Design and Fabrication of Angular Filter Film for CGH Display

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ABSTRACT

This topic analyzed the production and design of angular filter film. This element was designed to filter out the noise of the dynamic computer-generated holographic display. It could miniaturize the whole system to replace the original system which was larger.

1 Introduction

In recent years, the development of Computer-generated holography (CGH) had allowed wavefront to be directly calculated by the computer and produced on the spatial light modulator (SLM) to reconstruct dynamic three-dimensional images [1]. The CGH image could be reconstructed with the reference beam incident on the SLM [2-3]. Because the SLM had a grid structure, in addition to the noise directly reflected by the reference beam, noise would also be diffracted in the vertical and horizontal directions. These were all called DC noise. It could be seen that DC noise was related to the period of SLM grid structure, which was related to its pixel size, as shown in Fig. 1. In order to filter out DC noise, it needed to be filtered by a spatial filter based on the 4-f system. However, the system architecture was too large to achieve the miniaturization of the optical system. In order to reduce the size and increase the convenience, this topic would design a spatial filter optical element that could replace this system.

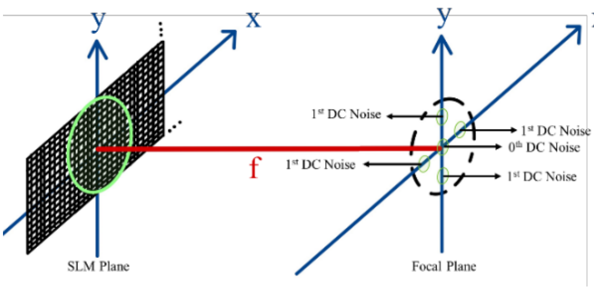


Fig. 1 SLM diffraction diagram

Based on the principle of Fabry-Pérot interferometer [4], the FP filter was designed in this paper. The two sides of the resonant cavity were coated with high-reflectivity materials and fabricated on the glass substrate to make it have strong penetration at a specific angle and filter out the angle where the noise located. The traditional CGH display based on 4-f spatial filter system was shown in Fig. 2. Then the completed structure could be used to perform the image without DC noise projected by the CGH. The angular filter film which had been made by the same principle had already verified that it could help figure out the bulky optical system, and we tended to do the study about the different wavelengths used in this topic.

This topic would first analyze the factors of its process instability, and try to improve it in subsequent experiments, and then designed an angular filter film that met the requirements of the SLM which had narrow bandwidth.

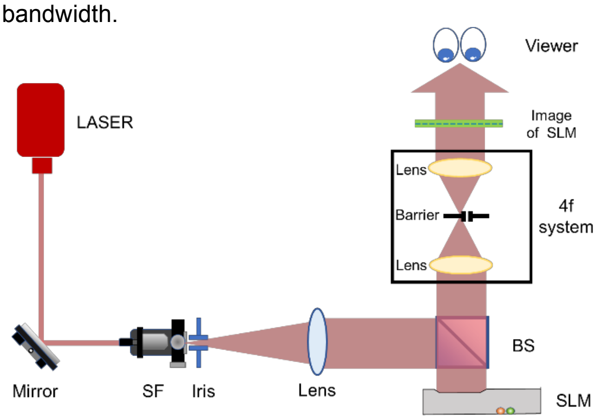


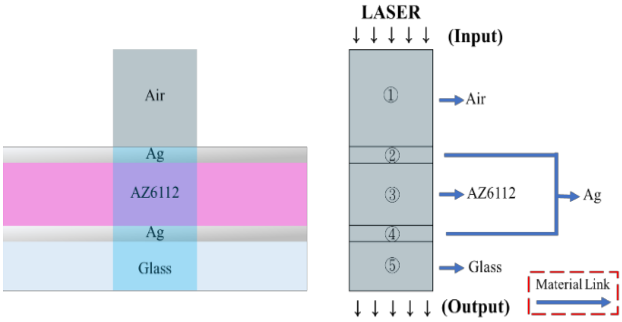
Fig. 2 The diagram of 4f system filtering out the DC noise

2 Experiment

In order for the angular filter film to effectively filter out the DC noise generated by SLM combined with CGH, its bandwidth must also consider the field of view (FOV) of the SLM used. The FOV is related to the pixel. The SLM pixel size used in this study is 6.4 μm. In order to maintain the contrast ratio, one-tenth of the peak value is used as the criterion for judging the bandwidth. The angle θ of the diffraction noise can be calculated using the LASER wavelength λ and the Pixel Size P of the SLM in this study as Formula 1:

$$\theta=\sin^{-1}(\lambda/P), \quad (1)$$

This research utilized simulation method, which not only reduced the repeated testing process, but also improved the process efficiency. Thereby, all the parameters to be used could be initially determined. This topic used the COMSOL to simulate. It is a simulation software that uses the Finite Element Method (FEM) to cut the complex objects into continuous small elements, and calculate the propagation of electromagnetic waves through boundary conditions. Thus, there is no need to input any formula. Input all the parameters in the experiment and set their characteristics, and then this topic will take an unicell to draw the sample structure to simplify the calculation and build the material link to connect the substances corresponding to each block, as shown in Fig. 3. Finally, set a certain independent variable and the desired dependent variable, then it can calculate directly and obtain function graphs without any formula.



