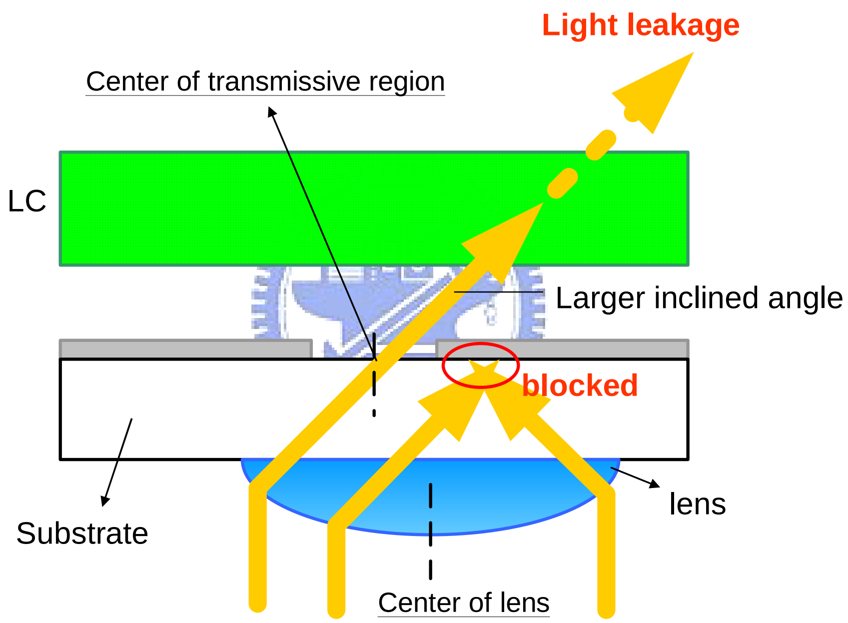


Fig. 3.1. Phenomenon of misalignment

The semiconductor processes including spin coating, lithography, and self-aligned exposure will be used to fabricate the designed structure. In general, although the semiconductor process produces structures on silicon wafer, for the display applications the glass is widely used as the substrate. Thus, a 0.7um of thickness of glass is used as substrate in following fabrication. We carry out our fabrication at semi-conductor research center (SRC) and precision instrument development center (PIDC).

The detail fabrication processes are listed below and the fabrication processes are shown schematically in Fig 3.2.

a. First lithography: for the display application, glass is widely adopted as a substrate. In the fabrication, the glass with 0.7mm thick was used. First of all, positive photoresist was spin coated on the top surface of glass substrate and then was exposed by UV light. Consequently, the pattern on the mask was transformed to the positive photoresist after developing. The pattern was used to define the geometric feature of reflective layer. In order to clearly explain the proposed fabrication processes, one of the designed pattern, rectangle, was adopted, as shown in Fig. 3.2(a).

b. Sputter and lift-off: The glass substrate with patterned photoresist was sputtered by metal film and then the reflective layer was form by lift-off technology. After fabricating the reflective layer, negative photoresist was spin coated on the bottom surface of the glass substrate.

c. Self-aligned exposure: Self-aligned exposure which used the reflective layer as a mask, was then used to expose the negative photoresist. As a result, the preliminary shape of lenticular-lens was form. It is worth noticing that due to the defocus exposure effect, the exposed area on the negative photoresist will be larger than the aperture size of reflective layer. The aperture size of reflective layer also referred to the size of transmissive region.

d. Thermal re-flow: After the negative photoresist exposed by self-aligned exposure, thermal re-flow technology was then used to smooth the surface of lenticular-lens.

e. Characterization: After the fabrication, the light utilization efficiency will be measured.

