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Silicon Nitride Materials Applied in Touch Sensor

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Abstract: The use of silicon nitride (SiN_x) in the field of touch sensor has been investigated. Silicon Nitride (SiN_x) with different thickness is deposited on the surface of bare glass by plasma-enhanced chemical vapor deposition technology. Using theoretical analysis and experimental test method, this article illuminates the impact on the touch sensor of transmittance and macro-color caused by film thickness and the refractive index. The results show that the refractive index of SiN_x has great impact on the average transmittance, while the film thickness has no obvious effect on it. The film thickness has great impact on transmittance at fixed-wavelength and the macro-color, and it is crucial to the process control.

Key words: TFT LCD; touch sensor; transmittance; silicon nitride

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氮化硅在触摸屏中的应用分析

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摘 要: 研究了氮化硅材料在触摸屏领域中的应用, 利用等离子体化学气相沉积技术, 在一定厚度的玻璃表面沉积不同厚度的氮化硅薄膜。通过理论分析和试验测试的方法得到了氮化硅膜层厚度和折射率对触摸屏透过率以及表面宏观颜色的影响。分析结果表明, 氮化硅膜层折射率对触摸屏的平均透过率影响明显, 而膜层厚度对触摸屏的平均透过率影响很小, 但是膜层厚度的改变对触摸屏特定波长处透过率和膜层宏观颜色影响很明显。在实际生产中可以通过改变沉积条件获得合适折射率及厚度的氮化硅薄膜材料。

关 键 词: 薄膜晶体管液晶显示器; 触摸屏; 透过率; 氮化硅

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1 Introduction

Touch sensor technologies have great developed in recent years. Different touch sensor technologies, such as resistor, capacitor, infrared sensor, surface acoustic wave have greatly

developed with the progress of modern information technology^[1-4]. Each type of touch sensor technologies has its advantages and disadvantages on mechanism, structures, production materials, process and so on.

Typical capacitive touch sensor consists of

glass substrate, ITO electrode, insulating layer and protective layer^[5]. Generally, the insulating layer and protective layer are made from transparent organic resin material. However, organic resin is good in transmittance but bad in the cost, insulating characteristic, the ability of blocking the water vapor and the mechanical strength. Therefore, silicon nitride (SiN_x) material has good performance at high dielectric constant, high dielectric strength, low leakage of Na and water vapor, and it has been widely used as insulation layer in the field of TFT-LCD^[6].

In TFT LCD Factory, compact SiN_x film can be made with good chemical stability and better mechanical properties using the plasma-enhanced chemical vapor deposition (PECVD) technology at low temperature. With SiN_x film, we can both achieve low cost and maximize productivity compared to other methods^[7-8]. If the SiN_x material is used in the field of touch sensor as insulation or protective layer, more stringent requirement for high transmittance and colorless is needed as well as high insulation, high dielectric constant. Usually, the transmittance at 550 nm for touch sensor is used as standard transmittance. The structure and the property of the film will have a significant impact on the transmittance, and it is necessary to study the relationship between film parameters and transmittance.

It is rarely study for the SiN_x material used in the field of touch sensor. This article illuminates the transmission characteristics of SiN_x film grown by PECVD method in the TFT LCD mass production using the theoretical analysis and experimental test method. We analyze the relationship between the film thickness, refractive index, transmittance and macro-color in order to get better film parameters. It will have a better guidance to the selection of process parameters for SiN_x in the produce of touch sensor.

2 Experiments and Analysis

The sample is selected with SiN_x deposited on the surface of bare glass with different thickness by PECVD method, and the thickness is controlled in the range of 200 ~ 600 nm. By keeping the other condition unchanged, SiN_x thickness is controlled by the deposition time, and we can analyze the relationship among film thickness, refractive index, transmittance and macro-color.

3 Theoretical Simulation

3.1 Theoretical model

We analyze the characteristics of single layer using the theoretical model. The structure model of film is in Fig. 1. The upper medium refractive index is n_1 , and the refractive index of the intermediate dielectric layer is n_2 with thickness h , and the refractive index of lower dielectric layer is n_3 .

