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The simulation and fabrication of $Ag/SiO_2/Ag$ thin films color filter

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Abstract

This research is based on concepts of the Fabry-Perot principle to design a non-absorption inorganic thin film color filter to increase the saturation of color filters. To make red (R), green (G), and blue (B) color filters, the SiO_2 should possess three different thicknesses sandwiched by the silver (Ag) reflective layer. Through thin film optical software simulation, the transmittance and color saturation of R, G, and B color filters were analyzed by changing different thin film materials and thickness thereof. In addition, the actual R, G, and B color filter samples were made by pulse direct current magnetron sputtering and radio frequency magnetron sputtering, respectively. The simulated results show that Ag film has a better transmittance and color saturation than aluminum film. The effect of the magnitude of refractive index, n of SiO_2 on the transmittance of R, G, and B color filters is not significant, but, it will result in the red color filter sample center peak wavelength shifts at about 20 nm. The better thicknesses of $Ag/SiO_2/Ag$ for the color saturation as well as transmittance in R, G, and B color filters are 30nm/170nm/30nm, 30nm/131nm/30nm, 30nm/100nm/30nm, respectively. Compared with the organic photo resistance coating color filter, this inorganic thin film color filter has better color saturation and optical transmittance than the organic photo resistance coating color filter. When the color filter deviates 15 degrees from the straight angle, the center peak wavelength of R, G, and B will shift left 15~30 nm, and its transmittance will also decrease 1~5%. This is because that with a larger viewing angle, the longer the path for the light has to traverse through the color filter, which would result with the change in the color wavelength as well as effect to transmittance.

PACS: Type pacs here, separated by semicolons ;

Key Word： Fabry-Perot, thin film color filter, magnetron sputtering

1. Introduction

The mainstream flat panel display nowadays is the thin film transistor liquid crystal display (TFT-LCD). And the primary research is oriented at how to enhance the brightness and color saturation, as well as cutting down the power consumption in addition to adopting materials of non environmental pollutant as the core elements [1-3]. Nonetheless, amid all of these, the color filter is one of the pivotal elements for TFT-LCD. Hence, it becomes the most important subject for color filter when this technology faces issues of effective light utilization and the enhancement on color saturation. Up until now, traditional color filter manufacturing technology still relies upon using the layer-by-layer organic-based photoresist coating [4-5], ink-jet printing [6], and laser pattern transfer [7], etc, to manufacture the R, G, and B colors. However, the traditional photoresist manufacturing approach would

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absorb two thirds of the visible light with one third of the remaining light transmittance. In addition, the color saturation is also not ideal resulting in wavelength expansion for the transmittance from R, G, and B colors. The light wavelength range of the transmitted R, G, and B light is too wide and full width at half maximum (FWHM) is up to 150nm [6] ; therefore, the color saturation is not perfect.

This research is based on concepts of the Fabry-Perot principle [8-12] to design a non-absorption inorganic thin film color filter to increase the saturation of color filters. It is utilized with dual brightness enhancement film (DBEF) on the backlight source to reuse the reflection of the untransmitted spectrum. Theoretically, under the same conditions of backlight source, TFT-LCD can decrease the light absorption created when light is transmitted to improve light efficiency. In addition, the material and deposition process of Ag and SiO_2 thin films can be compatible with the state-of-the-art TFT-LCD process. To make R, G, and B color filters, first, the Ag and SiO_2 thin films were deposited on glass substrates; next, three runs of lithography and etching processes were employed to result in three different thicknesses of SiO_2, finally, the Ag thin film was covered on the SiO_2 to become a sandwiched structure. The structure of non-absorption inorganic thin film color filter and its optical mechanism are shown in Fig. 1. When light passes through the color filter, it would reflect the light with other wavelengths prior to being reused. Up until it reaches a specific wavelength of the light beam, it would then transmit through the medium.

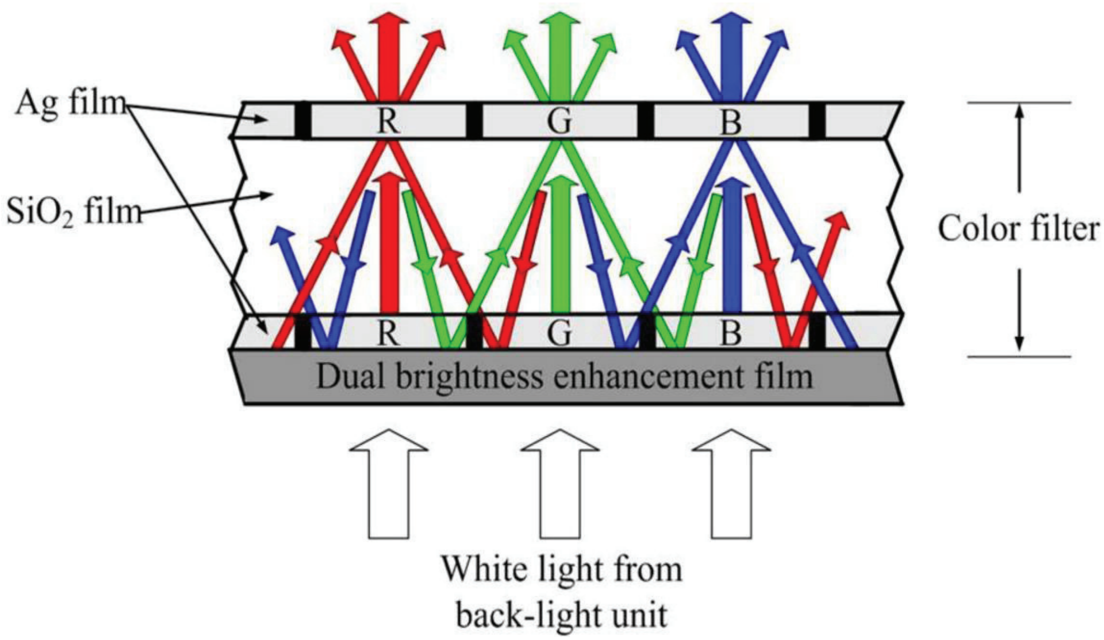


Fig. 1 Schematic diagram for color filter based on Fabry-Perot principle.