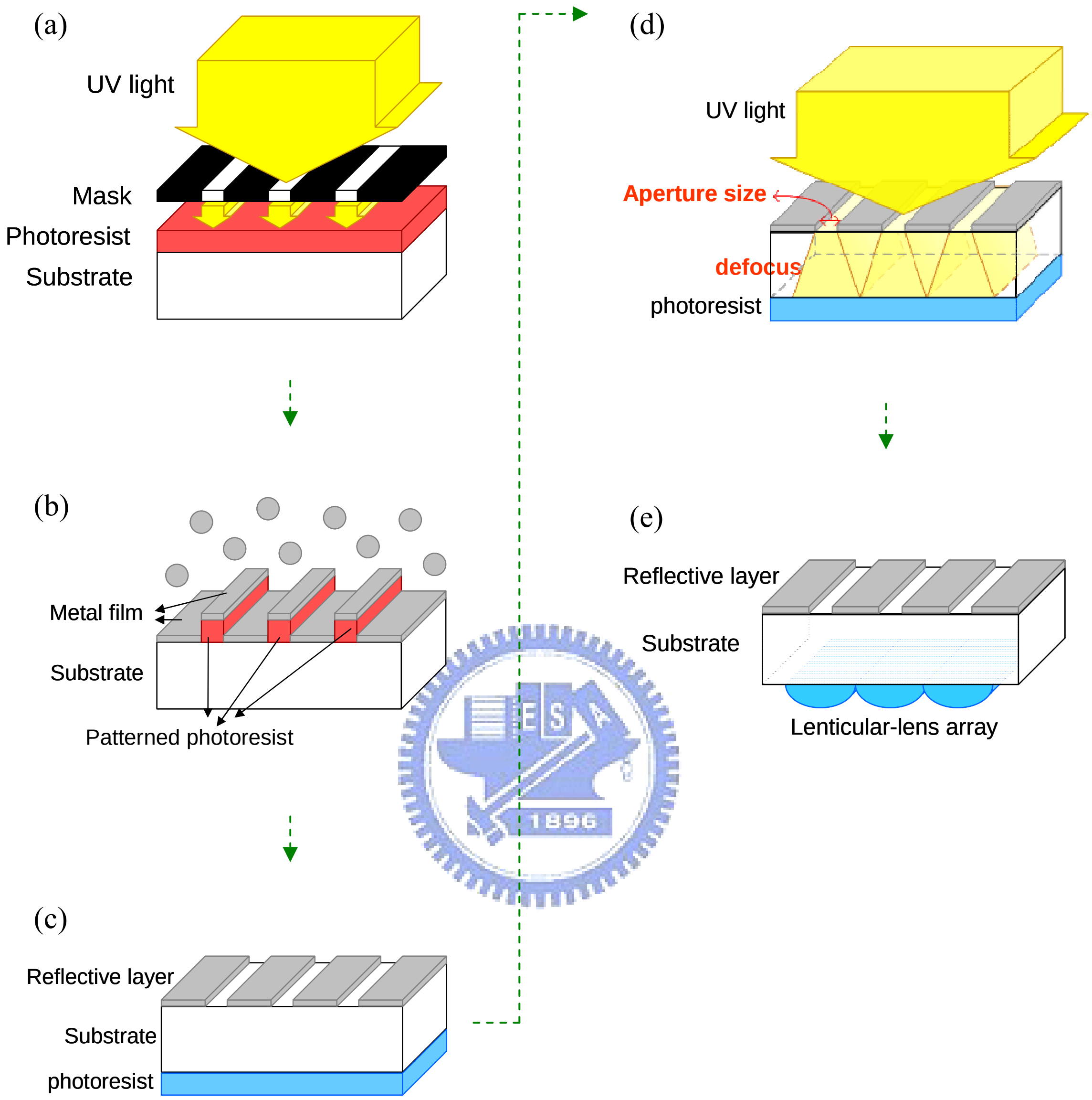


Fig. 3.2. The flow of fabrication process for the micro-lens array (a) first lithography (b) Sputtering metal film (c) Lift-off (d) Self-aligned exposure and (e) Thermal re-flow

3.3. Measurement System

After the fabrication of the micro-lens array structure, the inspection will be performed to ensure that the fabricated structure agrees with the designed structure. At first, surface profile measuring system and scanning electron microscope (SEM) will be introduced. In addition, after the fabrication process, the measurement system is necessary to verify the performance of micro-lens array. Accordingly, a measurement system, the ELDIM EZContrast 160R (diffuse type), will be illustrated.

3.3.1. Surface Profile Measuring System

Surface profile measuring system can analyze the vertical surface profile of the sample: its roughness, waviness and step height, as shown in Fig. 3.3. Measurements are made electromechanically by moving the sample beneath a diamond-tipped stylus. Surface profile measuring system provides accurate height measurements with vertical resolution of 5 Å in a long lateral scan range of 50 um to 30 mm. The instrument combines a reliable measurement accuracy of 10 Å, 1σ step height repeatability, enabling precise measurements of thin films below 100 Å. The machine is supplied with a video camera and provides both the real time viewing of the scan in progress and saving a video image of the analyzed surface for further reference. The detail performance specifications are list in table 3.1. In our experiments, this instrument is utilized to measure the diameter and height of micro-lens, and then the radius of micro-lens can be calculated.

Fig. 3.3. Schematic diagram of surface profile measuring

Table 3.1. Performance specifications of surface profile measuring system

Vertical data resolution	5 Å maximum
Vertical range	65.5 μm maximum
Scan length range	50 μm to 30 mm
Stylus tip radius	12.5 μm standard
Stylus force range	10÷50 mg.
Step height repeatability	10 Å, 1σ typical
Data points per scan	2000 maximum
Sample stage diameter	127 mm
X-Y stage transition	20 mm x 80 mm
Theta sample positioning	360 °
Sample viewing	Color camera, 90x

3.3.2. Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) is an essential instrument to measure the accuracy and fidelity of the fabricated microstructure, as shown in Fig. 3.4. It scans electrons reflecting onto a fluorescent screen across the target where the image is captured by a camera and enlarged. Electrons are much smaller than atoms, so a scanning electron microscope paints a razor-sharp image of the target, and the feature variation of few Å can be observed. This is useful for mapping details of objects that optical microscopes can not resolve. Using the electromagnetic lenses to focus the accelerated electron beam, the diameter of electron beam can be converged to the dimension of 10^{-3} um. The secondary electrons are generated where the focused accelerated electrons bombard the sample. Detecting the secondary electrons can determine the location of bombardment. Simultaneously, the focusing electron beam scans the surface of sample, with the aid of scanning coil, to map the feature of measured region.