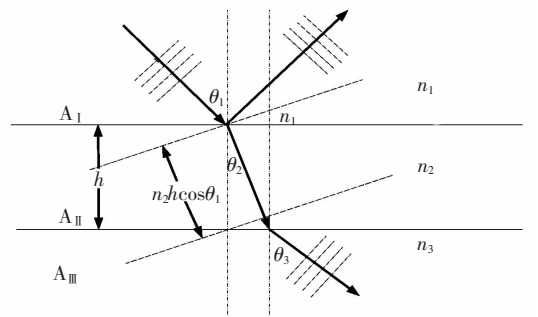


Fig. 1 Light propagation for monolayer

A monochromatic light beam with wavelength λ radiates into a medium from upper side with a fixed incident angle θ_1 . When it passes the interface A_1 and goes into the intermediate dielectric with angle θ_2 . At last, it exits from interface A_2 with the angle θ_3 . According to the equation of refraction, we have the formula:

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2}, \frac{\sin\theta_3}{\sin\theta_2} = \frac{n_2}{n_3} \quad (1)$$

For the TE mode, using the transfer-matrix method^[9], the relationship among electromagnetic field components E_1 , H_1 , E_2 , H_2 at

both sides of the interface can be obtained.

$$\begin{bmatrix} E_I \\ H_I \end{bmatrix} = M_I \begin{bmatrix} E_{II} \\ H_{II} \end{bmatrix} = \begin{bmatrix} \cos\beta & -j \frac{\sin\beta}{P_2} \\ -j P_2 \sin\beta & \cos\beta \end{bmatrix} \begin{bmatrix} E_{II} \\ H_{II} \end{bmatrix} \quad (2)$$

The M_I in the equation is called Eigen-matrix. For the TM mode, according to the same formula, it can replace P_2 with q_2 , and

$$q_2 = \frac{\sqrt{\frac{\epsilon_0}{\mu_0}} n_2}{\cos\theta_2} \quad (3)$$

It is the same for the case of multi-layers, such as the interfaces of A_{II} and A_{III} in Fig. 1, and the formula can be derived in the following:

$$\begin{bmatrix} E_I \\ H_I \end{bmatrix} = M_I M_{II} \begin{bmatrix} E_{III} \\ H_{III} \end{bmatrix} \quad (4)$$

The incident electric field component $E_I = E_{iI} + E_{rI}$ on the interface A_I , and E_{iI} is the amplitude of incident electric field, while E_{rI} is the amplitude of reflection electric field. We define the reflectivity of amplitude for electric field component $r = E_{rI} / E_{iI}$, and the reflectivity $R = |r|^2$. To simplify the calculation, we set to the normal incidence of light on the surface layer of dielectric film, and it is $\theta_1 = \theta_2 = \theta_3 = 0$. Then, the TE wave and TM wave are indistinguishable, and the reflectivity of the film is:

$$R = \frac{(n_1 - n_3)^2 \cos^2\beta + \left(\frac{n_1 n_3}{n_2} - n_2\right)^2 \sin^2\beta}{(n_1 + n_3)^2 \cos^2\beta + \left(\frac{n_1 n_3}{n_2} + n_2\right)^2 \sin^2\beta} \quad (5)$$

Ignoring the case of absorption, we can obtain the transmittance of the film:

$$T = 1 - R \quad (6)$$

3.2 Validity of theoretical model

To validate the feasibility of the theoretical model, the transmittance of bare glass is measured, and then we compare the film character though the results of theory and measurement.

The test sample is Corning glass. The transmission spectrum of bare glass is as followed in Fig. 2.