2. Simulation

The design and fabrication of non-absorption inorganic thin film color filter based on concepts of the Fabry-Perot principle by the simulation and pulsed direct current/ radio frequency magnetron sputters have been investigated. In addition, the effect of viewing angle on color spectrum and transmittance of R, G, and B color samples was studied. To find the optimum optical properties of a color filter, simulation software, TFCalc3.5 (Software Spectra, Inc.) was employed. The simulation conditions included: (1) the reflective metal layer materials (silver and aluminum) and thickness thereof; (2) the SiO_2 thickness so as to understand the color saturation for R, G, and B colors as well as the respective transmittance. In this study, the monochromatic light with respective wavelengths of λ_R=700 nm for red, λ_G=546.1nm for green, λ_B=435.8 nm for blue as the standard colors spectrum [11]. During simulation, the substrate was glass had air underneath as well as the light source detector. The upper layer was deposited thin film with a simulated light source. In addition, suppose the light source emits into the medium orthogonally. The magnitude of reflective index (n) in the SiO_2, Ag and Al for simulating was 1.455, 0.055

and 0.82. The magnitude of extinction coefficient(k) in the SiO_2, Ag and Al for simulating was 0, 3.32, and 5.99. In addition, the study of effect of viewing angle on color spectrum and transmittance, the magnitude of n from 1.442 to 1.461 is assigned.

3. Experiment

To verify the results of simulation, an Ag and SiO_2 films were prepared on Corning 1737F glass substrate by pulse direct current magnetron sputtering and radio frequency magnetron sputtering, respectively. The film of Ag and SiO_2 were made with the optimum sputtering parameters. The pulse direct current magnetron sputtering process parameters were as follows: power 50 W, work pressure 0.39 Pa, pulse frequency 10 kHz, and without heating during the deposition process. The radio frequency magnetron sputtering process parameters were as follows: power 200 W, work pressure 0.67 Pa, and without heating during the deposition process. After deposition, a spectroscopic ellipsometer (Nano-View MF-1000 Spectroscopic ellipsometer) in a wavelength range from 400 to 750 nm was employed for reconfirming the source data of n and k values of Ag and SiO_2 from TFCalc software. Finally, a three-layer sandwiched Ag/SiO_2/Ag thin film color filter sample was prepared and the transmittance spectrum of sample was analyzed with a SHIMADZU UV-1700 UV/Vis spectrophotometer in a wavelength range from 400 to 750 nm. In addition, the color shift and transmittance induced by viewing angle were measured with a SHIMADZU UV-1700 UV/Vis spectrophotometer in an angle range from 0 to 15 degrees.

4. Simulation results

4.1 The material and thickness for metal thin film

The most common metallic materials with a high reflective layer within full-range wavelength visible light spectrum are Al and Ag. Hence, in the study, the optical property of Al and Ag films was investigated. Fig. 2 shows the transmittance spectrum of R, G, and B with Ag film of 30 nm thickness, Al film of 15 nm thickness, and SiO_2 film from 100 to 170 nm thicknesses. The simulation results show that the Ag film has a better transmittance spectrum than Al film in various SiO_2 film thicknesses. Because Ag has better reflectivity and optical transmittance than Al [12], therefore we selected Ag film as reflective layer material of three-layer sandwiched color filter. Fig. 3 is the effect of Ag thickness (up and down layers with same thickness) on respective transmittance and peak of wavelength from R, G, and B three color filters under various SiO_2 film thicknesses. The simulation results show that the Ag's thickness reaches 25 nm, it has higher transmittance with R, G, and B color filters. Nevertheless, it has wider FWHM and may result in worse color saturation. Hence, Ag film is chosen with 30 nm of thickness adopted as preferred parameters. From the above findings (using Ag as the reflective layer material and both the up and down layers having identical 30 nm of thickness) as the fundamental structure, we can adjust and change both up and down layers of Ag into different thickness to explore the effects on the color filter's transmittance. And the findings are depicted in Fig. 4. From the findings, it is evident when adjusting and changing both the upper and lower layers of Ag, the thickness of 30nm would exhibit better results, therefore, the R, G, and B color filters with respective wavelengths of 650 nm, 545 nm, and 463 nm, the corresponding transmittance were 61%, 69%, and 72%.