(a) (b)

Fig. 3 Sample simulated in COMSOL, (a) Sample structure diagram, (b) Unicell structure diagram and material link

This topic intended to design an angular filter with 632.8 nm LASER. In order to meet the bandwidth design, it would be brought into Formula 1, and the goal was 5.67°. Input the following parameters into COMSOL: LASER wavelength λ, frequency of light c/λ, thickness of AZ6112, thickness of silver layer, refractive index of glass substrate, refractive index of air, and refractive index of silver. After that, the sample design would be simulated by the FEM.

Changing various parameters in the simulation could help observe the difference in the results, and further discussed whether the difference was directly related to the goal of sample bandwidth, so as to modify the parameters and repeat the simulation to meet the requirements of the bandwidth goal. This study found that the thickness of the silver layer would seriously affect the sample bandwidth, so the error of the silver layer thickness on the glass substrate was measured by Atomic Force Microscopy (AFM). AFM uses scanning probe microscopy technology, which can detect the interaction between the probe and the sample surface. Half of the un-coated silver layer was left on the substrate, and the actual thickness could be obtained by measuring the vertical height difference between it and the boundary of the silver layer. The bandwidth could be re-simulated and then the error of the bandwidth could be calculated.

This topic used a round glass with its diameter of 4 inches as the substrate. The high reflectivity material on both sides of the resonant cavity used silver. The photoresist model used for the resonant cavity was AZ6112. The sample manufacturing process first coated the first layer of silver onto the glass substrate, which used vacuum evaporation technology. After the vacuum evaporator reached the vacuum condition, the material used for evaporation was heated to vaporize in a very high temperature, and then attached to the substrate to achieve the coating. Then AZ6112 was coated on the first layer of silver, which used spin coating technology. It was spin-coated at high speed to achieve a uniform thickness on the substrate, and then a thin film would be applied. Finally, vacuum evaporation was performed in the same way to coat the second layer of silver onto the resonant cavity. Then the complete sample could be obtained, as shown in Fig. 4.

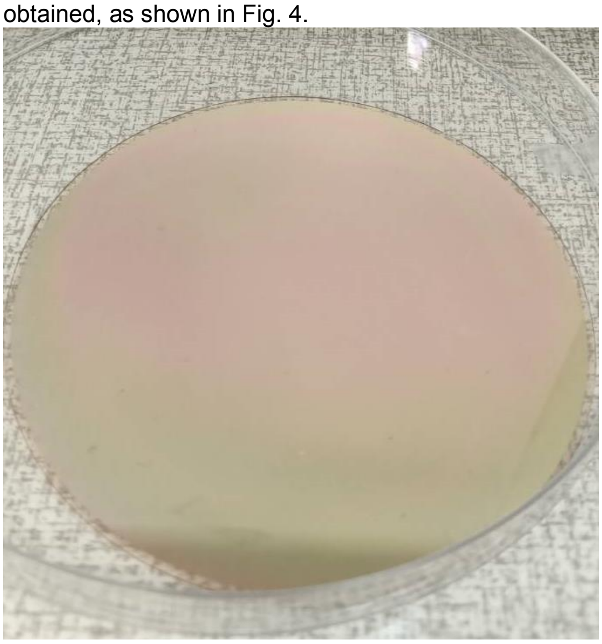


Fig. 4 The complete sample

3 Results

This study utilized COMSOL to simulate the design of angular filter film, and then it tried to find the factor which affect the sample bandwidth greatly.

3.1 COMSOL Simulation

This experiment used COMSOL to change different parameters in order to achieve the goal of the sample bandwidth. Changing the wavelength in the simulation showed that it would have an effect on the sample bandwidth, as shown in Fig. 5.