It can be calculated that the average transmittance is 91.9% with 1.4% uniformity, so the transmittance fluctuation in the visible spectral

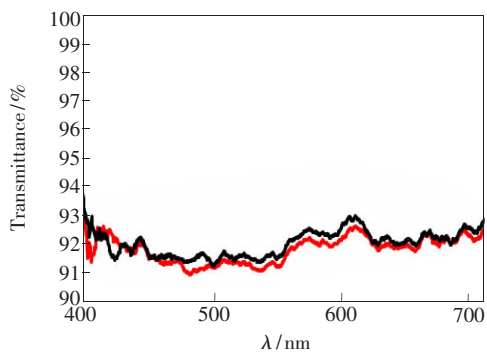


Fig. 2 Transmission spectra of bare glass

range is not obvious, and it can be seen as uniform transmission body. It is one reason that we use the transmittance theory of monolayer. In addition, compared to the thickness of bare glass, the sub-micrometer film thickness is negligible. On the other hand, we can treat bare glass as infinitely thick material. So in the following theoretical analysis, we will simplify the calculation equation, and treat certain thick bare glass as infinite thick substrate.

In order to verify the feasibility of the model, we deposited a certain thickness SiN_x on the bare glass. The transmission spectra of actual measurement and the theoretical analysis are shown in Fig. 3.

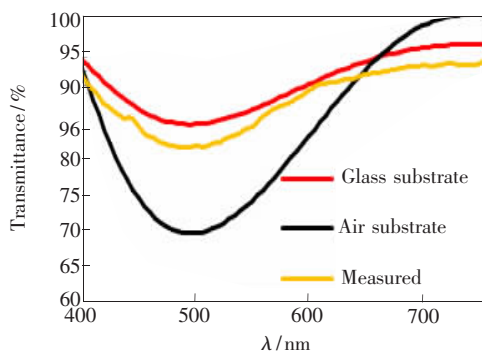


Fig. 3 Transmission spectra of measured and theoretical result for certain thick SiN_x (200 nm)

By comparing the transmission spectra of measurement and theoretical analysis for certain thick SiN_x (200 nm) in Fig. 3, it can be found that the fluctuation range is not the same. For the actual measurement, the fluctuation range is 80% to 93%, and the trough of transmission

spectra is located at 490 nm. When the transmission spectrum is calculated by simplified model, if the substrate is treated as air, the fluctuation range is 70% to 100%, and the trough is at 490 nm. If the substrate is treated as infinite thick bare glass, the fluctuation range of transmission spectrum is 85% to 95%, and the trough is located at 490 nm. Taking into account of scattering losses and other factors in the simplified transmission model, the measured results should be less than theoretical ones. So the theoretical model with infinite thick bare glass is consistent with actual measured results, whether it has slight discrepancy in waveform and fluctuation range. So we can use this simplify model to derive some useful results, and it will decrease the development cost and save circle time of scientific research.

4 Requirements of SiN_x Used in Touch Sensor

4.1 Impact of film thickness

According to simplified theoretical models,

we can see that the film transmittance is the function of $\sin^2\beta$ and $\cos^2\beta$, and the period is π . That is when $h = h \pm \Delta h$, the transmittance is unchanged

$$\Delta h = \frac{\lambda_0}{2n_2}$$

(7)

During the actual production of touch sensor, ignoring of the other factors, when film thickness of SiN_x changed by 148 nm, the transmittance at the wavelength of 550 nm is unchanged. By further calculation, when the thickness of SiN_x $h = 295 \text{ nm} \pm \Delta h$, the transmittance at 550 nm is maximum. The transmission spectrum is

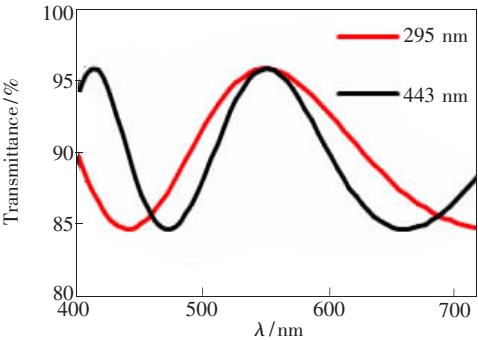


Fig. 4 Theoretical transmission curve for SiN_x thickness of 295 nm and 443 nm

Table 1 Macro-color picture and transmission spectrum for different SiN_x thickness

Film thickness	400 nm	500 nm	600 nm
Macro. Picture			
Tr. Picture (Actual measure)			
Tr. Picture (Theory model)			

shown in Fig. 4 for SiN_x thickness of 295 nm and 443 nm.