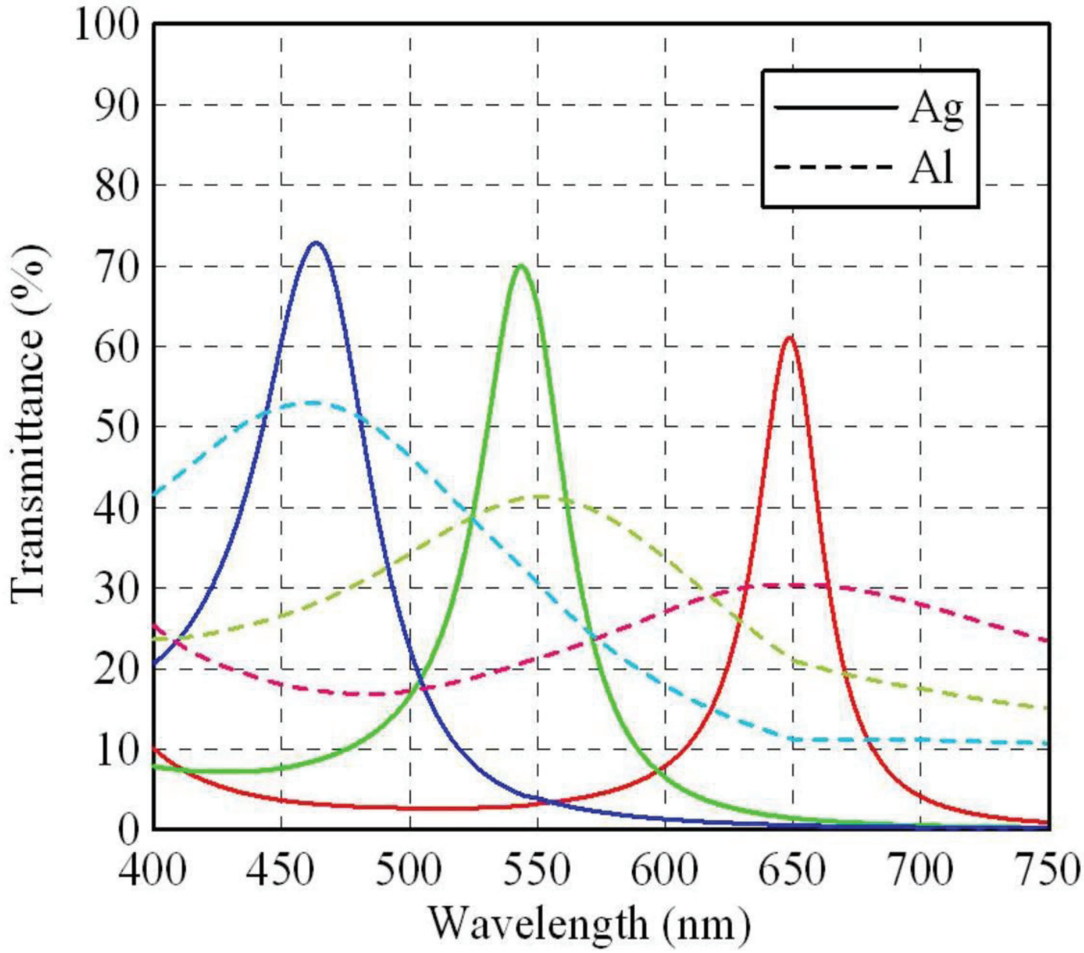


Fig. 2 The transmittance spectrum of R, G, and B with Ag film of 30 nm thickness, Al film of 15 nm thickness, and SiO_2 film from 100 to 170 nm thicknesses.

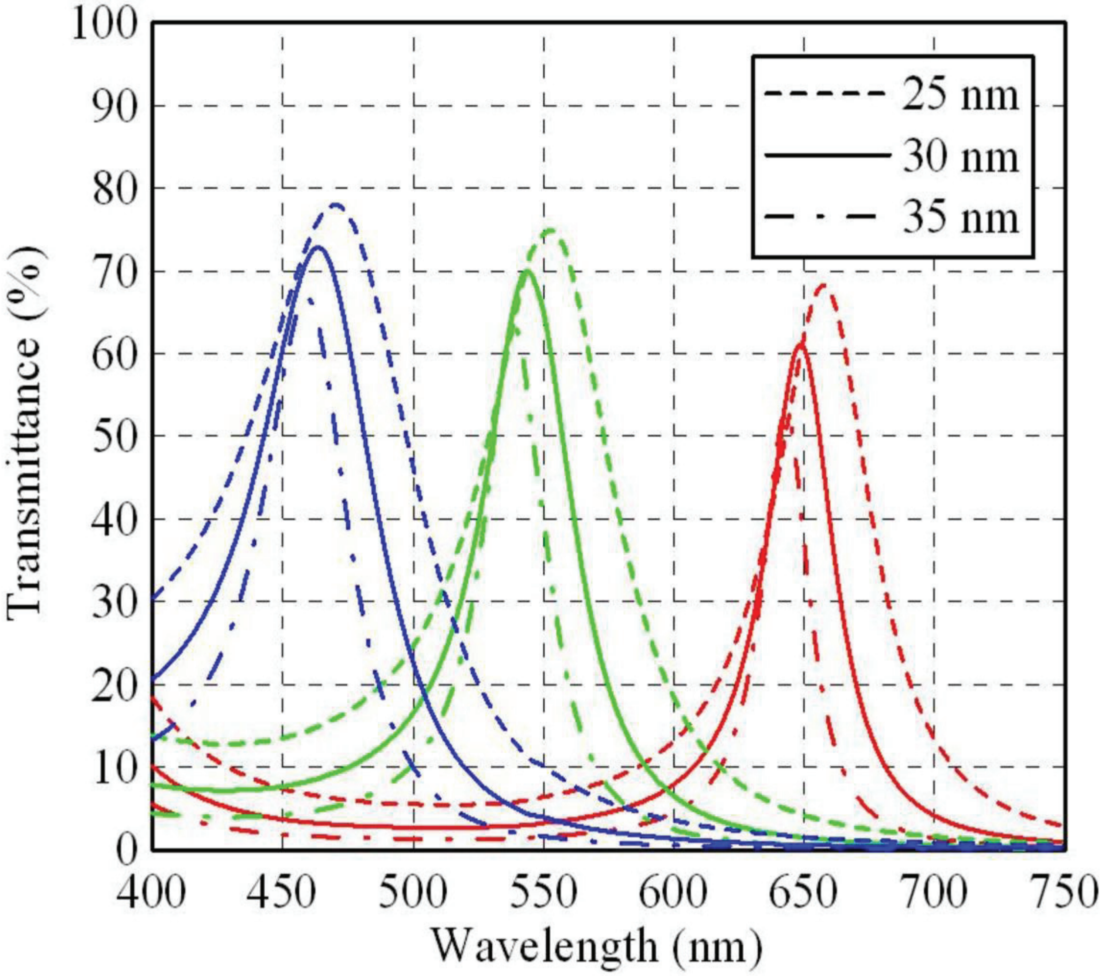


Fig. 3 The effect of Ag thickness (up and down layers with same thickness) on respective transmittance and peak of wavelength from R, G, and B three color filters under various SiO_2 film thicknesses.

