Quality evaluation of protective film based on optical coherence tomography

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Abstract. In order to evaluate the quality of the protective films, we built a Spectral-Domain Optical Coherence Tomography System. To get the 2D and 3D image of normal materials and defective materials, and the quantitative analysis has been done. Compared with the parameters provided by the manufacturer, the results of this method has a smaller detection error, higher precision and its results are 3D visualization. An optical non-destructive testing method with high precision and 3D visualization results has been provided to evaluate the quality of the protective films.

Introduction

With the rapid development of electronic digital products ,protective films are widely used . The quality of protective films produced by industry is directly related to whether they can be used normally and get a good evaluation. At present, testing are mostly completed with contact measurement methods, such as screw micrometer method, precise contour scanning (step method) and scanning electron microscopy (SEM). Contact measurement methods would damage the measured surface, and they can't be used in vivo measurement. With Spectral-Domain Optical Coherence Tomography, non-contact non-destructive in vivo measurement can be achieved, and high-precision 2D and 3D image can be got .

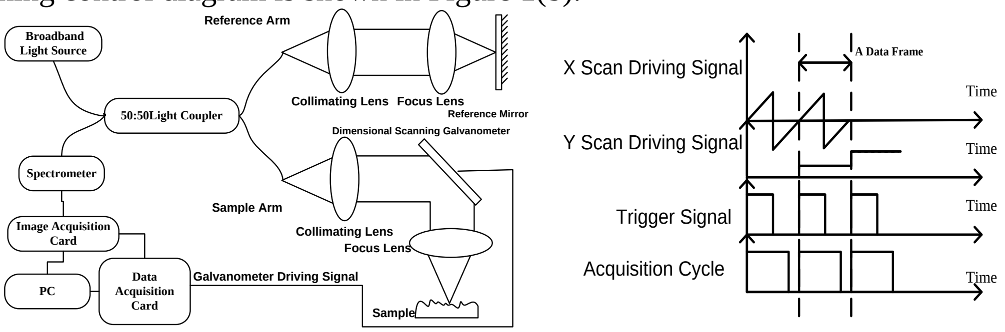
Spectral-Domain Optical Coherence Tomography (SD-OCT) techniques is based on low coherence interferometry of imaging principle , high-resolution 2D structure or 3D image can be obtained by the back reflection or scattering of incident light signal . It has been continuously a hot topic in the field of biomedical imaging and material testing since SD-OCT was proposed in 1991[1-4].

Spectral-Domain Optical Coherence Tomography

System Design

The spectral domain optical coherence tomography system is shown in figure 1. The light emit from a broadband light source (wavelength of 850 nm, and longitudinal resolution of about 8 um) and pass through a 2 x 2 fiber coupler, then get into the reference arm and sample arm respectively. The incident light on the reference arm along the way back when reaching the reference mirror, while the light on the sample arm pass through the galvanometer first and then through the objective lens (lateral resolution ratio is about 16um) ,and gather on the surface of the sample to be tested. The light reflected from the reference arm and sample arm intervene in the fiber coupler, and received by our homemade spectrometer[5].

In order to obtain a sample's 3D data, 2.0mmX2.0mm horizontal scanning has been completed on the sample through a 2D galvanometer system. Where, Fig1(b) shows that X-direction scanning is achieved driven by a Sawtooth Wave, and a B-scan cycle is completed during Sawtooth Wave' period (quick scan). And a B-scan includes 500 A-scan(A1-A500). Y-direction scanning (slow scan) is achieved driven by step ramp signal, where C-scan is achieved. A-scan is automatically obtained through the back scattering of sample [5]. In the system, data acquisition card is used to generate a pulse trigger signal, and to synchronous image acquisition and galvanometer scanning . The timing control diagram is shown in Figure 1(b).



(a) (b)

Figure 1 (a) Schematic of the spectral domain OCT system.(b) Timing control chart

The principle

The Michelson interferometer principle is used in SD-OCT.The interference spectrum I(k) can be expressed as:

$$I(k) = S(k)\left(E_R^2 + 2E_R\int_{-\infty}^{\infty} a(z)\cos(2knz)dz + \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} a(z)a(z')\exp(i2k(nz - nz'))dzdz'\right) \quad (1)$$

In older to get the depth information of the sample, we need get the second term of Equation (1). Calculating the Fourier transform of interference spectra in the wave number space, the distribution of back scatter of the sample in different depth can be obtained:

$$\begin{aligned} H_{obs}(z) &= F\left(S(k)\right)\otimes\left(E_R^2\delta(z) + [a(z) + a^*(-z)] + F\left(I_{SM}(k)\right)\right) \\ &= A\otimes(B + C + D) \end{aligned} \quad (2)$$