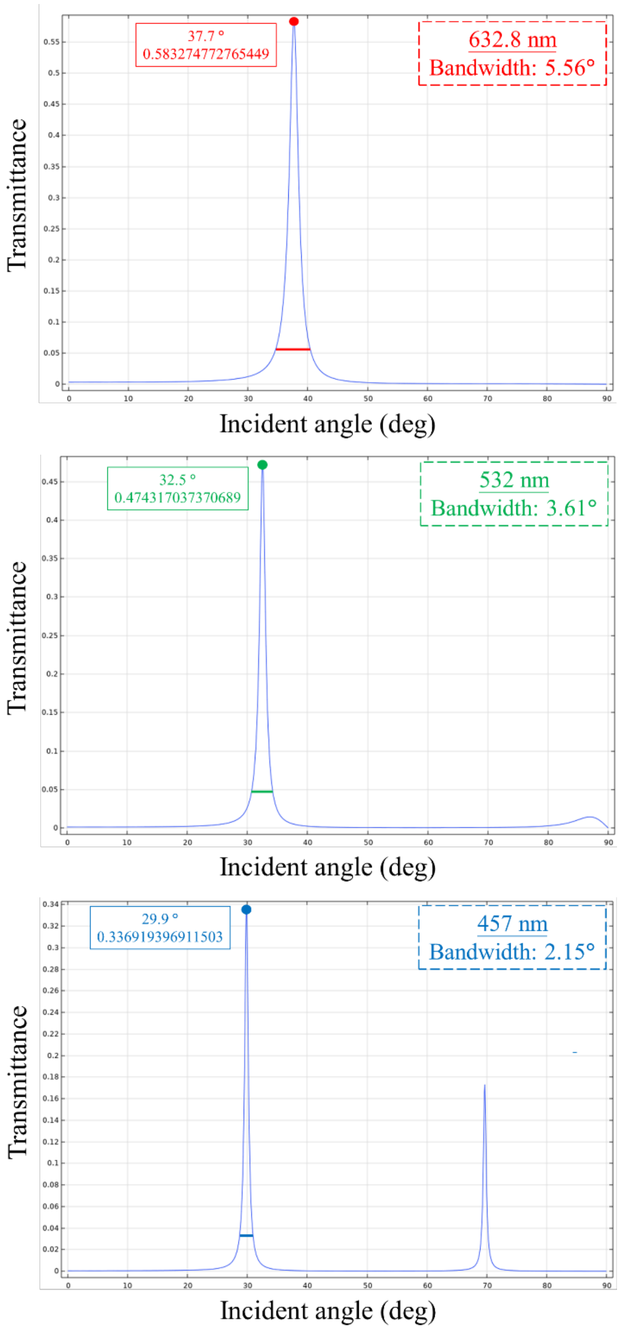


Fig. 5 The Different Bandwidths could be Observed by Changing the Wavelength

Further analysis could find that the wavelength had a functional relationship with the reflectivity of the silver layer, as shown in Fig.6. Therefore, it could be inferred that the thickness of the silver layer had a direct effect on the bandwidth of the sample.

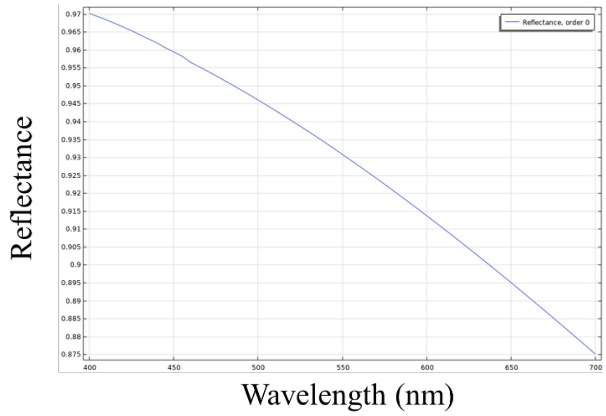


Fig. 6 The Function Graph of the Reflectance with Different Wavelengths

3.2 The Sample Thickness Measurement

According to the former simulation results, the actual thickness of the silver layer on the glass substrate was measured by AFM, and the parameters were updated with the actual thickness, then the bandwidth was simulated again to calculate how much the actual silver layer thickness error would affect the bandwidth error. After measurement, it could be seen that the thickness error of the silver layer was about 11.3 nm, and the error bandwidth is 4.43° after simulation and calculation. It could be observed that the actual vacuum evaporated thickness of the silver layer did have a great influence on the bandwidth of the sample.

3.3 The Experimental Setup and the Results

In this topic, the Ag thickness was set to 35.8 nm based on the simulation, and the AZ6112 was spin-coated at 4000 rpm for 40 seconds. The structure for observing and measuring was shown in Fig.7, the penetration rate of the 632.8 nm LASER at different angles was measured. The bandwidth was measured several times at different point on the sample, and the average was 10.77 °. The value is higher than the simulation because of the error of the Ag deposition.