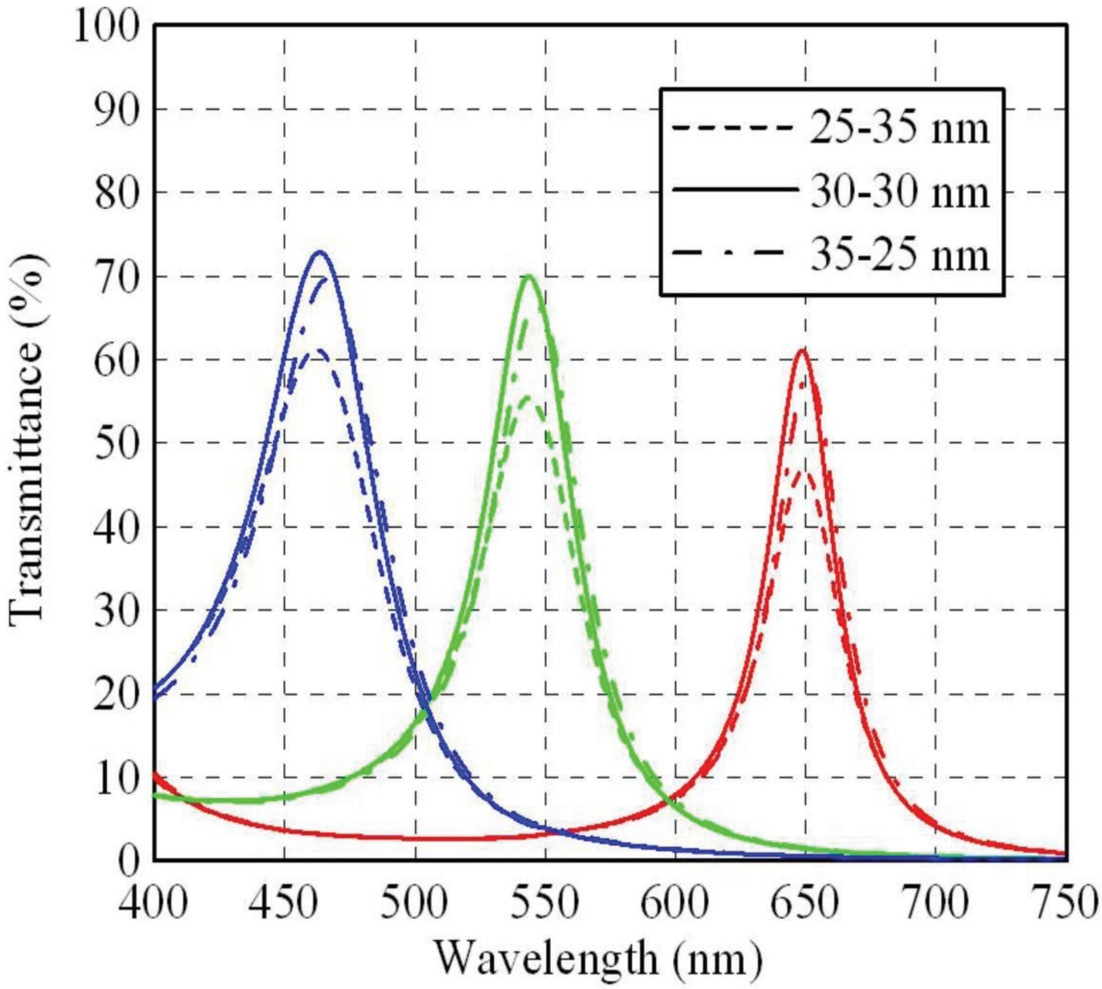


Fig. 4 The effect of Ag thickness (up and down layers without same thickness) on respective transmittance and peak of wavelength from R, G, and B three color filters under various SiO_2 film thicknesses

4.2 The n value and thickness for SiO_2

In this research, the dielectric material chosen for the medium layer is SiO_2. This is primarily because that SiO_2 has excellent optical properties (n, k values and high energy gap), lower cost, and is compatible with the state-of-the-art TFT-LCD process. In Fig. 5, it simulates the effects on the transmittance as well as the peak of wavelength of R, G, and B three color filters from various n values of SiO_2. From the Figure, it is evident that the effects of n values of SiO_2 on transmittance are minimal and it has only about 0.1~0.5% variance. Nonetheless, the peak of red wavelength color has about a 20 nm shift. Fig. 6 depicts the effects of SiO_2 thicknesses on transmittance and peak of wavelength in respective R, G, and B color filter by using Ag reflective layer with 30 nm thickness. The simulation results show that when SiO_2 thickness is 170 nm with wavelength of 650nm, its transmittance is 61%, whereas, when its thickness reaches up to 395 nm, we found interference light in purple tinted color resulting with the color filter unable to exhibit a singularly red color. And this is more evident when the thickness reaches 620 nm. Hence, if the red color filter is to be designed, its SiO_2 film thickness of 170 nm would be a much better fit. When SiO_2 thickness is set at one of the 131nm, 318nm, and 505nm, it can form a green colored filter; whereas, if it is at 505nm of thickness, since the interference light's period cycle is too close it would result with light transmittance at a wavelength of 420nm. This would result with the inability of exhibiting a singular green colored light for the color filter. Nevertheless, when SiO_2 thickness is at 318 nm, although there is no cycled interference wave, when under comparison, the color filters with thickness thinner than 131nm would have better transmittance performance. Therefore, if a green color filter is to be designed, we configure the SiO_2 film thickness at 131 nm. When the thickness of SiO_2 is either 100 or 260, it can form into a blue colored color filter. And for the next SiO_2 thickness of 420nm, its blue color filtered light would exhibit a wavelength which would have the occurrence of cycling interference wavelength. Although SiO_2 thickness is at 260nm, it has no cyclical wave interference. In comparison, the color filter with thickness of 100 nm has better transmittance. Hence, if a blue colored color filter is to be designed, we selected SiO_2 with thickness of 100nm to manufacture the color filter.

