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Quality assessment of the optical thin films using line field spectral domain optical coherence tomography

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ABSTRACT

In this study, the industrial inspection of optical thin film on touch screen panels was demonstrated using line field spectral domain optical coherence tomography. The conventional Fourier domain optical coherence tomography system requires a single scanner for two-dimensional cross-sectional images and two scanners for volumetric images. Our developed line field spectral domain optical coherence tomography has the advantage of needing only a single scanner for volumetric images, while two-dimensional cross-sectional images are obtained by the parallel acquisition of an illuminated line on a sample using an area camera. Further, the image acquisition speed was enhanced by implementing a high speed camera (340 frames per seconds) with improved quantum efficiency at near infrared region enabling two-fold frame rate. Cross-sectional and volumetric images were acquired to detect the internal sublayer defects in the optical thin films, which are difficult to observe using visual or machine vision-based inspection methods. The developed pseudo code for defect identification in optical thin films was well-utilized here for the defect inspection. The system characterization is demonstrated using United State Air Force (USAF) resolution target. The results indicate the possible application of the proposed system in touch screen panel inspection for the quality assurance of products at the consumer end.

1. Introduction

Optical thin films (OTFs), liquid crystal displays (LCDs), touch screen panels (TSPs), and light emitting diode (LED) panels have gained attention in the manufacturing industry of smart phones, notebooks, tablets, displays, and TVs. The large-scale productions of display devices with an increase in fault occurrence rate in the final product cause a huge loss to the display industry. Advances in semiconductor packaging technology, the fabrication process, and the miniaturization of electronic components have enabled the display industry to develop small and compact devices [1,2]. The uses of optical plastic with glass thin films, thin film coatings and flexible thin films in flexible displays have increased with the advancement of technology. Because defects in raw materials, the improper solidification of liquid resin, and the fabrication defect cause changes in the refractive index of touch screen panels, they degrade the quality of the final product. Therefore, there is a need to detect faults at an early stage prior to the product finalization. This will result in a fast, reliable, and efficient manufacturing process and improve the quality assurance at the consumer end. In smartphones, tablets, and other electronic gadgets with displays, the touch screen panel defects can deteriorate the quality of the product. Using visual or machine vision inspection, a touch screen panel defect can be detected, but the cause and nature of defects cannot be identified due to the absence of cross-sectional information [3,4]. Similarly, X-ray, CT (computed tomography), and ultrasonic imaging can give cross-sectional information of samples, but the axial resolution is limited to detect the defects in the sublayer of the sample [5–7].

Optical coherence tomography (OCT) is an optical inspection method that is based on low coherence interferometry. OCT was first introduced by Fujimoto as a noninvasive and nondestructive inspection technique [8]. High resolution volumetric information can be obtained either in the time domain (TD) or Fourier domain (FD) by OCT. Therefore, OCT is divided into two domains: the time domain and Fourier domain. In time domain OCT, depth information is achieved by a change in optical distance of the reference path whereas in the Fourier domain, the depth information is obtained by a spectrometer or swept source. A mechanical scanner is used in the reference arm in the case of TD-OCT, and a wavelength resolving mechanism is employed in FD-OCT for the