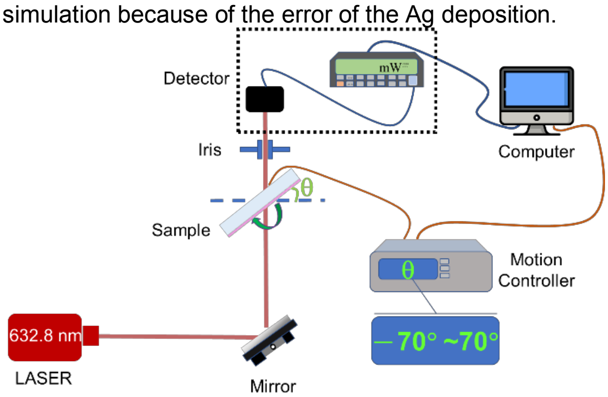


Fig. 7 The Experimental Setup for Measuring the Sample

3.4 Filter Out the DC Noise

The sample was arranged in the practical optical system as shown in Fig.8, and the results were shown in Fig.9. Since the pass bandwidth of the prototype filter is higher than the target value, an asymmetry 4-f system without spatial filter function was employed to generate a virtual SLM with smaller pixel pitch. The pixel pitch and maximum diffraction angle of the virtual SLM is 3.2 μm and 11.35°. The hologram was calculated based on Iteration Fourier transform algorithm method. The phase distribution multiples an additional lens phase to decide the longitudinal position and a prism phase to separate the signal and DC noise. Here, we employed a 4-f system to simulate an SLM with a smaller pixel pitch. If there is an SLM that meets this specification on the market, it can be applied to the sample.

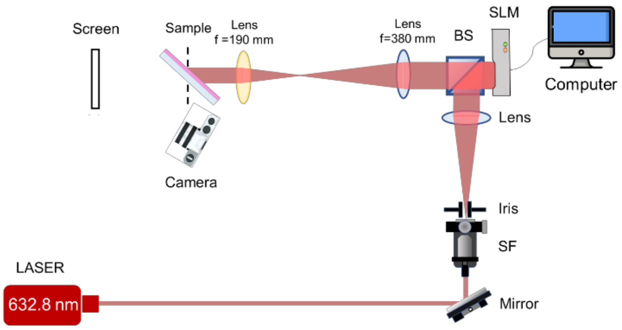
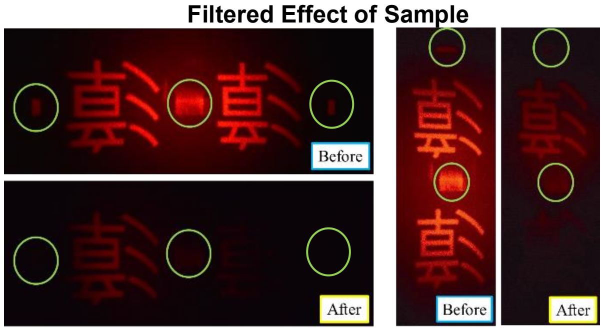


Fig. 8 The CGH Setup with SLM for Observing the Filtered Effect of Sample



(a) (b)

Fig. 9 The Filtered Effect of Sample, (a) Rotate the Sample Horizontally (Decrease the Contrast Ratio by 25%), (b) Rotate the Sample Vertically (Decrease the Contrast Ratio by 50%)

4 Discussion

It could be found from COMSOL simulation that the reflectivity and thickness of the silver layer would have a direct impact on the bandwidth of the final product. Its thickness error was 11.3 nm, which affected the bandwidth error about 4.43°. If the thickness of the silver layer cannot be accurately controlled, it will lead to inconsistent results when the samples are made with the same parameters.

According to the Fig.5, the bandwidth from the simulation could be found changed while the wavelength was set into different values. As 632.8 nm LASER met the bandwidth requirement for about 5.67°, setting the same parameters except for wavelength could found that 532 nm LASER and 457 nm LASER couldn't meet their bandwidth requirements simultaneously for about 4.77° and 4.09°, respectively. And it is obvious that there is a strong penetration while using 632.8 nm LASER, so it suits for applying AZ6112 as the resonant cavity. Owing to the result of functional relationship we observed from Fig.6, if it would like to achieve a full-color design for angular filter film, it would need to change the material of the resonant cavity, like PMMA or the transparent material for specific wavelength. And we could also find that the different bandwidths generated by different wavelengths from the Fig.6, the silver reflectance would affect the silver layer thickness which influenced the sample bandwidth. Therefore, the modification for the thickness of silver layer must be necessary for making a full-color design, too.

Based on the simulation, we coated the silver layer at 35.8 nm, AZ6112 at 4000 rpm for 40 seconds and 632.8 nm LASER was use. The average bandwidth was 10.77 °, it could be seen that there was the error about 5° in the sample bandwidth result and COMSOL simulation. It might because the setting of the parameters in the COMSOL simulation wasn't all accurate with the actual material, and the thickness of this optical element on each layer of materials needed to be precisely controlled to complete the production of an angular filter film.

5 Conclusions

In this study, the sample successfully filtered out the DC noise. It was observed that the silver layer on the angular filter film had a great influence with the bandwidth of sample. If the instability of the fabrication can be overcome, then the angular filter film can be a miniaturized element which is utilized to filter out DC noise in the whole optical system.

References

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