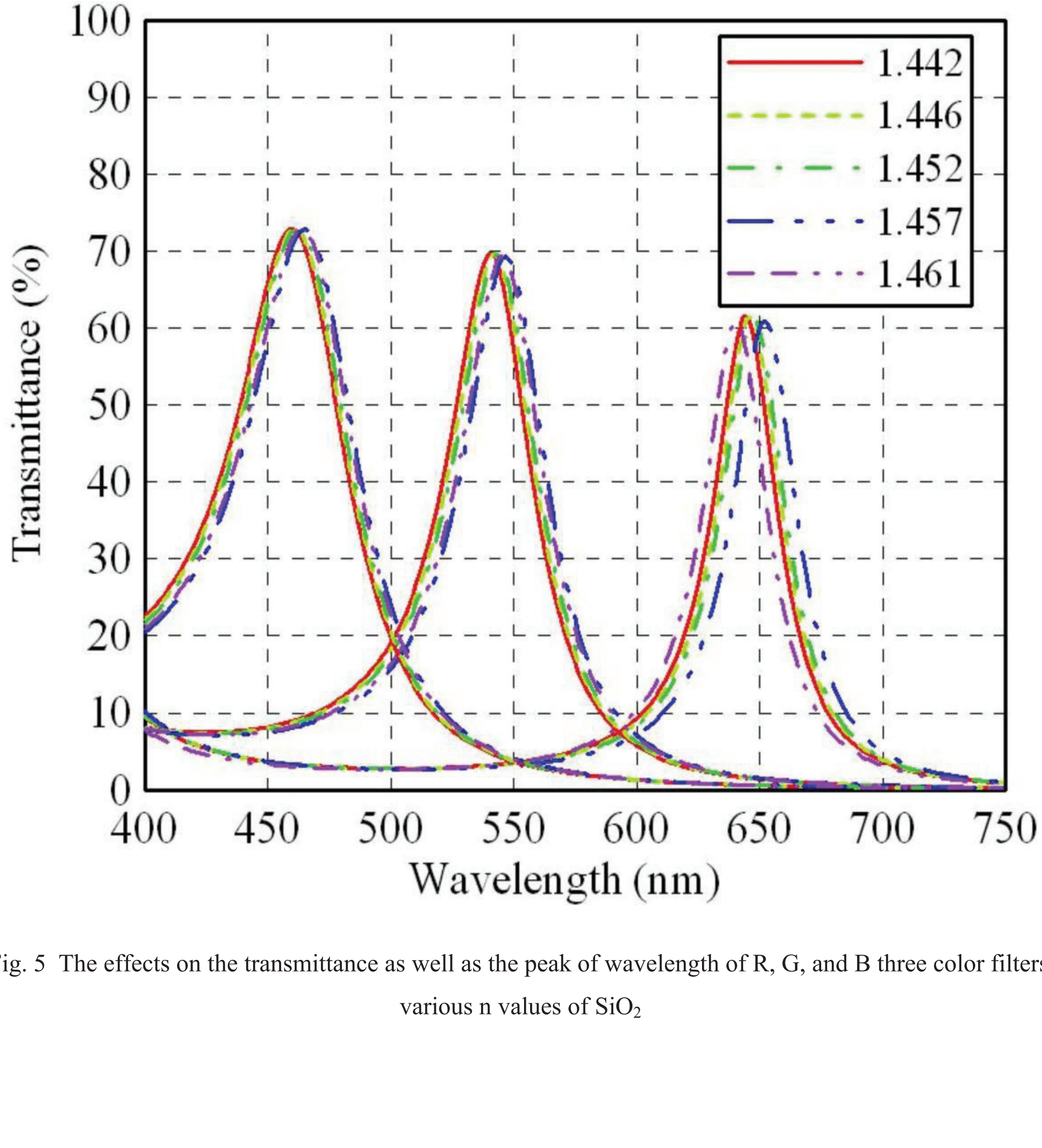
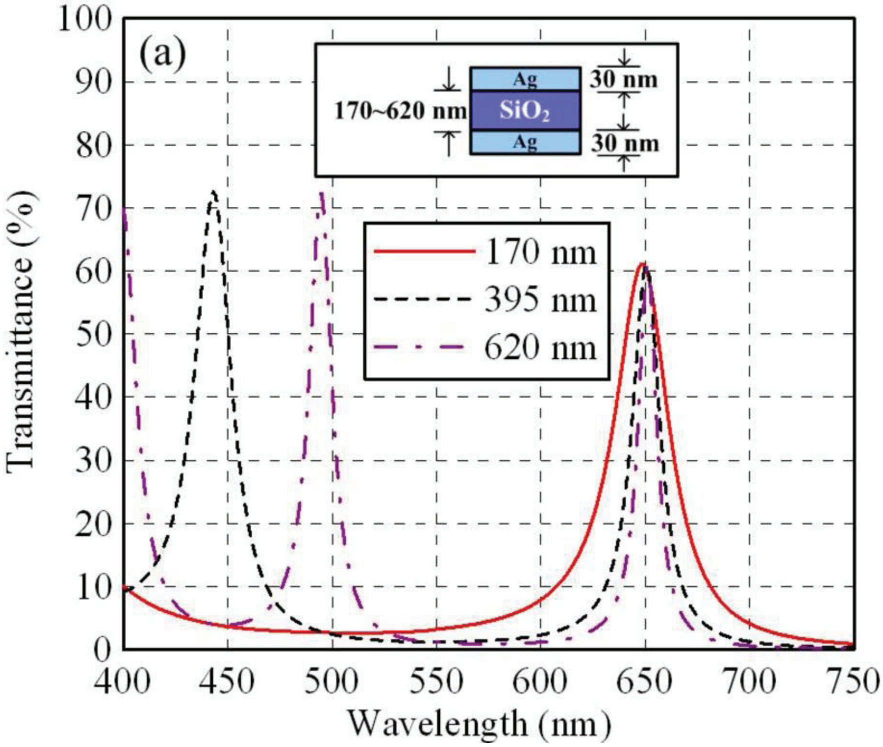
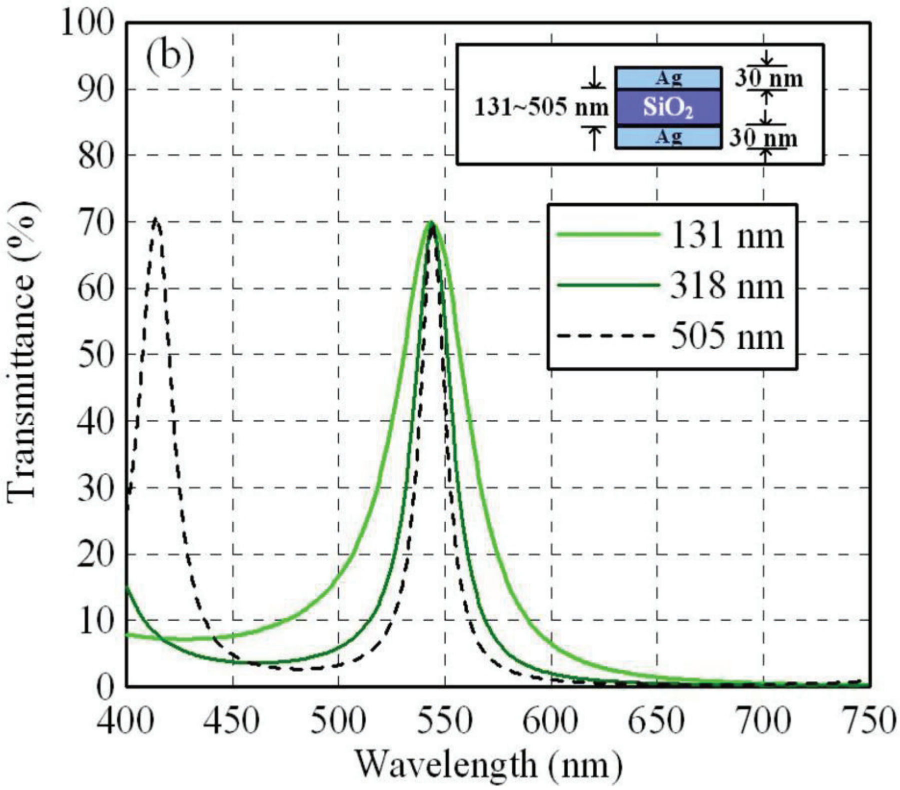