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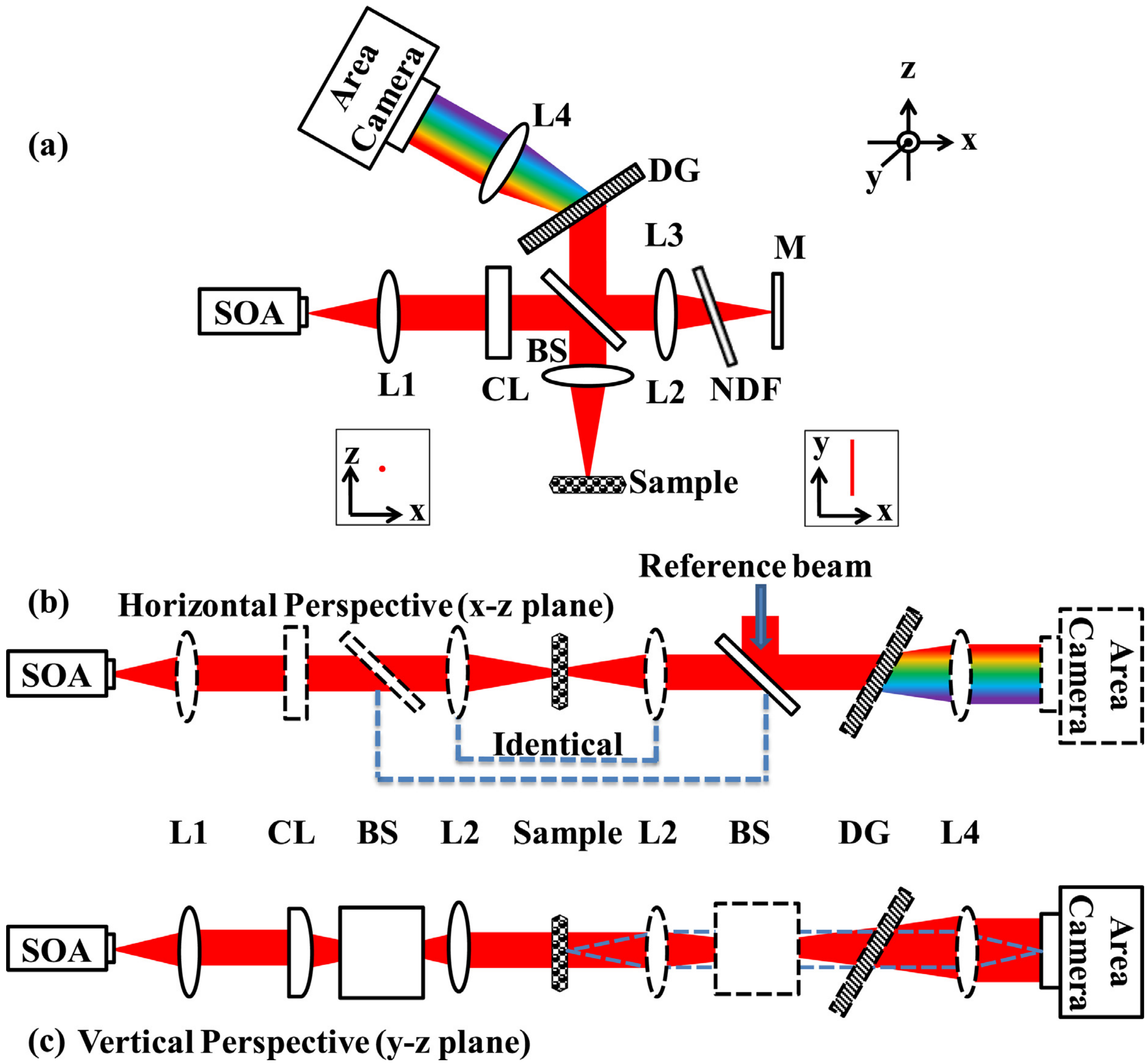

Fig. 1. Schematic diagram of LF- SD-OCT system. (a) is the top view of the optical setup of the interferometer with the sample and reference paths, and (b) and (c) are the horizontal and vertical perspectives of the optical layout of the setup. BS: beam splitter, CL: cylindrical lens, DG: diffraction grating, L1–4: achromatic lenses, M: mirror, NDF: neutral density filter, SOA: semiconductor optical amplifier.

axial line profile (A-scan). For two-dimensional cross-sectional images (B-scans), a single scanner is still required. Similarly, for obtaining volumetric images (C-scan) of samples, two scanners are required. Mechanical scanning can affect the stability of the OCT system. Additionally, the exposure and line readout time of a linear array detector are the limiting factors for a further increase in OCT speed. Line field spectral domain OCT has the advantage of obtaining a B-scan image without a mechanical scanner. As a result, the delay due to the synchronization for transverse scanning can be avoided using the line illumination on the sample.

OCT has wide applications in different medical fields such as ophthalmology [9–12], otology [13], dermatology [14], dentistry [15], and brain studies [16]. Furthermore, with the advancement of technology, the applications of OCT have been extended to agricultural fields for the quality inspection of seeds, food, and plants [17–20]. Similarly, OCT is employed in industries that detect defects in industrial products such as LEDs, LCDs, OTFs, TSPs, printed electronics, and composites [21–28]. Additionally, different techniques have been incorporated to improve the resolution, sensitivity, penetration depth, and speed of an OCT system [29–33]. Similarly, line field SD-OCT system has been reported for human eye measurements [34,35], dermatological investigations [36], the three-dimensional shape measurements of coin and solder balls [37,38], and glass inspections [39,40]. By employing the line field SD-OCT, the one-dimensional scanner in point scanning SD-OCT system can be removed using an imaging optics, which is usually cylindrical lens. Moreover in line field OCT, 3-dimensional data acquisition speed depends on the camera speed, repetition time of the scanner, and image processing time, which can be enhanced by utilizing a high speed camera with high quantum efficiency at near infrared region.

In this study, the line field OCT method is employed to inspect the optical thin film used on touch screen panels for smartphone display production. The parallel scanning of a sample is demonstrated without a galvanometer scanner using a cylindrical lens. As mentioned before, the utilization of a high speed camera with improved quantum efficiency at near infrared region can result in high signal to noise ratio, and therefore the area camera used in this study has frame rate of 340 frames per second at full pixels acquisition, which enabled us to achieve more than two-fold frame rate for real-time display in line field OCT system as no scanner is required as compared to the conventional point beam method. Further, the proposed system is applicable for the inline defect inspec-