The maximum transmittance at 550 nm can be achieved at both two cases. Considering actual situation of the production process, the thickness uniformity in different glass or different equipment chamber is not good. If we put more than 90% transmittance at 550 nm as a standard for the touch sensor product, we can calculate the Spec requirement for above two cases 295 nm $\pm$ 35 nm and 443 nm $\pm$ 37 nm. So the thinner film could achieve the low requirements for film uniformity and process capability, and the thicker of the SiN_x film, the stricter requirement of film uniformity on the whole glass.

Because of a certain fluctuation range of film thickness among equipments, the thicker the film becomes, the more fluctuation range required, and it is more likely to present severe macro-color due to the non-uniformity. Under the same conditions, we get the different thickness sample of SiN_x 400 nm, 500 nm and 600 nm by changing the deposition time.

The Table 1 is the macro-color picture and transmission spectrum of different thick SiN_x film on bare glass under different deposition time. As can be seen from the Table 1, the thicker the film thickness becomes, the more uneven color distribution on the macro-color, and more flat film uniformity is needed for one glass. It can conclude that the absorption is almost unchanged with film thickness. Within the range of allowable error, we can consider that the SiN_x film is without absorption in the range of the visible light spectrum.

4.2 Affect of refractive index

Through the control of film deposition parameters (power, temperature, etc.), it can change the transmittance of SiN_x film within a certain range, and the refractive index is somewhat different among different equipment and different chamber. So it is necessary to study the impact for refractive index of SiN_x film on the transmittance.

Simplicity, we take the SiN_x film thickness of 400 nm as an example, and for a more clear expression, we expand the range of refractive index of film. By changing the refractive index of the same thick SiN_x film, we calculated the transmission spectrum shown as in Fig. 5. There are two main effects for the change of refractive index of film. Firstly, the changing of the refractive index could be expressed as the changing of the optical film thickness. When the refractive index increases, the optical film thickness also increases. That is, when the original optical film thickness is $H=n\times h$, the changed optical film thickness will be $H'=(n+\Delta h)\times h$, and the transmission spectrum will shift to the longwave direction. The refractive index increase from 1.75 to 1.85 and the crest of transmission spectrum near 550 nm will shift to long-wave about 30 nm.

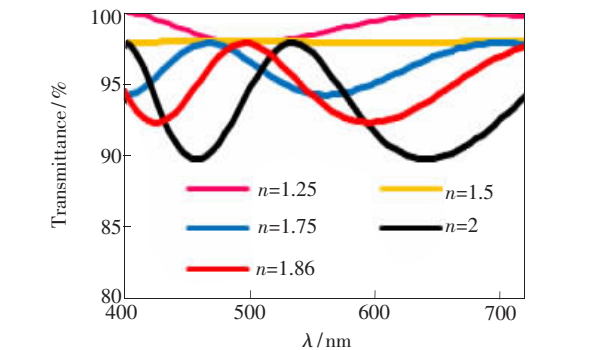


Fig. 5 Transmission curve of same thick SiN_x film with different refractive index (n)

Secondly, the change of the film refractive index will change the average transmittance in the range of visible light spectrum. During the increase of the refractive index from 1.25 to 2.0, the average transmittance also increases. It should be noted that if the film refractive index is smaller than the substrate refractive index, the peak of transmission spectrum remain unchanged, but the spectrum trough increases, and thereby the average transmittance increases. If the refractive index of film is equal to that of the substrate, the transmission spectrum is a straight line, because the film and substrate can be seen