Fig. 5 The effects on the transmittance as well as the peak of wavelength of R, G, and B three color filters from various n values of SiO_2


(a)
Ag
SiO2
Ag
170~620 nm
30 nm
30 nm
170 nm
395 nm
620 nm
Transmittance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
750


(b)
Ag
SiO2
Ag
131~505 nm
30 nm
30 nm
131 nm
318 nm
505 nm
Transmittance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
750

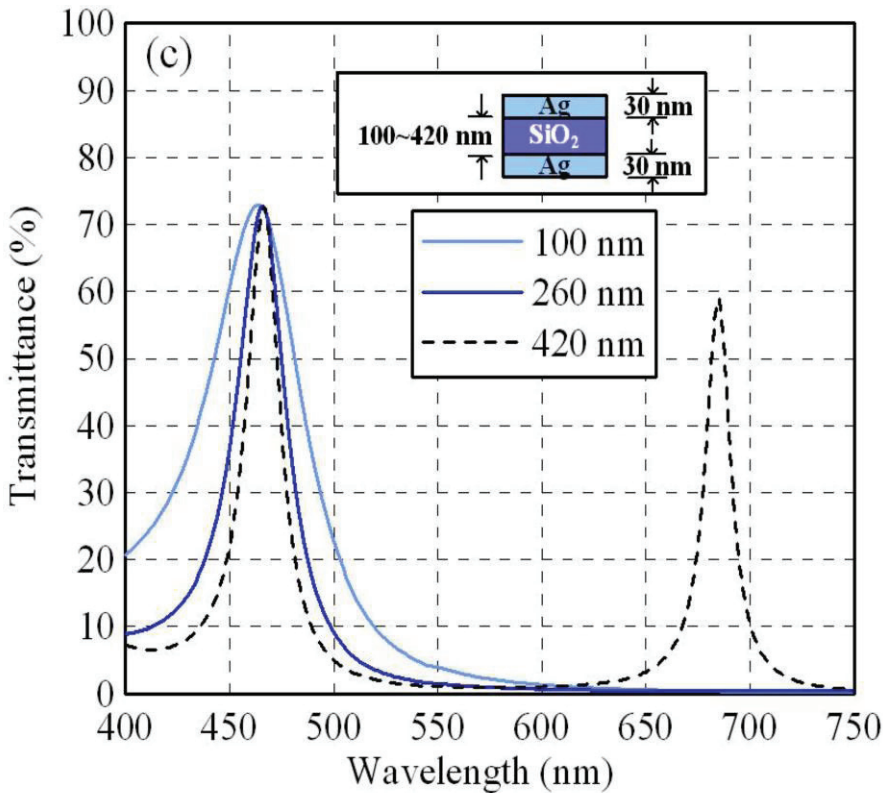


Fig. 6 The effects of SiO_2 thicknesses on transmittance and peak of wavelength in respective (a)R, (b)G, and (c)B color filter by using Ag reflective layer with thickness of 30 nm

5. Samples made and viewing angle measurement

5.1 Color filter samples made

To prove and compare the design result of TFCal software, we made the R, G, and B color filter examples with the optimum sputtering parameters. Fig. 7 shows the true sample made for R, G, and B three color filters. The visible light transmittance spectrum of true sample made for R, G, and B measured are shown in Fig. 8, and it was compared via simulation through software simulation packages to acquire the thickness. From the Figure, the errors of transmittance between experiment and simulation are separately listed as 2.3%, 2.4%, and 6.6%, respectively for the color of R, G, and B. The errors for FWHM in red, green, and blue colors are separately as 4 nm, 20 nm, and 5nm. The cause for decrease in transmittance could be resulted from film deposited thickness error, the surface coarseness for the film as well as the Ag oxidation resulting with changes in n and k values.