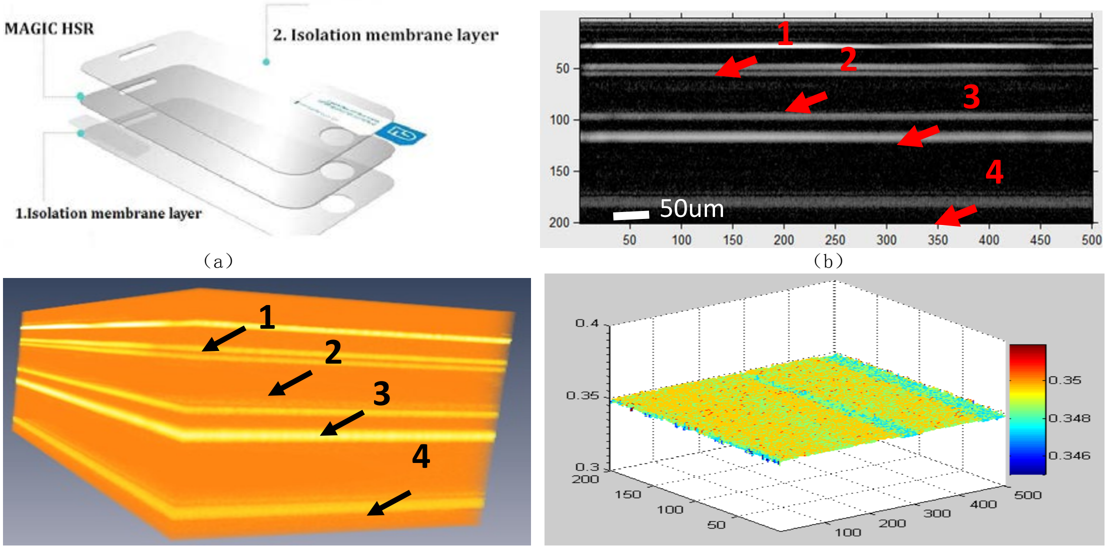
Where

$$I_{SM}(k) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} a(z)a(z')\exp(i2k(nz - nz'))dzdz'$$

A is the Fourier transform of light spectrum, namely the coherence function; the second term is the depth information of the samples which we need. The first term is subtracted in the image processing[6-7].

Experimental results and analysis

We use protective film with three layers which is made up of the most common PET material on the market as a sample for the experiment. Figure 2(a) shows the structure of PET protective film before being used. There are two layers of isolation layer, and the middle layer is HD membrane (working layer). We use the SD-OCT system to image the unused protective film. Because the reflection on the surface of the PET protective film is strong, the reflective surface of the SD-OCT image is bright line, and backward scattering is low, presenting dark. Figure 2(b) shows the 2D tomographic image of PET protective film we are obtained. which the first and third layers is isolation layer, and the second layer is HD membrane of working layer. Between the first layer and the second layer is shown a gap . The fourth layer bright line is return light of the object stage in the experiment. The protective film can also be observed from different angles through 3D display, as shown in Figure 2(c). Through the Calculation results we can conclude that the thickness corresponding to each point distribute uniform, and the error is less than 10 μm. The thickness distribution of protective film obtained by calculation is shown in Figure 2(d). After processing the experimental data we can conclude that the average thickness is 0.3485mm, and the average thickness of working layer is 0.2085mm..The data produced by manufacturers is that the total thickness is 0.35mm and the thickness of working layer is 0.21mm[8]. Compared with the data provided by the manufacturer, the measured values coincide with the theoretical value, and the experiment system has high precision .

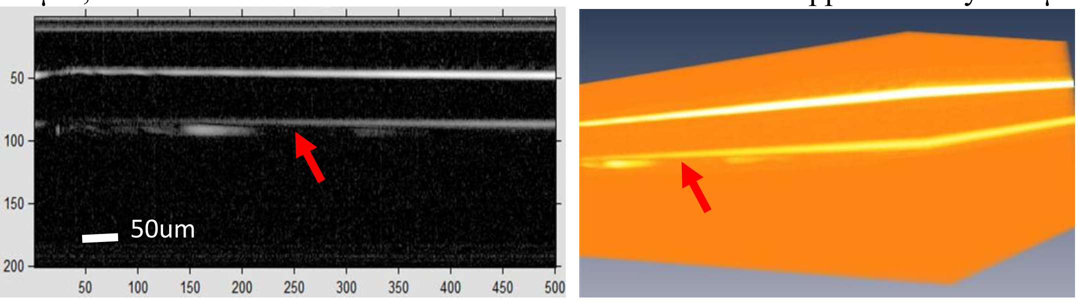


（a） （b）

（c） （d）

Figure 2(a) the structure of PET protective film (b)2D tomographic image of PET protective film (c)3D display of PET protective film (d)Curves of thickness distribution

The working layer was attached to the telephone screen , we can clearly see the defects in the lower surface of the working layer, as shown in Figure 3. The defects in the middle arrow determined to bubble, and using of system calibration result, which per unit distance represent 0.5μm, the lateral dimension of the bubble can be determined approximately 57.5μm.



（a） （b）

Figure 3(a)2D tomographic image (b)3D display of PET protective film

Conclusion

In this paper, SD-OCT, which is non-contact, high-sensitivity, high-resolution imaging speed, is applied to test the quality of PET protective film. The structure image (8μm-resolution)can be obtained, which is 3D visual structure graphic of protective film, which is benefit for quantitative analysis of the defect size and the precise positioning of defects. However,the scanning range is not big enough , we still need to improve. The system has high resolution and signal to noise ratio, and fast imaging speed, which has good value in quality testing of precision materials and positioning of defects. Therefore, the SD-OCT system can be widely used to measure the industrial materials.

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