Fig. 3.4. Schematic diagram of SEM

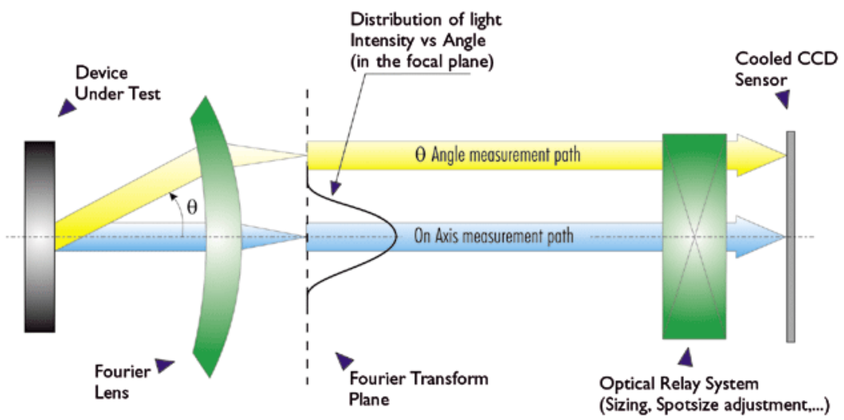
In our work, a HITACHI S-4000 SEM was used to measure the features of our fabricated microstructure elements. The aperture size of reflective regions, diameter of micro-lens and height of micro-lens can be accurately measured.

3.3.3. Measurement system for Light Efficiency

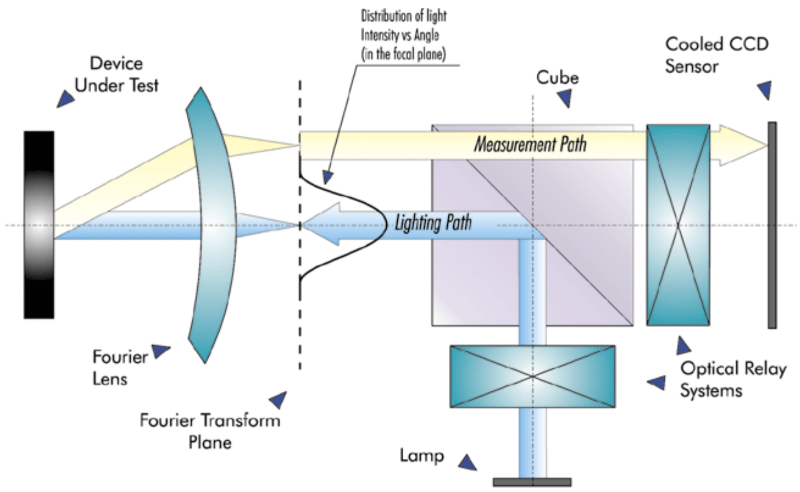
After the preliminary fabrication of the micro-lens array structure, a measurement instrument was used to measure the light utilization efficiency.

3.3.3.1. ELDIM EZContrast 160R

The ELDIM EZContrast 160R which has diffuse and collimated illumination types with a plane detector consisting of various directional CCD sensors to detect the transmissive and reflective light can be utilized to measure the luminance, contrast, color of the transflective LCDs at one time. The schematic diagram of the display measurements setup in both transmissive and reflective mode of ELDIM EZContrast 160R are as shown in Figs. 3.5 (a) and (b).



(a)



(b)

Fig. 3.5. Display measurement setup of ELDIM EZContrast 160R
(a) transmissive and (b) reflective mode

The options for testing under illumination are based on the combination of Fourier Optics and cooled CCD sensor head. A suitable light source on the side of the equipment provides the illumination. As shown in Fig. 3.5 (a), the measurement is used for transmissive mode LCDs, where the first lens provides a Fourier transform image of the display surface. Every light beam emitted from the test area with a q incident angle will be focused on the focal plane at the same azimuth and at a position x=F(q). The angular characteristics of the sample are thus measured simply and quickly, without any mechanical movement. The Optical Relay System scales the Fourier transform image of the measured surface on the CCD sensor. The captured image is used in order to obtain, after a suitable computation, the viewing angle map of the measured display which is dependent to the display luminance with angle. On the other hand, as shown in Fig. 3.5 (b), an optical relay system combined with a beam-splitter cube enables to conjugate the light source plane with the Fourier plane. The light source distribution function allows controlling the angular distribution of illumination. Beside, the light through the system can extend up to the viewing cone of the Fourier lens (+/- 80° or +/- 60°). In measurement, a directional backlight, which will be described in chapter 4, was utilized as a light source to analyze the light utilization efficiency and light efficiency enhancement of the fabricated micro-lens array structure.