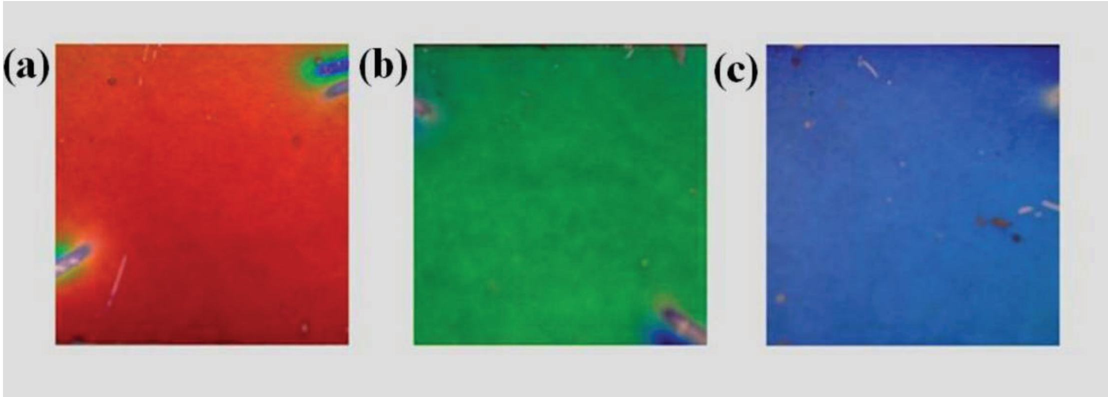


Fig. 7 Manufacture (a)R, (b)G, and (c)B three color filters in the size of 2cmx2cm with the optimum parameters

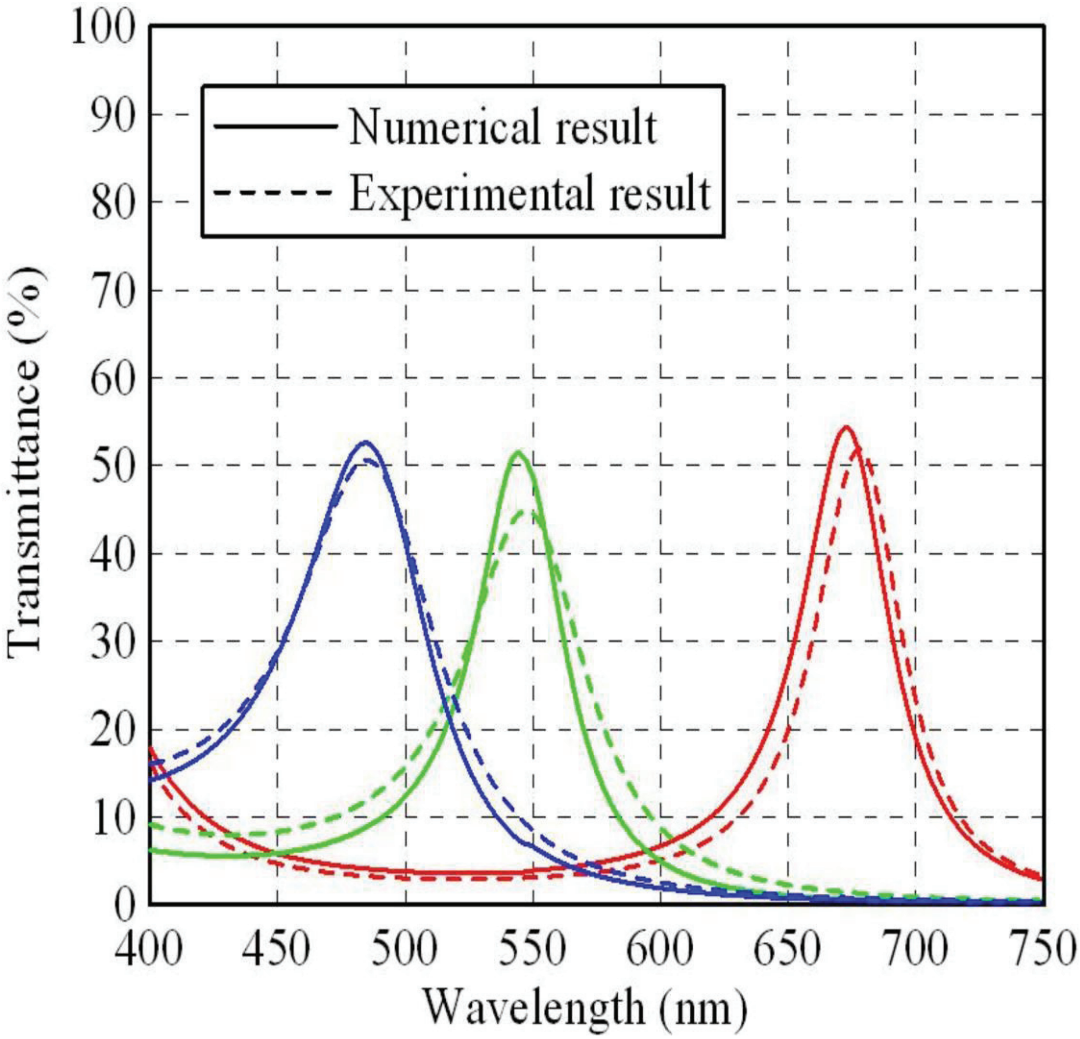


Fig. 8 Comparison of the transmittance spectrum for three color filters of R, G, and B by using simulation as well as using the optimized parameter to manufacture these color filters.

5.2 Viewing angle measurement

In Fig. 9, it depicts the measurement findings for color filter with 5~15 degrees deviation from a straight angle. The finding indicates that the greater the tilted viewing angle, the more the left shift for wavelength in the spectrum. This entails larger changes in coloring. The cause could be that since the tilting viewing angle increases, it would render the path traversed by light through the color filter increase as well. And this would effect the changes in color wavelength as well as transmittance. When the color filter deviates 15 degrees from the straight angle, its color undergoes changes somewhat. When light wavelengths with the maximum transmittance light for R, G, and B deviate towards the left in the approximate amounts of 20nm, 30nm, and 15nm respectively, its respective transmittance would decrease by approximately 5%, 2%, and 1%.

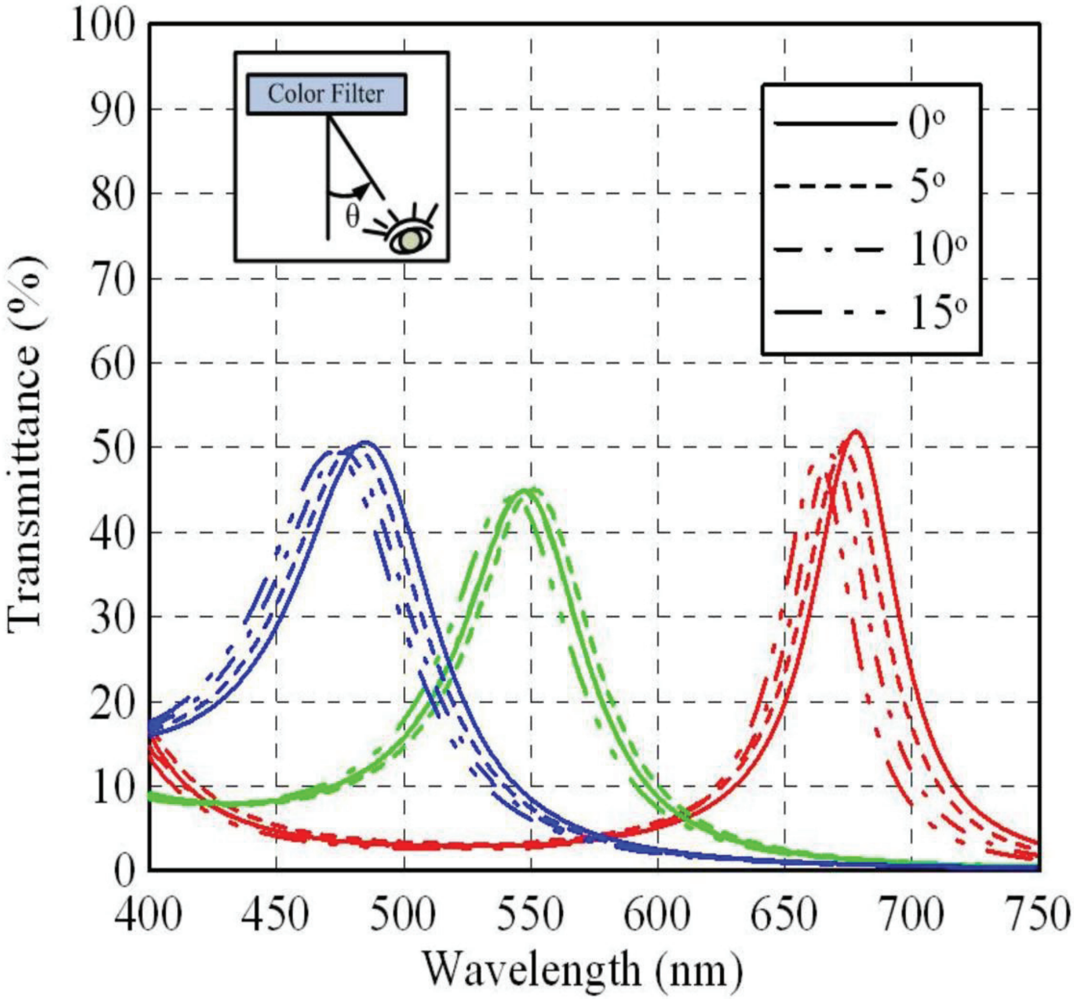


Fig. 9 Effects to R, G, and B filter wavelength as well as its transmittance from different viewing angles.

6. Conclusion

By applying TFCalc to configure material design for the most optimum thin film color filter, its metal film used is Ag which would result with better performance. With different n values for SiO_2 substituted into simulation formula, it is evident that the effect of n values for SiO_2 on transmittance is not significant. The respective thickness Ag/SiO2/Ag for R, G, and B color filters are configured at 30nm/170nm/30nm, 30nm/131nm/30nm, and 30nm/100nm/30nm respectively, all would possess better color saturation and transmittance. The transmittance differences for the R, G, and B color filter samples made and the simulation for simulation are 2.4%, 6.6%, and 2.3% respectively. When color filter deviates from the straight angle by 15 degrees, the maximum transmittance wavelength for R, G, and B would shift to the left about 15~30nm. And its transmittance would also decrease by 1~5%. With a larger tilted viewing angle, the wavelength tends to shift more to the left resulting in more coloring changes. Its cause could be that since the greater the viewing angle, it would increase the path which the light traverses through the color filter. Ultimately, it changes the wavelength for the color as well as the effects of transmittance.

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